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Intertrochanteric Fractures: Ten Commandments for How to Get Good Results with Proximal Femoral Nailing

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Intertrochanteric (IT) fractures in the elderly is a challenging surgery. The bones are osteoporotic with implants having less hold as well as the co morbidities associated in these elderly leads to almost one-third mortality by the end of one year, which is a major global economic burden. The hip fractures accounted for over 250,000 fractures in US itself every year [1]. The worldwide problem at present stands at over 2 million fractures and it is bound to triple by the next 50 years due to the elderly surviving more with better healthcare facilities. The treatment option for osteosynthesis includes open/closed reduction and fixation either with surface implants such as dynamic hip screw (DHS) or intramedullary (IM) implants such as proximal femoral nail (PFN) [2, 3].

Approximate period between 1999 and 2010, most of the studies [3, 4] and the Cochrane reviews were advising DHS or the sliding Hip screw for Stable IT fractures whereas for unstable fractures, the IM implants were advocated. Now, most of the studies [5, 6] including the recent Cochrane data advocates the use of IM hip implants both for stable and unstable fracture. The author also advocates the same.

As the author refers IM implants, here are few tips and tricks to get a better outcome with IM implants (PFN).

1. **Good anterior reduction and temporary fixation by two K-Wires** Sometimes we may not get an acceptable reduction on the orthopaedic table easily and in such cases, the reduction can be assisted either by manipulating the fragment by closed techniques or by percutaneous mini-open techniques such as using a bone lever, Bone spatula, bone hook, and collinear clamps. To add on it, the author’s preference is almost always intrafocal manipulation with Steinmann pin by passing at the fracture site and lifting the depressed fragment (either the neck or the shaft). Once anterior cortex is well aligned, percutaneously it is fixed with two Kirschner’s wires which are very anteriorly placed. Once the fracture is fixed temporarily with K wires, the hip can be adducted without fracture going into varus, making nailing an easy procedure (Fig. 1a).

2. **Good medial reduction (positive cortical reduction)** Valgoid reduction of at least 5 degrees more in valgus compared to the normal side is also very important. In valgoid reduction make sure that neck beak is outside the distal fragment (positive cortical reduction) and should not enter into the shaft (negative cortical support) [7]. One should aim at neutral with valgus or Positive cortical reduction. This can be done by intrafocal Steinmann pin pushing the beak out medially and reducing the foot traction minimally so that beak will overlap medially on the beak of the shaft and it can never slip back inside the distal canal due to this few mm overlap (Fig. 1b). This is more important if the lesser trochanter is avulsed. Due to good valgus, even though there is void medially, bone forms in due course without any hindrance. If there is a large medial fragment of lesser trochanter extending into the subtrochanteric area, the author prefers to fix them with encirclage wiring. In just avulsion of lesser trochanter, even if you do not open or reduce it into its bed, a good valgus compensates for the medial void very well.

3. **The entry point** It has to be done in line with the medullary canal, which is almost always either the piriiformis fossa (Which is a misnomer as this is much more posterior in the lateral view and not in the central part, this area is medial to the tip of trochanter at its base) or medial to the tip of the trochanter (Fig. 1c).
One should avoid the entry site getting lateralised, as the bone is weaker on the lateral aspect. While passing the centering awl or the entry reamer, more bone gets removed on outer aspect and the entry site will get lateralised leading to varus happening with the head and neck as well as screw position not proper leading to early cut out of the improperly placed neck screw in a varus head.

4. The neck screw placement It should be placed parallel to the calcar, in the inferior third of the neck in AP view so that the tip of the screw should also be in the inferior part of the head and not at the centre or superior portion of the head. This will allow easy sliding of the neck screw within the nail and causes less jamming. Similarly in the lateral view, it should be in the centre or slightly posterior to the centre so that it has the purchase in the strongest part of the bone (Fig. 1d). For passing these screws properly over guidewire, one should use the trocar first to make the starting hole in the lateral cortex of the bone. The long Guide wires of 1.8–2.5 mm are not made for drilling the thick lateral cortex like the drill bits and they may slip over the bone especially due to longer lever arm from the other end where drill machine is attached.

5. The Neck screw should be placed as subchondral as possible so that Calcar TAD (CalTAD) is less TAD is normally measured from the fovea centralis, which is in the central portion of the head [8]. Since screws are placed as inferior as possible in AP, the screw tip will be definitely away from the fovea centralis and the TAD will be more, in spite of screw being in a very good and strong bone position and in spite of screw tip being placed in a subchondral part of the head. So, author advocate you to measure Cal TAD by extrapolating the screw line where it will touch the articular surface, measure the TAD from that point and not from fovea centralis. This is called as Cal TAD or Calcar TAD [9]. So keep Cal TAD in both AP and lateral views as low as possible and definitely below 25 mm (Fig. 1e).

6. Compression of fracture on table One should compress the fracture on the table after releasing the traction as much as the fracture needs. The fracture should hardly collapse for the further union after fixation. For this one should measure and use proper length neck screws. If on table traction is not released before final tightening of neck screws, in the immediate post-operative picture itself one can see screws backing out (Fig. 1f). This longer screw having no support of a lateral wall...
to its head can rock in and out and loose purchase. Similarly, if we use a shorter screw, the surgeon may try to pass the screw more deeper so that the tip to reach the subchondral area by extra tightening of the screw, that few extra rotations will spoil the hold of neck screws in bone and they will slide back in due course as well as if the screw is shorter, TAD will be also more in these shorter screws, leading to higher chances of failure. The author feels that fracture needs to be compressed as much as possible after releasing traction on table itself so that fracture need not require the sliding mechanism of the neck screws in the nail in all cases. In few cases where there will be extra resorption at the fracture site only the implants sliding neck screw mechanism should be relied.

7. **Tips for headless screw** Head less neck screws like Helicle blade of PFN A2 or any other newer single screw system, make sure that the back end of the neck screw remains at least 3–5 mm outside the lateral cortex so that they can slide out easily when the fracture further collapses during the course of healing. By chance, if they penetrate inside the lateral cortex, during the course fracture collapse, the hole in the bone may not match the neck screw to slide out leading to jamming of sliding out mechanism and hence high penetration chances into the hip (Fig. 1g).

8. **Nail projection at entry site** The nail has to be little projecting above the entry hole so that the purchase of the nail at this site prevents medisation of the shaft. If it is buried inside the cancellous bone, it can toggle, migrate medially and can lead to instability, non-union and implant failure (Fig. 1h). It can be addressed by additional end cap over the tip of the nail to build up the nail to project out at the entry site.

9. **Static/dynamic locking** Though there are many literatures showing good out comes with static locking, but few cases where fracture resorption is a bit more than normal, either they require dynamization by about 6 weeks’ time or it can be dynamically locked from day one itself. To be on the safer side, dynamic locking should be done in all nails whenever possible.

10. **Choice of implant** Finally, good implants from a good manufacturer with laser marking to trace back if complication arises and not a poor copy from a fly by night lesser-known company, costing a bit less should be used to avoid complications related to metal quality and strength of the implant.

Finally, after a very robust and stable fixation, the patient should be mobilised as pain tolerated weight bearing with a walker to enhance early fracture union and to minimise complications of prolonged immobilisation.

Once the patient is made to walk, his morale will be boosted and will cooperate for proper physiotherapy.

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Management of Physeal Fractures: A Review Article

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Abstract

Background Physis is the weakest structure in the skeleton of a child and a frequent site of an injury or fracture. A physeal fracture presents a unique challenge in the management as the sequelae of such an injury could lead to growth disturbances.

Methods In this review, mainly focussing on traumatic physeal injuries, the authors discuss the applied anatomy, different fracture patterns, clinical assessment and management of physeal fractures in children.

Results Discussion on acute physeal injuries as well as physeal arrest and approach to its management is presented. Past attempts for treatment of physeal injuries and recent advances in their management is also discussed.

Conclusion The ideal approach to treat physeal injuries should take into account the location of injury, age of the patient, fracture type and growth potential of the involved physis. Prompt diagnosis and physeal-respecting treatment techniques are important.

Keywords Physis · Fractures · Growth · Arrest · Management · Review

Introduction

Physis (growth plate or epiphyseal plate) is the cartilaginous disc present at ends of a long bone and is responsible for the longitudinal growth of the bone in a child. Physis is the weakest structure in the skeleton of a child and is thus, a frequent site of an injury or fracture. An injury which would cause a ligamentous sprain of a joint in an adult, would cause a physeal fracture in a child. Several factors must be considered while evaluating a child with a physeal fracture like the age of the patient, location of the physis, fracture type and growth potential of the involved physis [1]. A physeal fracture presents a unique challenge in the management of the child as the sequelae of such an injury could lead to growth disturbances. These growth disturbances could manifest as limb length inequality or angular deformities. Of all the physeal fractures, growth arrest or disturbances are seen in 5–10% of the cases [2].

In this review, we discuss the applied anatomy of the physis, different physeal fracture patterns, clinical assessment of a child with physeal injury and management of physeal fractures. We briefly discuss physeal arrest and approach to its management. Lastly, we would review the past attempts for treatment of physeal injuries and recent advances in their management. Although physeal injury can result from infection, malignancy, metabolic abnormalities or iatrogenic damage, the current review would be limited to traumatic physeal injuries or physeal fractures.

Incidence

Physeal fractures account for 30% of all the paediatric fractures [3]. These fractures are more common in adolescence as in a younger child, the epiphysis is more cartilaginous and acts as a shock absorber with significant amount of forces been transmitted to the metaphysis [4]. Boys are affected twice as often as girls as their physis remain open till a later age and they may be more susceptible to trauma due to increased sports participation [3, 5–7]. Regardless
of the site, distal physis are more commonly involved than the proximal physis with distal radial physis as the most frequent site to be involved followed by distal tibial physis [3, 5–7].

### Applied Anatomy

To effectively manage physeal fractures, it is essential to understand the anatomy of the physis (Fig. 1). Long bone development begins at 6th week of intrauterine life as condensation of the mesenchymal anlage. By 8 weeks, a primary ossification centre develops in the middle of long bones. The primary ossification centre grows by endochondral ossification and extends towards the end of the long bones. On radiographs, the physis is visible as a radiolucent zone separating the metaphysis and epiphysis at the end of long bones. It is also referred to as metaphyseal or primary physis. This is to distinguish it from articular [8] or secondary physis [9] which is responsible for growth of the secondary ossification centre of the epiphysis towards the joint. The word ‘physis’, by default, refers to the primary physis. Relative contribution of different physis to longitudinal growth and absolute amount of growth per year is given in Fig. 2.

The periphery of the physis is attached securely to the metaphysis through the Zone of Ranvier and Ring of LaCroix. The Zone of Ranvier is a groove around the periphery of the physis that contains chondrocyte progenitor cells and is responsible for the circumferential growth of the physis [10]. The Ring of LaCroix is a fibrous continuation of periosteum and provides mechanical support to the physis [4].

### Microstructure

Physis is made up of hyaline cartilage and it consists of chondrocytes organized in columns along the long axis of the bone. It is divided into four zones from epiphysis to metaphysis: Germinal, Proliferative, Hypertrophic and Endochondral Ossification. The germinal layer includes chondrocytes in somewhat inactive state. The proliferative layer includes chondrocytes that undergo rapid mitotic division and are organized in stacked columns. These two layers are rich in extracellular matrix and collagen fibres and are therefore able to resist shearing forces [11]. In the hypertrophic zone, the chondrocytes lose their ability to proliferate and differentiate into mature chondrocytes with increased cell volume. The extracellular matrix and amount of collagen fibres are negligible. Therefore, hypertrophic zone is weaker in comparison to other zones and most of the physeal fractures occurs through this layer. In the zone of provisional calcification, the chondrocytes undergo apoptosis and the cartilaginous matrix begins to calcify. These islands of calcified cartilage act as scaffold for new bone formation, facilitated by invasion of capillaries from the metaphysis. The osteoclasts and osteoblasts from the metaphysis break down the calcified cartilage and replace it with mineralized bone.

Physeal injuries heal faster than bony injuries. Typically, a physeal fracture would heal in 3–4 weeks. However, in case of an injury to a large undulating physis, like distal femur physeal fracture, the fracture plane would traverse through various zones of the physis. Likewise, intra-articular

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**Fig. 1 Structure of physis**
physeal fractures, like Salter–Harris (SH) type III and IV fractures, would traverse through various or all zones of the physis. Such injuries have worse prognosis as the chances of bone formation across the physis increases when multiple zones are injured.

**Blood Supply**

Knowledge of the blood supply in and around the physis is necessary to understand the consequences of physeal fractures. Physis receives its predominant blood supply from the epiphysis (Fig. 3a). Other sources of blood supply are from the metaphysis and the perichondrial ring [13]. Epiphyseal circulation essentially supplies the germinal and proliferative layers of the physis. It is further divided into two types by Dale and Harris (Fig. 3b) [12]. In type A, the epiphysis is entirely covered by articular cartilage and receives its blood supply from vessels that enter the epiphysis by traversing the perichondrium at the periphery of the plate. Thus, physeal separation or injury, as in femoral neck physeal fracture, could lead to destruction of the blood supply to the epiphysis and resultant avascular necrosis. In type B, the epiphysis is partially covered by articular cartilage and receives its blood supply by vessels that directly penetrate the epiphyseal cortex at areas that are not covered by articular cartilage. Thus, physeal injury would lead to temporary interference with endochondral ossification marked by increased thickness of the physis, followed by rapid healing within 3–4 weeks.

The metaphyseal circulation comes from the branches of nutrient artery and they supply the zone of endochondral ossification. The perichondrial ring of LaCroix supplies the periphery of the physis. It is evident from the above discussion that hypertrophic zone remains relatively avascular.

**Classification**

The most widely used classification system for physeal fractures is the Salter and Harris classification system, (Fig. 4) which divides the physeal injuries into five types. [14] This classification system helps guide the treatment as well as prognosticate the facture pattern. Types I and II are extra-articular fractures with good prognosis. These fractures mostly occur through the hypertrophic zone of the physis and have significantly lower rates of physeal arrest. Types III and IV are intra-articular fractures that would typically involve various or all layers of the physis with increased potential for physeal arrest. Type V fractures are diagnosed in retrospect after the occurrence of growth arrest and deformity. Rang added a type VI fracture that involved the periphery of the physis, including the perichondral ring (Fig. 4) [15]. This injury and loss of peripheral physis is typically seen around an open injury to the medial malleolus. Peterson described a classification system in which the initial four types of Salter–Harris classification were retained while adding two new types (Fig. 4) [9].

**Imaging**

The initial investigation usually done to diagnose physeal injuries are plain radiographs. The radiographs should
include two orthogonal views and should focus on the site of fracture to appreciate the true injury pattern and displacement. It is not recommended to evaluate distal radius physeal fractures on forearm radiographs or ankle physeal injuries on full leg radiographs. The extent of injury would be unappreciated on such views due to parallax, image distortion, magnification errors and inadequate visualization. Other radiographs should incorporate a joint above and joint below the site of injury. When in doubt or when ossification variants mimic fractures, contralateral radiographs can help. Sometimes, an oblique view is required to better portray the fracture pattern, as in the internal rotation oblique view to evaluate fracture of lateral condyle of distal humerus. Stress views are not recommended as it can displace the fracture, can cause iatrogenic injury to the physis and can cause significant discomfort to the patient.

Although MRI can be used to diagnose occult physeal fractures, its value and usefulness in paediatric trauma is
Fig. 4  Classification of physeal fractures (Images source: Mallick A, Prem H. Physeal injuries in children. Surgery (Oxford). 2017 Jan;35(1):10–7.)
limited. Gulfer et al. detected occult physeal fractures around the elbow, ankle and knee in 8 of the 23 patients (34%) who presented with clinical symptoms and signs of injury, but had negative radiographs [16]. MRI is recommended for evaluation of traumatic haemarthrosis of a joint without an apparent fracture. For example, TRASH (The radiographic appearance seemed harmless) lesions of the elbow joint would be a primary indication for MRI [16]. MRI is recommended for evaluation of traumatic haemarthrosis of a joint without an apparent fracture. For example, TRASH (The radiographic appearance seemed harmless) lesions of the elbow joint would be a primary indication for MRI [17]. MRI can also be helpful for assessment of chondral/osteochondral injuries and ligament injuries of major joints [18–21].

CT scan is recommended for delineation of fracture lines and for preoperative planning for intraarticular physeal fractures, mainly around the knee and the ankle [22]. In a study comparing CT scan and radiographs of triplane ankle fractures, the CT scan changed the diagnosis in 46%, changed the treatment plan in 27% and changed the number and trajectory of the screws in 41% patients, as compared to radiographs [23]. Thus, CT scan can help to delineate intraarticular fracture geometry and aid in treatment planning. Besides this, CT scan can be used for 3D assessment of complex injury patterns or their sequelae, i.e. growth arrest, deformity or malunion [24, 25].

Intraoperatively, an arthrogram can provide valuable information by outlining the largely cartilaginous articular surfaces and is routinely used in paediatric trauma [26]. It not only provides information about articular surface gap or step-off, but also aids in the placement of percutaneous fixation by delineating the chondral surface. An arthrogram can be performed for any joint to evaluate the articular surface, but is more commonly used around the elbow joint.

Partial or complete growth arrest is one of the most significant complication of a physeal fracture. Partial arrest is classified into: central, peripheral, linear or combined depending upon the location of physeal bar (Fig. 5). It is essential to assess the exact location and size of the physeal bar and estimate remaining growth, to help formulate management decisions [27]. Plain radiographs of the involved and contralateral uninvolved physis can provide general information about the physeal bar. Serial plain radiographs can be used to evaluate for any developing deformity or limb length discrepancy. A left-hand bone age radiograph can help to estimate remaining growth. For assessment of the physeal bar, a CT scan can help to determine the exact location and size of the bony bar and create physeal bridge map. The drawbacks of CT scan are that it does not provide information about a fibrous bar or about health of the remaining physis [28]. Moreover, there is a small risk of radiation to the children. MRI is the imaging modality of choice for assessment of physeal bar and specialized software or manual calculation can help to map the area of physeal arrest [29].

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**Fig. 5** Classification of physeal bar (Images source: Mallick A, Prem H. Physeal injuries in children. Surgery (Oxford). 2017 Jan;35(1):10–7.)
Principles of Management of Physeal Injuries

The following principles are recommended to manage physeal injuries in children with some modifications depending upon location of injury and age of the child.

1. Displaced physeal fracture should be reduced with sustained traction and gentle manipulation. Forceful reduction manoeuvres, repeated attempts of reduction or insertion of instrument into the physis to manipulate fracture fragments should be avoided as it could grate the physis and cause iatrogenic physeal injury. Open reduction is better than multiple attempts at closed reduction.

2. For an extra-articular physeal fracture (SH 1 and 2) delayed reduction attempts beyond 5 days after injury should be avoided. Such attempts could lead to iatrogenic physeal injury and resultant growth arrest. Instead, it is better to allow the fracture to heal and remodel. Management of malunion is relatively easier than management of growth arrest in a young patient.

3. Intra-articular displaced physeal fractures (SH 3 and 4) should be reduced anatomically and stabilized by internal fixation, irrespective of their time of presentation. Articular surface congruity and reduction is of utmost importance. The reduction can be achieved by closed, arthroscopic or an open approach.

4. Implants used for internal fixation should be placed in a physeal-respecting manner. They should be placed parallel to the physis when the fracture geometry allows for it. If an implant is placed across the physis (transphyseal), compression should be avoided. If more than 2 years of growth is remaining, the transphyseal implant should be removed once the fracture is healed.

5. There are several methods for assessment of accuracy of articular surface fracture reduction for SH 3 and 4 physeal fractures. These include direct visualization, fluoroscopy, arthrogram or arthroscopic assessment.

6. Resecting a small portion of periosteum on either side of the physis during an open reduction of fracture may help to reduce the risk of bony bar formation, although this is controversial [22].

7. For an exposed or crushed physeal injury, an acute or anticipatory Langenskiold procedure (use of free fat graft to cover the physis) can be performed to help prevent growth arrest [30, 31].

8. Most physeal fractures heal in 3–4 weeks.

9. Growth arrest lines (Park–Harris lines) are transverse lines seen in the metaphysis (Fig. 6). Their orientation and relationship to the physis are used to assess growth and growth disturbances [32, 33].

10. For a displaced physeal fracture, the patient should be monitored for growth disturbances for at least a year or until the patient is skeletally mature. For undisplaced physeal fracture, there is no need for serial radiographs. Instead, the family should be counselled about low potential for growth arrest and to follow-up if any symptoms or deformity are noticed.

Fig. 6 Growth arrest lines normal and abnormal Park–Harris (PH) lines. a Arrows point to normal PH lines which are parallel to physis. b Dashed arrow points to area of physeal arrest. PH line is not parallel to the physis and coverages towards the area of growth arrest.
Iatrogenic Physeal Injury

Iatrogenic injuries to physis can be caused by forceful reduction manoeuvres or due to placement of periphyseal or transphyseal implants (Fig. 7). At times, it is difficult to differentiate iatrogenic injuries from the initial injury insult. Physeal arrest (SH V) has been reported after metaphyseal and diaphyseal fractures not involving the physis \[34\]. Similarly, inadvertent physeal injuries can occur during routine treatment of metaphyseal and diaphyseal fractures. Several factors decide the fate of physis after an initial injury.

- Forceful and repeated manipulation of physeal fracture could lead to increased physeal damage. For extra-articular physeal fractures, satisfactory alignment of the fracture fragments is acceptable rather than forceful attempts to achieve anatomic reduction. Physeal gap of up to 3 mm may be due to periosteal interposition in the fracture fragment. It is not necessary to remove this interposition as it has not shown to affect the rate of premature physeal closure \[35\]. If the fracture fragments cannot be aligned and there is persistent deformity after reduction attempts, then open reduction should be performed to remove any tissue interposition.

- K-wires: several animal studies have shown a correlation between transphyseal pinning and growth disturbances \[27, 36, 37\]. Premature physeal arrest has been reported after pinning of distal radius fracture by several authors \[38–40\]. Boyden and Peterson observed that premature physeal closure was potentially related to pin size, location of the pin within the physis, obliquity of the pin within the physis, use of threaded pins, and increased duration of retention of pin in the physis \[38\]. Smith et al. showed that the use of temporary transphyseal pinning in juxaphyseal fractures of upper limb, resulted in physeal arrest in 1 out of 5 patients on MRI evaluation at 6 months after the removal of K-wire \[41\]. Thus, transphyseal K-wires should be used judiciously across the physis and multiple K-wires, multiple attempts at insertion of K-wires, large-size K-wires, intrafocal K-wires and permanent K-wires should be avoided.

- Intramedullary Nails: Piriformis entry of intramedullary rigid nail for treatment of femoral diaphyseal fractures in children can lead to avascular necrosis of the femoral head (due to vascular injury) or coxa valga (due to injury to the medial aspect of trochanteric apophysis). This has been observed in 30% of the cases in one series \[42\]. This did not depend upon the dimension and duration of retention of nail \[43\]. Another study showed that physeal arrest developed in three out of the eight patients following nailing due to reaming \[44\]. Trochanteric entry or lateral entry nail have shown to minimize such complications. Other authors showed favourable result with nailing when the nail was placed in the centre of the physis and diameter of the nail was small in relation to the physis \[45\]. Similarly, injury to distal femoral physeal arrest could happen during placement of retrograde flexible intramedullary nails. It is recommended that insertion point for such nails should be in the metaphysis and dissection should be avoided in the area of the physis during nail placement.

![Fig. 7](image) An example of iatrogenic physeal arrest following ORIF of tibial tubercle fracture-Physeal arrest could be due to primary injury but keeping screws across physis after fracture healing in a growing child would lead to iatrogenic growth disturbances. This could be potentially prevented by the removal of screws after fracture healing.
• Threaded pins and screws: threaded pins and screws across the physis are avoided due to potential risk of premature physeal closure except in some instances. For example: threaded K-wires/Steinmann pins are used for fixation of displaced proximal humerus physeal fractures. Smooth K-wires have shown to migrate when used around the shoulder area as early as 5 days after placement, and may end up in vital structures (lungs, heart, vessels, mediastinum) and could be fatal [46]. When threaded implants are placed across the physis, it is recommended to remove these implants after fracture healing.

**Principles of Management of Physeal Arrest**

Physeal arrest (bony bar, physeal bar, bony bridge) leading to growth disturbances occurs in about 5–10% of physeal fractures [2]. Growth disturbances are always a possibility after injuries around the physis and the family should be counselled about it at the start of the treatment and the information should be reinforced periodically during follow-up. The follow-up radiographs should be carefully scrutinized to detect early signs of growth disturbances. An anatomic reduction, with or without internal fixation, does not guarantee against a growth arrest. Management of physeal arrest would depend on the physis involved (location and extent), type of bony bar (location and size), growth remaining and existing or expected deformity/limb-length discrepancy [47, 48].

Minor disturbances in physes are seen in a high percentage of physeal injuries, but may not require any treatment except for observation. Several animal studies have concluded that injury to 7–10% of the physis did not result in permanent growth arrest and may not require any treatment [49–51]. On rare occasion, a small bony bar may break due to continuous longitudinal growth of the uninjured physis [52]. This would typically occur in younger patients when the physis has significant growth potential. Sometimes, the physeal bar may resolve spontaneously [53–56]. An atypical incomplete bar (forme fruste bar) due to cartilaginous aberration may be seen after physeal fracture. It is due to increased production of physeal cartilage which could temporarily tether the growth and cause growth disturbances. Possible explanation for this phenomenon is temporarily cessation of blood flow to the metaphysis delaying the invasion of the cartilage columns in the hypertrophic zone by the vascular and bone forming activities of the zone of provisional calcification [57].

The principles of management of physeal arrest are summarized in Fig. 8. This is a simplified flowchart to help with complex decision-making process. Assessment of the remaining growth is based on the skeletal age and not chronological age. Although it has been reported that a physeal bar occupying up to 50% of physeal area could be successfully removed, 30% seems to be a threshold based on the recent reports and authors experience. Similarly, the general indications for hemiepiphyseodesis and osteotomy have been listed here as > 5° and > 10° of deformity, respectively. This may vary based on the physis, remaining growth and physician–patient–family shared decision. [58].

**Past Attempts and Recent Advances in Management of Physeal Injuries**

- **Acute Langenskiold procedure** Langenskiold popularized the method of free fat graft interposition after resection of partial physeal arrest. The fat graft would prevent reformation of the bony bridge. Similar concept could be used in an acute setting. With high-risk fractures, like SH IV and VI, when the physis is crushed or exposed, an acute Langenskiold procedure can help prevent a bony bar [31]. Foster et al. reported two cases of SH IV fracture and one case of SH VI fracture treated with acute free fat grafting over the exposed physis. Based on their excellent results and success in prevention of bone bridge formation, the authors recommended a definite role for an anticipatory Langenskiold procedure in the management of acute high-risk physeal injury [30]. Recently, Abbo et al. reported on an SH VI fracture of distal tibia in an 11-year-old boy, where an anticipatory Langenskiold procedure was performed successfully using bone cement instead of fat graft [59].

- **Interposition materials** They are used after bony bar resection in order to prevent accumulation of blood in the cavity which can lead to recurrence of bar formation. Various interposition material used are fat, polymethylmethacrylate (PMMA), silastic, cartilage, bone wax and dura. Fat and PMMA are the two most commonly used interposition materials [9]. Fat has the advantage that it’s nonimmunogenic and can be harvested locally. The disadvantage is that it is not haemostatic and tends to float out of the cavity when the raw bone surfaces bleed after the removal of bony bar. Application of either thrombin or bone wax can provide haemostasis and help prevent fat migration. The other option is to suture the fat to the epiphysis and metaphysis using drill holes. Langenskiold recommended suturing ligament, muscle or subcutaneous tissue over the fat to prevent migration [60, 61]. Another disadvantage of fat is that it does not provide structural support to the weakened bone, thereby predisposing the bone to pathologic fracture. Thus, postoperative immobilization and limited weight bearing may be required [62]. Lastly, fat cells can undergo degradation or necrosis that can lead to recurrence of bony bar formation [63]. PMMA without barium (Cranioplast) has several desirable characteristics like being inexpensive, minimally...
thermogenic, easily available, inert, haemostatic and radiolucent. It can provide structural support after bone bridge resection and thus early weight bearing could be initiated [64]. When used as an interposition material, PMMA should be tethered to the epiphysis to prevent it from migrating into the metaphysis. This can be achieved by creating drill holes in the epiphysis, using K-wire through the epiphysis and PMMA or by undermining the epiphyseal walls to create PMMA plug anchor.

- **Fibrin** (*fibrin glue, fibrin sealant*) is routinely used for its haemostatic and surgical sealing properties and is easily available in the market. Its role in prevention of bony bar has been explored in animal models. Besides minimizing bleeding at the site of physeal injury, it can create a microenvironment that is suitable for chondrocyte induction and conduction [65]. Jie et al. reported that fibrin could effectively inhibit bony bar formation in a proximal tibia physeal injury rat model. Fibrin application led to the formation of a scar-like tissue instead of a bone bridge [66]. In a porcine model of distal femur physeal injury, Abood et al. reported that fibrin alone could prevent formation of bone bridge in 4 of 5 specimens and was more effective than fat as interposition material. When fibrin was mixed with autologous articular cartilage, the mixture prevented bone bridge formation in all specimens [67]. Thus, fibrin appears to be an attractive, readily available, alternative to other interposition materials although its clinical results are lacking.

- **Physeal distraction** Symmetric distraction of physis by an external fixator has been used for bone lengthening in children [68, 69]. In animal studies, the rate of distraction had an effect on the fate of the physis as rapid distraction (1 mm per day) led to ossification and closure of the physis but slow distraction (0.25 mm twice a day) maintained the normal physeal thickness and growth potential [70]. These principles have been applied to post-

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**Fig. 8** Flowchart showing principles of management of physeal arrest
traumatic physeal bar and resultant growth deformities. Slow, asymmetric physeal distraction could potentially break the physeal bar and allow for deformity correction followed by normal physeal growth. Aldegheri et al. reported on 35 lower extremity post-traumatic deformities and their best results were achieved when the bone bridge occupied less than 20–30% of the physis [71]. Canadell and De Pablos reported on eight cases with bony bar and deformities affecting the lower extremities. They reported adequate correction with physeal distraction without the need for resection of the bone bridge [72]. Bollini et al. reported successful treatment of a centrally located bony bridge of the lower tibia using distraction by Ilizarov technique [73].

The main drawback of this technique is the variable rate of physeal growth after distraction with reports of growth disturbances and premature physeal closure ranging from 0 to 100% [74, 75]. Hence the procedure is reserved for those near skeletal maturity. Other complications include pin site infections, joint stiffness and sudden increase in pain due to breakage of bone bar.

- **Physeal transplantation** An alternative to the treatment of physeal bar would be to exchange it with normal functioning physis to produce meaningful growth. The physeal transplant could be an autograft or allograft and it could be vascularized or non-vascularized. Autograft availability of physis is significantly limited by lack of donor site in the body. Possible donor sites for physeal cartilage include proximal fibula, distal ulna, distal clavicle, phalanx, toe, costal cartilage or iliac crest apophysis. The physis could be transplanted as a bone block (containing sliver of epiphysis and metaphysis with intervening physis), as the end of a bone bridge or as part or whole physeal plate without bone. Mayr et al. reported on 3-year follow-up of successful reconstruction of medial malleolus defect in a 10-year-old boy using iliac crest apophyseal cartilage and physeal transplant [76]. Gigante and Martinez reported on 4-year follow-up of a successful case of excision of bone bridge from distal radius physis in a 12-year-old boy and replaced it with an autologous block from iliac crest apophysis [77]. The cartilaginous transplant was oriented such that the bony part of the iliac crest was placed against the metaphysis of the radius. Despite clinical case reports and encouraging animal study results, physeal transplant is not popular as the results are unpredictable. The donor site is limited and the donor physis retains its growth potential which may be different from the growth rate of the recipient site [78, 79]. The physis has to fit exactly at the recipient site so that the metaphysis and epiphysis are aligned appropriately. Slight mismatch could lead to bony bar formation. For non-vascularized grafts, inadequate vascularity and nutrition could lead to ischaemia and death of the physis [80]. To obviate the issue of limited donor site availability, physis allograft transplantation has been studied in animal models. Microvascular transplantation of physeal allograft is appealing but its use restricted due to lack of data on the survival of cartilage cells in the physis and the risk of immunogenic reaction in the host, which would require immunosuppressive therapy [81].

- **Regenerative and tissue-engineering approaches** Various studies have proposed newer approaches which suggests that, not only the bony bar formation be prevented but can also be regenerated to healthy physis. Autologous chondrocytes embedded in scaffolds have been successfully integrated into growth plate in animal models [82, 83]. However, their use may be limited by the need to isolate chondrocytes from normal tissues, thus creating secondary injury sites. To counter this, mesenchymal stem cells (MSCs) from periosteum and bone marrow have been used. These MSCs resulted in native like repair tissue in animals [84]. To promote cartilage differentiation of cells, chondrogenic factors such as IGF-1, TGF BETA-1 and 2 are commonly used [85]. For cells and chondrogenic molecules to have an effect at the site of physeal injury, they have to be delivered locally by a temporary scaffold. Commonly used scaffolds are collagen I and II, hyaluronate–collagen–fibrin composites, Collagen chitin scaffolds, agarose, chitin, gelatin and PLGA. Another potential approach is to modulate the pathways that stimulate osteogenesis. Bevacizumab, a humanized anti-VEGF antibody, showed reduction in osteogenic gene expression, fewer blood vessels, and decreased bony bar formation [86]. Other pathways which have been studied include Wnt/β catenin. Inhibition of this pathway in rat models have led to decreased bony bar formation [87]. Thus, the field of regenerative medicine holds a lot of promise for the future.

**Conclusion**

Physeal fractures are common. The ideal approach to treat these injuries depends on thorough understanding of principles of physeal fracture management, taking into account the location of injury, age of the patient, fracture type and growth potential of the involved physis. Prompt diagnosis and physeal-respecting treatment techniques are important but may not be sufficient to prevent future physeal growth arrest and resultant growth disturbances. Family counseling and careful vigilance would help in identification and management of such growth disturbances should they occur.
Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any study with human participants performed directly by any authors for this particular paper.

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Trash Lesions Around the Elbow: A Review of Approach to Diagnosis and Management

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Abstract
TRASH lesions are a group of special injuries around the elbow resulting from high energy trauma that are routinely missed at initial presentation because of seemingly normal X-rays. These are a group of osteochondral injuries having a high propensity for surgical intervention and usually have poor outcomes if not treated adequately. Prompt diagnosis warrants a high index of suspicion even when a radiograph appears to be normal with a disproportionately swollen elbow in a child. TRASH lesions include radial head osteochondral fractures, medial condylar fractures in unossified elbow, transphyseal separations of the distal humerus, monteggia lesions, entrapped incarcerated medial epicondylar fractures, capitellar shear fractures, lateral condylar fractures extending to the cartilage. This article attempts to review in brief, the approach to early diagnosis and management with literature review and case examples.

Keywords TRASH · Osteochondral fracture · Elbow · Humerus · Late diagnosis

Introduction
The elbow of a child is made predominantly of cartilage. Secondary ossification centers appear around the ages as depicted in the image below (Fig. 1). Fractures around the elbow constitute 12% of all paediatric fractures [1]. Most common fractures around elbow in a child less than 10 years are supracondylar fractures followed by fractures of the lateral condyle of humerus [2]. A few uncommon injuries that occur through the unossified part of the elbow prior to the appearance of secondary ossification centers, are relatively difficult to diagnose and are not routinely appreciated on a radiograph. These lesions if undetected or detected late may lead to serious long-term complications.

Waters et al. described these frequently missed injuries around the elbow as TRASH (The Radiographic Appearance Seemed Harmless) lesions in 2010 [3]. They present with a painful swollen elbow with an otherwise normal-looking radiograph. A high index of suspicion, early further imaging like ultrasound, arthrogram, MRI helps give us a prompt diagnosis and a chance for early surgical intervention.

TRASH lesions include the following osteochondral fractures.

- Radial head osteochondral fractures with progressive radiocapitellar dislocation.
- Unossified medial condylar fractures.
- Transphyseal separations of the distal humerus.
- Monteggia lesions.
- Entrapped incarcerated medial epicondylar fractures following dislocation of elbow.
- Capitellar shear fractures.
- Lateral condylar osteochondral shear fractures.

In this article, a brief overview of the individual TRASH lesions, with tips and potential pitfalls in diagnosis and management protocol are addressed.

History, Examination and Management of Individual Lesions

Radial Head Osteochondral Fractures with Progressive Radiocapitellar Dislocation

Fractures of the radial head in a child are infrequent due to its cartilaginous nature and resiliency. Intra-articular radial
head fractures are seldom noticed in comparison to radial neck fractures and are associated with a poor prognosis [4, 5]. Most of the intra-articular fractures can be managed successfully conservatively. A subset of intraarticular fractures tends to subluxate posteriorly leading to progressive radiocapitellar dislocation if not detected early (Fig. 2) [6]. This can be graded using the Bell et al. criteria [7]. Type I lesion is a posterior radiocapitellar subluxation, and a type II lesion is a posterior dislocation of the radial head with minimal displacement. A type III lesion is a posterior dislocation of the radial head which is proximally migrated crossing the midline of the humerus. Delay in diagnosis poses a risk of complications such as delayed radial head subluxation, radiocapitellar arthritis, osteochondral defect, fibrous non-union, full-thickness chondral defect, radial head enlargement, and premature physeal arrest leading to relative shortening of the radius [5]. If presented acutely with subluxation or dislocation, it may warrant open reduction and internal fixation with annular ligament repair, if required. If the patient presents late with complications, salvage procedures like radial head excision, cheilectomy, anterior capsular release might be needed to improve elbow function.

Unossified Medial Condylar Fractures

Medial humeral condylar fractures are uncommon injuries, comprising 1–2% of all pediatric elbow fractures [8, 9]. Medial condylar secondary ossification center appears around 8 to 9 years. Medial humeral condylar fractures prior to this age may be mistaken for medial epicondylar avulsion fractures if a metaphyseal wafer of bone attached to fractured medial condyle is confused with the epicondyle.
The distinction between fractures limited to the epicondyle and other more extensive fractures involving the medial condyle is critical as the latter are unstable and must be treated promptly with surgical intervention to prevent instability, deformity and restriction of range of movements.

Owing to the location of medial epicondyle outside the joint capsule, fractures limited to this center usually do not produce joint capsular distention and consequently will not produce a positive fat pad sign \[10\]. Pain, swelling, ecchymosis over the medial side of the elbow, and radiographic clues like soft tissue shadow confined to the medial aspect of the elbow with a metaphyseal wafer of bone and a positive fat pad sign should arise suspicion of medial condylar fracture and should be evaluated with further imaging techniques like an ultrasound, arthrogram or an MRI. If C-sign (sickle-shaped malrotated small metaphyseal fragment) (Fig. 3a) appears on the medial side of the elbow in a child younger than 8 years, a medial condyle fracture must be ruled out \[11\].

The development of non-union, cubitus varus deformity occurs as a result of failure in identifying these fractures \[8, 11\]. Patients in whom diagnosis was made early and received prompt surgical intervention had better functional outcomes. Risk of avascular necrosis of trochlea and fish tail deformity has been described following open reduction and posterior dissection of the medial condyle which may compromise the blood supply of the trochlea \[11\].

**Transphyseal Separation of Distal Humerus**

Transphyseal fractures of the lower end humerus are rare injuries. They occur typically in children under 3 years of age and are often mistaken for elbow dislocations. However, elbow dislocations are rarely seen in children younger than 3 years, because the cartilaginous physis is weaker compared to bone ligament junction in young, which makes them susceptible to transphyseal separations \[12\]. The most common mode of injury in a newborn is during obstetrical maneuvers used to deliver the baby especially with shoulder dystocia or with excessive traction during the caesarian section \[13, 14\]. In toddlers, common mechanisms are fall on an outstretched hand and non-accidental trauma due to child abuse. An injured child will have diminished spontaneous movements of the affected extremity, swelling, and ecchymosis around the elbow. Many of these injuries are missed by primary care physician discounting them as normal or elbow dislocations.

The key to the diagnosis of transphyseal fractures on plain radiography is recognizing that a line drawn along the shaft of ulna is not aligned with the shaft of humerus on an AP view. The forearm is displaced posteromedially, whereas in most elbow dislocations, it is displaced posterolaterally (Fig. 4). If the secondary ossification center of capitellum has appeared, the radiocapitellar alignment is maintained (as opposed to elbow dislocation) and is displaced posteromedially with the entire forearm. A positive posterior fat-pad sign is noted in these cases which is suggestive of an occult fracture.

Children older than 3 years typically have Salter-Harris type II injuries with a metaphyseal Thurston-Holland fragment attached to the distal fragment, and younger children have Salter-Harris type I injuries with pure transphyseal fractures \[15\]. When in the dilemma of the diagnosis, Ultrasound, MRI or arthrogram can be done. The majority of the transphyseal fractures of the distal humerus can be treated successfully with closed reduction and percutaneous k-wire fixation, with the aid of an arthrogram. Acceptable criteria following closed reduction are similar to those of the

Fig. 3 6-year-old child presented with swollen elbow following fall on outstretched hand. a, b Radiograph reveals a small flake of bone with C- sign (arrow mark) medially suggestive of medial condyle fracture. He was managed conservatively initially. c 6 months later child presented with cubitus varus deformity with nonunion. d Intra-operative image following open reduction and fixation with cancellous screw and a k wire

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supracondylar fractures - the anterior humeral line should pass through the middle third of the capitellum; varus alignment, and malrotation should be avoided. The most common complication of the transphyseal separations is cubitus varus deformity [16]. Other known complications are osteonecrosis, growth disturbance, compartment syndrome, decreased range of movements, and neurovascular injuries. It is recommended to avoid late manipulation (after 5–7 days) due to the danger of avascular necrosis, physeal injuries, and growth disturbances, and deal with residual deformity if any, at a later date.

Hence, particular attention has to be paid in children younger than 3 years with elbow trauma for prompt recognition and appropriate treatment, often with closed reduction and percutaneous k wire fixation with the aid of an arthrogram results in excellent outcome.

**Missed Monteggia fractures**

Radial head dislocation in combination with the plastic deformity of the ulna is a subgroup of Monteggia fractures [17]. All isolated traumatic radial head dislocations noted in children are Letts type A Monteggia variants [18, 19]. Variation in radiocapitellar line and a positive ulnar bow sign on a lateral radiograph are diagnostic of monteggia fracture with plastic deformation of the ulna and radial head dislocation. The radiocapitellar line helps demonstrate radial head dislocation, where in a line drawn along the long axis of the radial shaft fails to pass through the middle third of the capitellum in any degree of elbow flexion (Fig. 5a, b, c). The ulnar bow line normally is a straight line from the level of the olecranon to the distal ulnar metaphysis when drawn on the true lateral view of plain radiograph along the dorsal border of the ulna. This shows concavity with > 1 mm displacement from the ulnar shaft at the maximal ulnar bow in cases with plastic deformity of the ulna and radial head dislocation (Fig. 5a, b) [18]. Proper lateral view of elbow is needed to interpret these lines accurately.

When diagnosed early, closed reduction by manipulation of the radial head and correction of ulna bow is a viable option. If radial head reduction is not stable, it may lead to a painful deformed elbow with restricted movements. When there is no ulnar bowing, closed reduction of the radial head alone is sufficient. However, if ulnar bowing deformity is left uncorrected, congruent radial head reduction is likely to fail with disappointing functional results. A dorsal open wedge (flexion) osteotomy of the ulna, and fixation with a contoured plate, combined with open reduction of radial head and a short period of immobilisation is a safe and dependable method of treating the delayed presenting monteggia lesions (Fig. 5d, e). Annular ligament reconstruction is not always mandatory. The annular ligament is frequently flipped over the radial head, with the formation of meniscoid scar tissue thereby preventing reduction, which ultimately demands resection.

Good radiographs, ability to recognize the ulnar bow sign, and altered radiocapitellar line in all children presenting with a painful swollen elbow and restricted movements will minimize the chances of a missed diagnosis. Prompt treatment to reduce the plastic deformation of ulna and dislocated radial head will give the best possible outcome. In late cases, corrective osteotomy of the ulna with radial head open reduction with reconstruction of annular ligament when required gives functionally acceptable results.

**Entrapped Incarcerated Medial Epicondyle Fractures Following Elbow Dislocation**

Medial epicondyle ossification center appears around 5–7 years and is last to fuse to the distal humerus, at around 15–17 years [20]. The peak age of incidence of medial
Epicondylar fractures is around 11–12 years [21]. It occurs in about 30 to 55% of elbow dislocations in children and adolescents [21]. Medial epicondylar fracture has been classified into 4 types by Papavasiliou (Fig. 6) [22]. Entrapped medial epicondylar fractures present with pain and swelling accompanied by loss in motion especially extension of the elbow. Elbow stability has to be assessed in all cases of medial epicondyle fractures, which is best seen by gravity-assisted valgus stress test. This is done with the patient lying supine, abducting and externally rotating the shoulder to 90°, flexing the elbow to 15°, and checking for medial opening at the elbow under gravity. The ulnar nerve may be involved in displaced medial epicondyle fractures given its proximity to the epicondyle. Internal oblique and axial views of the elbow are preferred as they better delineate the fracture displacement.

Medial epicondyle incarceration within the joint, marked elbow instability, ulnar nerve symptoms, and compound fractures are absolute indications for surgery. It is approached through the medial incision, entrapped epicondyle is released, freshened and fixed with one or two 3.5 mm or 4 mm screws. Kirschner wires are preferred in very young patients (Fig. 7). The ulnar nerve is delineated and protected in all cases and anterior transposition is done in cases with ulnar nerve affection. Screws are positioned above the olecranon fossa and are preferably unicortical to prevent radial nerve injury and stress riser effect that may occur if a bicortical purchase is achieved [23]. High index of suspicion is needed in very young in whom the apophysis is not ossified. Clinical features such as swelling or tenderness on the medial side of the elbow and palpation of the fragment must arise suspicion of this injury. An incarcerated medial

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**Fig. 5** a, b 7-year-old girl with injury to wrist and forearm following a fall. Distal radius and ulna with proximal ulna fracture were treated with closed reduction and above elbow cast. But Monteggia lesion was missed during the initial treatment. Note Mc Lauglins line (solid line) passing anterior to capitellum and Ulnar bow sign (dotted line) is positive. c Child presented 5 months following injury with block in flexion, elbow pain and restricted prono-supination. d Ulnar dorsal open wedge osteotomy along with open radial head relocation was performed. e Radiograph shows good healing of osteotomy site and well reduced radial head (restored Radiocapitellar line)
Fig. 6 Papavasiliou classification of medial epicondyle fractures. Type I is minimally displaced avulsion, type II is avulsed, non-entrapped at the level of joint, type III with an avulsed fragment incarcerated in the joint, type IV with a fragment in the joint with dislocated elbow.

Fig. 7 a, b 5-Year-old child presented with pain, restricted elbow movements and paraesthesias in ulnar nerve distribution following elbow dislocation reduced at other centre, the radiograph shows Papavasiliou type 3 medial epicondylar fracture fragment at joint level indicating incarceration following elbow dislocation. c MRI shows medial epicondylar fragment entrapped with ulnar nerve in the joint. d Exploration revealed ulnar nerve entrapment; e Neurolysis, anterior transposition of ulnar nerve and medial epicondylar fracture fixation were performed. f, g Postoperative radiograph with screw insitu.
epicondylar fragment has to be considered when there is a restriction in elbow extension following an elbow reduction with radiographs showing a small fragment at the level of joint. These injuries warrant additional investigations such as arthrography, sonography, or MRI, and prompt surgical intervention is needed to avoid future complications.

Capitellar Shear Fractures

Capitellar shear fractures are often seen in adolescents beyond 12 years of age as trauma in younger children usually leads to supracondylar fracture of humerus owing to the cartilaginous composition of capitellum [24]. Radiological diagnosis of capitellar fractures is challenging in children below 10 years of age as it is not completely ossified and fused [25]. These injuries occur following a fall on an outstretched hand, where the radial head exerts a shearing force on the capitellum.

Four types of fractures are described by Bryan- Morrey and McKee (Fig. 8) [26, 27]. Type I or Hahn- Steinthal fragment is where the entire articular part of capitellum is fractured which occasionally includes lateral crista of trochlea. Type II or Kocher-Lorenz fragment is a superficial osteochondral fracture involving only cartilaginous part of the capitellum with a part of subchondral bone attached to it. This type is difficult to diagnose on radiographs and needs advanced imaging like MRI. Type III or Broberg-Morrey/ Grantham fracture is a comminuted/ compression fracture of the capitellum. Type IV fracture, McKee’s modification of type I, is a shear fracture across the capitellum extending medially to include the lateral half of the trochlea. Another type of fracture unique to children called “sleeve fracture”, includes a large fragment of capitellar articular cartilage with subchondral bone, which separates in continuation with metaphysis and physis resembling a sleeve [28, 29]. Treatment includes fixation with headless compression/ bioabsorbable screws aiming at restoring the articular congruity or excising the fragments if they are too small (Fig. 9).

Missed capitellar fractures present with loss of flexion–extension movements, crepitation on movement, preserved supination and pronation movements. Diagnosis is made by radiographs in AP, lateral and oblique views. The capitellar subchondral bone and lateral part of trochlea forms a characteristic ‘double arc sign’ on an elbow lateral radiograph, which is typical of Mc Kee’s type IV fracture [30]. Presence of concomitant radial head fractures should be screened for on the radiograph.

When there is a suspicion of capitellum fracture, MRI or arthrogram aids in confirming the diagnosis which if missed and left untreated, may lead to substantial disability in elbow motion and may result in early radio-humeral arthritis.

Fig. 8  Bryan-Morrey classification type I—Large osseous fragment of capitellum, type II—shear fracture of articular cartilage with little/no bone, type III—comminuted fracture of the capitellum, type IV—Mc Kee’s modification—coronal shear involving capitellum and trochlea
Lateral Condyle Avulsion Shear Fractures

Fractures of the lateral condyle are the second most common fractures around the elbow in children [31]. As the articular portion of lateral condyle ossifies in late adolescence, fractures extending through this cartilaginous part are not readily visible on radiographs. Hence, complete delineation of lateral humeral condyle fractures cannot be made on a plain radiograph. Minimally displaced fractures pose a problem because of inaccurate diagnosis and subsequent complications. Song’s classification helps define management protocol. Stable fractures are those with intact articular cartilage hinge and unstable ones lack cartilaginous articular continuity. Unstable fractures warrant reduction and fixation with smooth wires to prevent nonunion and subsequent complications. Differentiation of stable from unstable fractures can be done with various studies such as MRI, stress radiography, arthrography, ultrasonography, etc. Most important distinction between stable and unstable fractures can be made by measuring and comparing the fracture gap in anteroposterior and internal oblique views. Proper internal oblique view is obtained with the patient seated, arm extended comfortably, forearm pronated and elbow rotated medially until the anterior surface of the elbow is at a 45° angle to the X-ray beam. If the fracture displacement is more than 2 mm in either anteroposterior or internal oblique view,
they are deemed unstable and need closed reduction and k-wire fixation [32]. Additionally, arthrogram helps differentiate Song’s stage 1 and 2 from others when the presence of radiopaque contrast within the fracture line indicates disruption of the cartilage hinge (Fig. 10). MRI is also valuable in determining the integrity of the cartilaginous articular hinge, but the need for sedation in children makes it an unattractive option. When conservative management is chosen, it is recommended to procure fresh AP and internal oblique views of the elbow out of cast during the initial weekly follow-ups to look for the late displacement of the fracture and intervene if necessary [33]. Stable fractures (stage 1, 2) need conservative management with a cast. Unstable fractures (stage 3, 4) need traction and varus force followed by direct compression of the distal fragment in anteromedial direction and valgus force in extension to stabilize and k-wire fixation. For unstable (stage 5) fractures K-wire assisted joystick reduction may be attempted to reduce the rotated fragment followed by fixation as mentioned above or it can be converted to open reduction if it is unsuccessful [32]. Failure to distinguish between stable and unstable fractures may lead to inadequate treatment and subsequently present with late complications like nonunion, cubitus valgus, tardy ulnar nerve palsy, elbow stiffness, etc.

**Summary**

TRASH lesions around the elbow are a collection of osteochondral injuries which if left untreated or inadequately treated result in long-term consequences. Prompt diagnosis needs a high index of suspicion in an elbow swollen out of proportion to a radiograph appearing normal. This group of injuries are displaced and unstable but is seldom seen on a radiograph owing to their cartilaginous nature. These lesions almost always warrant further imaging like Ultrasound or MRI or Arthrogram or CT scan for an accurate diagnosis. The aim should be to achieve anatomical reduction following internal fixation with or without soft tissue repair to have a fully functional elbow and prevent subsequent complications.

![Fig. 10](image)

**Fig. 10**  

- a 4 year old child with lateral condyle fracture AP, lateral and internal oblique views showing fracture gap > 2 mm. 
- b Integrity of articular hinge was examined with an arthrogram which has shown dye leaking through the fracture site indicating disrupted articular hinge and an unstable fracture. 
- c This was managed with closed reduction and percutaneous K wire fixation.
Compliance with ethical standards

Conflict of interest  On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Standard Statement  This article does not contain any studies with human or animal subjects performed by the any of the authors.

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Remodelling in Children’s Fractures and Limits of Acceptability

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Abstract
Remodeling follows inflammatory and reparative phases of bone healing and is very pronounced in children. Unlike adults, in growing children, remodeling can restore the alignment of initially malunited fractures to a certain extent, making anatomic reduction less essential. Remodeling is not universal and ubiquitous. Animal experiments and clinical studies have proven that in a malunited fracture, the angulation corrects maximally by physeal realignment (75%) and partly by appositional remodeling of the diaphysis also known as the cortical drift (25%). Remodeling potential reduces with the increasing age of the child; lower extremities have higher remodeling potential compared to the upper extremity. Remodeling is most pronounced at the growing end of the bone and in the axis of the adjacent joint motion. Correction of a very small amount of rotational malalignment is possible, but it is clinically not relevant. Overgrowth of the bone after a fracture occurs due to hyperaemia of fracture healing. Overgrowth is the most common after paediatric femur fractures, though it is reported after fractures of the tibia and humerus as well. The orthopaedic surgeon treating children’s fractures should be familiar with regional variations of remodeling and limits of acceptance of angulation in different regions. Acceptability criteria for different bones are though well defined, but serve best as guidelines only. For the final decision-making patient’s functional capacity, parents’ willingness to wait until the completion of the remodeling process, and the experience of treating doctor should be considered concurrently. In case of the slightest doubt, a more aggressive approach should be taken to achieve a satisfactory result.

Keywords  Remodeling of fractures · Fracture healing · Limits of acceptability · Overgrowth

In growing children, remodeling can restore the alignment of initially malunited fractures to a certain extent, making anatomic reduction less essential than adults. Bone remodeling is dependent upon muscle action, joint reaction forces, and physiological stresses of body weight. Intrinsic control mechanisms like the periosteum also play a role in remodeling [1]. Knowledge of remodeling can help in managing many fractures in young children conservatively. Contrary to that, over-reliance on remodeling potential may lead to permanent deformity. Hence, a precise understanding of regional remodeling potential is crucial.

Fracture Healing in Children
Fracture healing comprises three phases: (1) inflammatory, (2) reparative, and (3) remodeling. The remodeling phase is more prolonged and pronounced in children than in adults.

Inflammatory Phase
The inflammatory phase begins immediately after the fracture with the formation of endosteal, subperiosteal, and extraperiosteal (if periosteum is torn) hematoma. Due to hematoma formation, few millimetres of bone on either side become avascular. Following the removal of this dead bone, the fracture line becomes better visible after a few days.

The vascular response initiates the cellular response. TGF-β released from the extracellular matrix of bone and platelets controls the mesenchymal precursor cells, which form osteoblasts and osteoclasts. Growth factors convert the multipotential cells into osteoprogenitor cells. Fracture
bridging occurs by subperiosteal bone formation and endochondral bone formation at the endosteal areas [2]. Motion at the fracture site leads to lower oxygen tension, which leads to more cartilage formation, which is ossified later. There is gradual revascularization of the dead bone at the fracture site.

Reparative Phase

The reparative phase is highlighted by the formation of new blood vessels and the beginning of cartilage formation. Initially, neighbouring soft tissues provide vascular ingrowth to the periosteal area followed by the endosteal area. Endochondral bone is formed by calcification of the cartilage anlagen adjacent to the fracture site. Undifferentiated mesenchymal cells of the periosteum differentiate into osteoblasts and form intramembranous bone without a preceding cartilage model at the periphery.

As new bone forms under the periosteum, it is pushed away from the bone, making a collar of bone around the fracture. Primarily, this tissue is cartilaginous and fibrous and not very well ossified. It is not visible on a radiograph, but after mineralization and conversion to the bone, it becomes better visible [2].

Fracture unites clinically after the bony callus surrounds the fracture fragments and connects with the callus coming from the opposite side. At this point, the bone is clinically stable enough for the patient to begin extremity usage.

Remodeling Phase

Remodeling is the last phase of bone healing, which may last for a short time in a young child or continue throughout the growth period or even beyond the cessation of growth in an older child. Once the bone is clinically stabilized, remodeling of early soft woven bone occurs due to physiological stresses and strains. Single-cell types like osteoclasts or osteoblasts are not responsible for remodeling, but coordinated bone resorption and bone formation over large regions around the fracture are responsible for it [2].

Cartilage healing is not similar to bone healing. When the physis is injured, inflammatory and reparative phases occur, but there is no remodeling phase [2].

Remodeling of Bone in Children

Higher remodeling potential of bone in children permits treating doctor to accept suboptimal alignment with conservative treatment. The remodeling is not uniform and ubiquitous. Many factors affect bone remodeling and knowledge of which is very important for an orthopaedic surgeon treating paediatric fractures.

Remodeling can potentially correct translation, axial, and rotational deformity. It can correct shortening but not lengthening (which is occasionally iatrogenic).

Correction of Translation (side by side displacement)

It is purely a periosteal correction and is dependent on the age of the patient. In children up to the age of 10–12, complete side-to-side displacement of entire shaft width can correct practically in the entire skeleton baring some exceptions [3] (Figs. 1, 2 and 3).

Correction of Axial Deformity (coronal and sagittal)

There are a few laws, which guide remodeling of the bone with axial deformity.

Wolff (1892) stated that new bone is produced where it is necessary mechanically (in the weight-bearing area) and is reabsorbed from areas where it is not necessary. So when fracture unites in angulation, new bone is formed in concave areas, and resorption dominates on the convex side. This process produces a certain realignment of the bone. Although it also occurs in adults, it is more remarkable in children [4]. Pioneering work by multiple authors has established that it accounts for approximately 25% of the correction and is commonly referred to as bone drift and comes from periosteum [5, 6].

According to Hueter Volkman’s law (1862), after a malunited fracture, adjacent physes tend to realign perpendicular to the forces acting through them (Fig. 4). This modifies the orientation of the fracture to the bone axis [4, 7]. According to Murray, asymmetric growth of the physeal plate accounts
for approximately 75% improvement in fracture angulation [5]. Wallace in a clinical study of remodeling after femoral fracture noted 74% correction at physes and only 26% at shaft [8] (Fig. 5). Freiberg also noted the larger role of epiphyseal reorientation in remodeling of distal radius fractures [9].

After animal experiments, Murray concluded that after malunion of the fracture in the immature skeleton: (1) the overall limb and joint alignment corrects rapidly due to asymmetrical physeal growth, (2) the angulation at the fracture site rectifies slowly by the bone drift, (3) division of periosteum has a minor effect on angulation improvement, (4) under some circumstances the growth plate grows in a helix and by this mechanism torsional deformities may ensue and may rectify [5].

**Factors Affecting Remodeling**

Remodeling of the angular deformity is dependent on multiple factors.
• Extremity—remodeling is reduced in the upper extremities compared to lower extremities, probably because the lower extremities are subjected to greater mechanical loads [7].

• Skeletal age—remodeling is proportional to the remaining growth potential and is more pronounced in younger children (< 8 years) [9, 10].

• Fracture site—the proximity of the fracture to a growing physis is a favourable factor for remodeling. The greater the growth potential of the physis (physes around the knee), the better will be the angulation correction [9, 10].

• Degree and orientation of the deformity—if the angulation lies in the plane of movement of the adjacent joint, the more substantial will be the remodeling [9] (Fig. 6). Consequently, in the tibia and femur, malunion in the sagittal plane (procurvatum–recurvatum) shows a better remodeling than the coronal plane [10–12].

Overgrowth

Overgrowth following fracture occurs as a result of hyperaemia of fracture healing. The increased vascularity spreads to the epiphyseal plate leading to growth stimulation and overgrowth [13, 14]. Neer noted overgrowth to be permanent [15]. Overgrowth has been observed after fractures of the femur, tibia, and humerus.

Femur

Shapiro followed 74 children (< 13 years old) following femoral shaft fracture until skeletal maturity and found universal femoral overgrowth. There was an average of 0.92 cm (range 0.4–2.7) femoral overgrowth, which was independent of age, fracture level, or position of fracture fragments at the time of healing. The majority of overgrowth occurred within the first 18 months of fracture. Simultaneous ipsilateral tibial overgrowth of 0.29 cm (0.1–0.5) was found in 82% of children. In 71% of children, overgrowth stopped after 3.5 years, but in 9%, it continued throughout the remaining growth period, albeit at a slower rate. They recommended that in children between 2 and 11 years, shortening of 1.5 cm may be allowed [13].

In a study of 44 children with femur fracture treated with traction Colton reported an average 8.1 mm femoral overgrowth, which was significantly greater in boys. Overgrowth was not influenced by the age, the fracture type or site, the amount of fragment overlap, or by the handedness of the patient [16]. Malkawi reported an average 8.75 mm growth acceleration in children with fracture shaft femur treated with traction, of which 6.8 mm was make-up growth and 1.95 mm was overgrowth. They noted that overriding of the fragments at the time of union stimulates growth and indicated that the greater the initial shortening, the greater the growth stimulation. Overgrowth was most significant in the 3–9 year age group. The fracture type had no effect growth stimulation [11].
Bergmann et al. noted an average overgrowth of 5 mm in 3–10-year-old girls and 3–12-year-old boys. They also noted growth retardation in older children. Growth disturbance was not affected by the fracture type or residual angulation and lasted for 1–2 years. They recommended not to accept any shortening in girls > 10 years and boys > 12 years [17].

Shannak reported an average growth acceleration of 4.35 mm following tibia fracture, with 3.05 mm of make-up growth and 1.3 mm of overgrowth. They noted that increased shortening at the time of the reduction, comminuted fractures, fracture at the proximal and distal end, and young children had higher overgrowth [12].

Following humerus fracture, Emmenaénus noted overgrowth in 63 of 71 children irrespective of the level of the fracture. In the majority of the children, overgrowth stopped at 18 months [14].

Currently, many children from 5 years and above with femur shaft fractures are treated with flexible nailing hence it is imperative to know the amount of overgrowth following flexible nailing.

Flynn reported 5 mm lengthening/shortening in the majority of children treated with flexible nailing, 6 of 58 children had 1–2 cm of inequality on early follow-up. He recommended a longer follow-up to assess the final effect of overgrowth post nailing [18]. Mazda reported lengthening in 38% of 34 patients treated with flexible nailing for femur fracture, the majority of them had < 10 mm lengthening, but 8% had lengthening of 10–15 mm [19].

Park studied femoral overgrowth in 43 children (3.6–12 years) treated with flexible intramedullary nailing with a mean follow-up of 3.5 years and found mean femoral overgrowth of 0.6 cm; 25.6% of children had an overgrowth of ≥ 1 cm [20].

Khan et al. noted limb lengthening in 15 of 29 children treated with titanium nailing in the first year, but after 3 years, only nine children were longer (average 2.7 mm); they concluded that lengthening declines at an average rate of 1.5 mm per year [21].

It has been proved experimentally in an animal model that rotational deformities can correct with helicoidal growth of the physeal plate [5]. In human studies, the correction of rotational malalignment by remodeling is controversial and limited to a small amount [22].

Brouwer studied 50 patients with femur shaft fractures treated conservatively after 27–32 years. They found a single case of persistent rotational malalignment without any untoward consequences. The average difference in femoral anteversion (studied by X-ray measurement) was only 5.8°. There were ten patients with a rotation difference of ≥ 10°, of which five patients had reduced and five had increased anteversion compared to the unaffected side. Surprisingly, their control group also showed individual L/R differences in the rotation of 0°–15°, and angles of anteversion ranging from −9° to +38° (average 10.9°) [23].

David found poor remodeling of posttraumatic femoral torsional deformity in children after CT scan measurement but noted that up to 25° malrotation can be well tolerated [22]. Contrary to that, Buchholz performed MRI at 4 years follow-up in children aged 3–6 years treated with an external fixator for fracture shaft femur to study rotational deformity correction and reported full correction of rotational deformity in three of the five children [24].

Shannak et al. did not find any correction of rotational malalignment following tibial fractures [12].

Regional Variation of Remodeling and Acceptability Criteria After Closed Reduction of Fractures

Good understanding of general remodeling principles is essential, but regional variations and limits of acceptance of angulation in different regions help in quick decision-making. A ready reckoner bone-wise charts of acceptability criteria are helpful to clinicians in their daily practice (Tables 1, 2, 3, 4, 5) [25]. These charts should serve as guidelines only. Functional capacity of the patient, willingness of parents to wait till the completion of remodeling process, and the surgeon’s experience should be considered before deciding whether to depend on the remodeling capability of the specific fracture or to choose an invasive technique to obtain a satisfactory result [25].

<table>
<thead>
<tr>
<th>Table 1 Femur shaft</th>
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<tr>
<td>Age</td>
</tr>
<tr>
<td>Birth—2 years</td>
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<tr>
<td>2–5 years</td>
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<td>6–10 years</td>
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<td>11 years+</td>
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</table>
Wallace studied 28 malunited fractures of the femur over 45 months and noted that an average 75% of the deformity had remodelled by three years, and remodeling was complete at 5 years. The degree of remodeling was not influenced by either the direction or the magnitude of the angulation. Younger children remodelled a little better. He concluded that in children younger than 13 years, 25° malunion in any plane will remodel, and normal alignment of the joint surfaces will be restored \[8\].

Malkawi from a study of children with fracture shaft femur (treated with traction) aged 2–10 years, and followed for 2–10 years recommended: (a) distraction should be avoided, (b) 15 mm of overriding may be compensated by growth stimulation, and (c) coronal plane deformity < 20° and sagittal plane deformity < 30° will culminate in a satisfactory outcome \[11\] (Table 2).

**Tibia**

Shannak in a study of tibia fracture treated conservatively in a 3–10 year age group noted that up to 10 mm shortening of may be compensated entirely or partially by growth acceleration. Varus deformity of < 15° can correct spontaneously, whereas valgus deformity and posterior angulation will persist to a certain degree and rotational deformities will not correct \[12\].

Similarly, Amitabh et al. studied children with tibial fracture (average age 7.2 years and average follow-up 4 years) and found anterior angular deformity to correct maximally (52.7%) followed by varus (40.9%) and valgus (23.9%), while posterior deformity had the least correction (18.5%). They noted that 12° anterior, 6° posterior, 10° varus, and 8° valgus can remodel completely \[26\] (Fig. 7) (Table 2).

**Humerus**

**Proximal Humerus**

The good prognosis of this fracture despite residual deformity following severe displacement can partly be explained by the great mobility of the shoulder joint and the extraordinary remodeling capability of the proximal humerus in children \[27\]. Kohler reported excellent results in children from 2 to 16 years with proximal humeral metaphyseal and epiphyseal injury treated conservatively and attributed good results to excellent correction of angulation and displacement by bony remodeling \[28\]. McBride noted that results of conservative and operative treatment were similar in this region due to excellent correction of angulation and displacement by bony remodeling \[29\] (Fig. 8) (Table 3).

**Shaft Humerus Fractures**

O’Shaughnessy demonstrated that a majority of children with humeral shaft fractures treated nonoperatively healed with few concerns \[30\]. Caviglia reported that most of the humerus shaft fractures can be treated nonoperatively and malrotations or angulation beyond 15° at the mid-diaphysis or 20° close to the physis should not be accepted \[31\] (Fig. 9) (Table 4).

**Proximal Radius**

Arjandas noted that given the discrepancies in the literature, it is not surprising that the treatment recommendations vary greatly for proximal radial fractures. He recommended that patients with < 45° angulation should be treated with casting without manipulation and in patients with > 45° angulation, closed reduction should be attempted \[32\]. In children younger than 10 years, Vocke reported spontaneous correction of up to 50° angulation.
Steele and Graham recommended considering both the displacement and angulation in the management of radial neck fractures [34]. The overall consensus is to accept angulation up to 30° and offer a closed reduction in children with > 30° angulation [35] (Fig. 10).

**Distal Radius Fractures**

Mahlmann in a study of boys younger than 14 years and girls younger than 12 years showed that angulations less than 15° and shortening of less than 1 cm will completely remodel...
within an average of 7.5 months. They challenged the need for a reduction under anaesthesia for this fracture [36]. Many authors have noted remodeling with higher angulations [9, 37]. Kimberly found distal radius dorsovolar malunion of 23° (15–49) and radioulnar malunion of 21° (15–33) remodelled to 8° (–2 to 21) and 10° (3–17), respectively, with remodeling speed of 2.5° (0.4–7.6) per month [37]. Crawford et al. treated children with distal radius fracture aged an average of 6.9 years by applying cast with gentle correction of angulation without anaesthesia and accepted shortening of average 5 mm (1–14 mm) which corrected to 0° ulnar variance in all children [38]. Plánka also treated patients with distal radius fracture without reduction and reported complete remodeling of up to 30° angulation to normal anatomic level in 86% of children younger than 12 years [39]. These results encourage more frequent use of conservative treatment on an outpatient basis in young children with distal radius fractures, avoiding the risk of anaesthesia, and saving cost.

Akar reported the highest remodeling of distal radial fractures. They noted that in children up to 10 years of age, up to 39° radial and dorsal angulation, 22° volar angulation, and complete displacement correct fully, while in older children (10–15 years), 38° dorsal angulation, 23° radial angulation, and 16° volar angulation may be accepted [40] (Fig. 11).

Radius and Ulna Shaft Fracture

Boeck studied remodeling after plastic deformation and noted that after 6 years of age, remodeling was less than generally accepted; in children > 6 years with cosmetically unacceptable bowing deformity and angulation of > 10°, they recommended reduction under anaesthesia [41].

Price after studying functional results following malunion of radius and ulna shaft fractures recommended that in children < 9 years with fractures at any level, 15° of angulation, 45° of malrotation, and complete displacement is acceptable, but in children > 9 years, for proximal fractures, 10° of angulation and distal fractures, 15° angulation and 30° of malrotation can be accepted. Complete bayonet apposition was found to be acceptable for distal radius fracture if angulation was < 20° with 2 years of growth remaining [42]. Fuller found that in children < 8 years 20°, malunion remodelled completely but in children > 11 years, spontaneous correction of the malunion cannot be anticipated, although they noted some correction in boys between 8 and 10 years [43] (Fig. 12) (Table 5).

**Conclusion**

The remodeling potential of fractures in children is a unique phenomenon that can correct a certain amount of malalignment. It allows many paediatric fractures to be treated nonoperatively, which otherwise in an adult would necessitate operative intervention. Remodeling is the last part of the fracture healing and is not the same at all the levels of the bone. Side to side displacement (translation) of up to full shaft thickness, completely corrects in children < 10 years. This correction is periosteal in origin. After the malalignment of fractures in children, 75% of the correction comes from the realignment of growth plates.
(Hueter Volkman’s law). Cortical drift corrects the remaining 25% with the new bone formation on the concave side, and bone resorption on the convex side (Wolff’s law); this correction is periosteal in origin. Hence, acceptance of high angulation after a diaphyseal fracture may lead to persistent deformity with a good realignment of the proximal and distal physes to the limb axis. Remodeling potential is inversely proportionate to the age and is the highest in neonates. Lower extremities have higher remodeling potential compared to the upper extremity. Remodeling is most pronounced at the growing end of the bone and along the axis of the adjacent joint motion (especially in the case of hinge joints like elbow and knee). A small amount of rotational malalignment correction is possible but it is negligible, hence rotational malalignment should not be accepted. Overgrowth of bone following femoral shaft fracture is very well known, but shortening more than 1.5 cm should not be accepted in a child with fracture shaft femur. Overgrowth following fracture of tibia is clinically insignificant and no shortening of tibial shaft fracture in children should be accepted. For the best functional results, age-wise regional acceptability criteria provide valuable insight. After accepting the angulated reduction of fracture in children, a pictorial chart showing successful remodeling of the malunited fracture is very helpful in convincing parents.

Compliance with Ethical Standards

Conflict of Interest Author does not have any conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study informed consent is not required.

References


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Research Update on Stress Riser Fractures

Jehyun Yoo1 · Xiao Ma2 · Jonghwa Lee2 · Jihyo Hwang2

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Abstract
Stress fractures are fatigue-induced fractures which are caused by repetitive force, often from overuse. They are well-established and frequently encountered in the field of orthopedics. Stress fractures occur in the bone because of low-bone strength and high chronic mechanical stress placed on the bone. Stress riser fractures are also stress fractures that occur because of the presence of cortical defects (holes), changes in stiffness, sharp corners, and cracks (fracture lines). Periprosthetic or peri-implant fractures are good examples of stress riser fractures that occur in regions where stress forces are higher than those in the surrounding material. Most stress riser fractures are related to technical errors (iatrogenic causes) and are difficult to manage. It is possible and more effective to prevent the creation of stress riser fractures through better surgical techniques. The proper terminology for stress fractures, stress riser fractures, periprosthetic fractures, peri-implant fractures, interprosthetic fractures, and interimplant fractures is discussed. This review of the current state of knowledge, diagnosis, treatment, and prevention of stress riser fractures is based on clinical evidence and recent literature.

Keywords Stress fracture · Stress riser fracture · Periprosthetic fracture · Peri-implant fracture · Interprosthetic fracture · Interimplant fracture

Introduction
Stress fractures are well known in the field of orthopedics and were originally discovered in military recruits and athletes. By convention, stress fractures are caused by accumulated trauma with repeated submaximal loading from running or jumping. The first description of stress fractures dates back a 100 years. Rib fractures due to chronic cough were first described by Gooch in 1733 [1].

Stress riser fractures are a type of stress fracture caused by a concentration of stress in localized regions of the cortical bone and can cause catastrophic failures rather than stress fractures. Therefore, stress riser fractures are more iatrogenic than stress fractures. Stress concentration is a well-established concept in the field of engineering. Metal fatigue and cracks at the corners of aircraft windows or ship hatches are classic examples of what happens because of stress concentration. When stress risers experience fatigue, torsional, or tension forces, fractures may occur at the area of stress concentration. The empty hole remaining after the removal of an implant is a typical example of stress concentration in the field of orthopedics.

Laurence et al. estimated the load and strength of an intact and drilled tibia in 1969 [2]. This is one of the first studies to examine the stress effect of drill holes. Stress riser fractures are also called “stress raiser fractures,” “stress concentration fractures,” or “Young’s modulus fractures.” Cameron et al. first used the term “stress riser” fractures and “Young’s modulus” fractures in their case report [3]. New terms, such as interprosthetic, peri-implant, interimplant, implant-related, and non-prosthetic peri-implant fractures have since been introduced [4–7]. The term “peri-implant fracture” was first used in the case report by Kim et al. [4]. Usually, stress riser fractures are related to technical errors, and a majority of them can result in difficult operations; hence, surgeons should focus on prevention, which can be more effective than surgery.

Stress rising phenomenon is generally biomechanical concept and hardly detected clinical ways. Clear definition
and demarcation from other type of stress fractures can be difficult. Here are typical stress riser fractures which can be detected easily in clinical field.

The purpose of this review was to focus on the terminology and definition of stress riser fractures, verify the high-risk factors, and discuss the prevalence, mechanism, prevention, and treatment of stress riser fractures based on evidence and our clinical experiences.

**Definition and Etiology**

Stress concentration falls into three categories in the field of engineering: (1) geometric discontinuities, (2) material discontinuities (changes in material composition), and (3) discontinuities in applied loads. Geometric discontinuities cause an object to experience a local increase in the intensity of a stress field. Examples of parameters that cause these concentrations are cracks, sharp corners, holes, and changes in the cross-sectional area of the object. Changes in the cross-sectional area are rarely seen in the literature or in the field of orthopedics. Material discontinuities may occur during manufacturing. In orthopedics, stiffness changes are frequently encountered as material discontinuities by surgeons. Any implant including prostheses, screws, plates, nails, and cement applied to the bone can change the mechanical properties of the bone; this can lead to a stress concentration and can cause stress riser fractures. Discontinuities in the applied load have not been demonstrated in human studies or described in the literature. It is the author’s opinion that holes, changes in stiffness, cracks, and sharp corners act as a stress riser and are risk factors for stress riser fractures in orthopedics (Fig. 1).

**Terminology**

**Stress Fractures**

Stress fractures are shown as tiny cracks in a bone often from overuse. Stress fractures include insufficiency fractures and fatigue fractures. Insufficiency fractures are the result of normal or physiological stresses on an abnormal bone that lacks proper strength. Fatigue fractures are results of abnormal stresses on a normal bone. Stress riser fractures are mostly related to insufficiency fractures and also can be related to fatigue fractures caused by repetitive (cyclic) loading stresses on a normal bone with normal strength. They occur most frequently in weight-bearing limbs. A pathologic fracture is usually limited to bony abnormalities and bones weakened by tumors and metastases.

**Implant Failure**

If the stress concentration occurs on the implants which can be nails, screws, plates, cement etc., these kinds of implant can be broken or cracked due to the stress. These type of stress fractures are fatigue type fractures and not categorized properly in stress riser fractures.

**Periprosthetic Fractures**

McElfresh and Coventry identified three types of periprosthetic fractures: (1) stress fractures caused by the increased use of a limb after surgery; (2) fractures caused by stress risers in the femoral shaft, including cortical defects and inadequate amounts and distribution of cement; and (3) fractures caused by traumas violent enough to fracture a normal limb [8]. Most injuries result from low-energy trauma, with high-energy trauma reported in fewer than 10% of all

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Fig. 1 A sketch map and real photos show the factors that lead to stress riser fractures. The crack from the hole is a good example of stress riser fractures, and the crack is propagated from the sharp corner
cases. The risk factors for periprosthetic fractures include holes and stiffness changes due to the cement. Defects in the femoral cortex (screw holes and misdirected reaming) or an inadequate amount and distribution of cement at the tip of the femoral stem are predisposed to femoral stress riser fractures. If a loosened stem is combined with these types of stress risers, a secondary fracture is more likely to occur than with a well-fixed cemented stem.

Stress riser fractures refer to fractures occurring in the bone due to a mismatch of bone strength and chronic mechanical stress placed upon the bone. Here are examples of stress riser fractures: The following are (1) Periprosthetic and interprosthetic fractures: broken bone that occurs around and between the replaced joints, respectively, and (2) peri-implant, interimplant, and implant-related fractures: fractures around the plate, rod, screw, cement, or prostheses. An implant may include the word “prosthesis” because the terms “implant” and “prosthesis” are used interchangeably in the field of orthopedics. According to the literature, “periprosthetic” and “interprosthetic” are used properly; however, “peri-implant” and “interimplant” are related to plates, nails, and screws and not the prostheses. Generally, fractures around the joint replacement prostheses are commonly called periprosthetic fractures, whereas fractures around the plates, rods, or screws can be more generally termed as peri-implant fractures. Recently, non-prosthetic peri-implant fractures have been introduced, and this is the most accurate term for fractures around plates, rods, and screws [5] (Table 1). Zhou et al. reported the risk factors for stress riser fractures in femurs, and the four risk factors were summarized based on clinical evidence and mechanical studies [9].

### Risk Factors

Stress (riser) fractures are the result of accumulated trauma from repeated submaximal loading. The strength of the bone is variable and the amount of stress concentration is also diverse; therefore, it is difficult to pinpoint which condition leads to a fracture. The fracture can occur because of stress fatigue, bone insufficiency, and iatrogenic events. The proper combinations and biomechanical forces for these risk factors have been investigated. Listed below are the risk factors for iatrogenic events.

### Cortical Defects (Holes)

Stress riser fractures caused by empty holes have proven to be the most common culprits causing stress riser fractures and include the following risk factors: (1) removal of hardware such as plates, nails, and screws; (2) attempts to pass a guide pin, especially during reduction of femoral neck fractures; (3) removal of temporary external fixators (Schanz screws); (4) bone biopsy using a trephine; (5) core decompression by multiple drilling or use of a trephine in osteonecrosis of the femoral head; (6) bone tunnels for anterior or posterior ligament reconstruction in the tibia or femora [10]; and (7) pin holes for the navigation trackers [11].

During the fixation of fractures, the surgeon uses different kinds of guide pins, drill bits, and screws with different diameters. Brooks et al. showed that the stress concentration increased by 60% if the diameter of a bicortical screw hole exceeded 30% of the bone diameter [12]. After analyzing 24 publications with 45 cases, Barquet et al. reported that the incidence of femoral neck fracture was 14.5% after removal of the hardware in healed trochanteric fractures [13]. Jung et al. described types of empty holes and classified them as unicortical, bicortical, half-bicortical, and transcortical, all of which create different degrees of stress riser fractures. Transcortical pin penetration creates a cortical hole with the

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Implant</td>
<td>An organ or device that has been put into the body in a medical operation such as dental implant, orthopedic implant, breast implant, heart valve implant et al</td>
</tr>
<tr>
<td>Orthopedic implant</td>
<td>Prosthesis, plate, nail, screw, pin, cement et al</td>
</tr>
<tr>
<td>Prosthesis</td>
<td>Artificial joints</td>
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<tr>
<td>Periimplant fracture</td>
<td>The fracture around any implants</td>
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<tr>
<td>Nonprosthetic periimplant fracture</td>
<td>The fracture around implant except prosthesis</td>
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<tr>
<td>Periprosthetic fracture</td>
<td>The fracture around prosthesis</td>
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<tr>
<td>Interimplant fracture</td>
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<td>Interprosthetic fracture</td>
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</table>

Table 1  Nomenclature of the term related to the stress riser fracture
greatest decrease in bone strength [11]. This type of stress riser fracture has frequently been correlated with technical errors by the surgeon. It is iatrogenic; therefore, it can be prevented. In our case, the stress riser was an inadvertently inserted guide pin (2.8 mm) hole in the subtrochanteric area (Fig. 2). Inexperienced surgeons can incorrectly insert guide pins in the lateral cortex of the proximal femur and create empty holes when correcting or adjusting their position. This type of stress riser fracture has previously been introduced as a rare complication. Although the size of the empty hole by a guide pin may be insignificant, the area of stress concentration in the subtrochanter is very sensitive. So, the subtrochanteric area in the femur is the most common sites of stress riser fractures. For the treatment of osteonecrosis of the femoral head, core decompression is one of the most common joint-preserving procedures. The authors experienced stress riser fractures in the subtrochanteric area after core decompression using a 7-mm trephine. The screw holes placed in a collinear pattern in the humerus fracture resulted in fixation failure by longitudinal fissuring of the far cortex [14]. The biggest holes might be a tunnel for ligament reconstruction. Tibial or femoral tunnels can also be stress risers [15].

Changes in Stiffness (Young’s Modulus Fractures)

Implanted bone by prosthesis, plate, or cement can change the mechanical properties of the bone. The stiffness or modulus of elasticity can be changed abruptly using these materials. This type of fracture can be expressed as a “Young’s modulus” fracture [16]. This type of stress riser fracture is usually related to a weakened bone, as seen in osteoporosis.

The first report of this type of stress riser fracture was the “iatrogenic subcapital fracture of the hip” in 1975 [17]. Camerun et al. showed a subcapital fracture running into the tip of the blade plate [17]. Barquet et al. reviewed femoral neck fractures after internal fixation of trochanteric fractures with the implant in situ (104 cases of 77 publications). The median incidence of this complication was 0.43%, and their etiology should be considered multifactorial [18]. The authors had cases of this categorized patient (Fig. 3). In the biomechanical evaluation of periprosthetic refractures following distal-locking plates, cerclage wiring may be an option in distal femur periprosthetic fractures in alleviating stress risers in vulnerable bones [19].

The most common “Young’s modulus” fractures are inter-implant fractures. Combinations are between two prostheses.
(interprosthetic fractures), non-prosthetic implants (non-prosthetic interimplant fractures), and non-prosthetic implants and prostheses in the ipsilateral limbs. The term “interprosthetic fracture” was introduced in a case report by Kenny et al. [7], and the term “interimplant fracture” was introduced by Rupprecht [20]. Kenny et al. reported an incidence of 1.25% (4 out of 320 limbs) for this type of fracture, but this fracture is becoming increasingly common because both the life expectancy of the population and the number of joint replacements are increasing [7]. Velasco et al. discovered a death rate of 40% at 4 years for individuals with interimplant femoral fractures [21]. There are also a few case reports on this type of fracture in the humeri [22]. The 2005 study by Iesaka et al., certified that the distance between two ipsilateral prosthetic stems does not affect the peak tensile stress of the femur [23]. They emphasized the tips of loose stems and cortical thickness [23]. Weiser et al. also suggested that the interprosthetic distance has little influence on the fracture strength in interprosthetic femoral fractures, highlighting the thickness of the cortex as apparently being the determining factor [24]. Lehmann et al., using a femoral interprosthetic model, showed that the highest risk for a fracture in the femur with an existing hip prosthesis came from a retrograde nail [25]. They also mentioned that the fracture occurred between the two “kissing” implants in all cases examined in the interprosthetic group [25]. So, there is no guideline about the distance from the implant and prosthesis to avoid these types of stress riser fractures.

**Cracks (Fracture Lines)**

Cracks, even very small ones, can create an obvious stress concentration. If the stress continuously acts on the hairline cracks, the range of the fracture will be expanded, and an explicit stress fracture appears. This type of hairline fracture cannot be seen clearly on plain X-rays, and it can exist in malunions or delayed union of the fracture. Microcracks are a source of this type of fracture. O’Brien et al. described the length of microcracks that can be propagated in the compact bone [26]. The theory of critical distances has been applied to predict notch-based fracture and fatigue in a wide range of materials and components [27]. Due to irritation symptoms associated with the metal, removal of the implant was performed 22 months after the first operation to repair a trochanteric fracture. The re-fracture from a tiny crack occurred in the subtrochanteric area, and the authors repaired it using an intramedullary nail. This is a high-risk factor for stress riser fractures; however, this type of stress riser fracture is rarely reported. The authors also reported on a stress riser fracture in a patient with Paget’s disease. A hairline crack had been missed, which was discovered in the subtrochanteric area just after performing a total hip arthroplasty. As it was at the middle level of the femoral stem, a conservative treatment was selected; however, the hairline crack progressed and deepened the fracture (Fig. 4). With any type of osteotomy, the sites are at risk of stress riser fractures. A tibial fracture after a tibial tubercle osteotomy for recurrent patellar dislocation is another example of this type of fracture.

**Sharp Corners (Notches)**

Sharp corners, which can be called notches, are possible during bone preparations in arthroplasties, can be iatrogenic, and are relatively well-known risk factors. When a surgeon performs a box osteotomy at the greater trochanter
area in a hip arthroplasty, a sharp corner can form if the osteotomy is too deep. The author (J. Hwang) experienced a case of a greater trochanter fracture postoperatively, which occurred because of a sharp corner that was created by a deep box osteotome at the trochanteric area during a total hip arthroplasty.

Sharp corners appearing from the violation of the anterior cortex (femoral “notching”) during a total knee arthroplasty is another good example, and this femoral notching is much more frequent in knee arthroplasty than during a hip arthroplasty. Finite element modeling of the anterior distal femoral notching reveals that there is a large stress concentration on the sharp-cornered (over 3 mm) notch at the anterior tip of the distal femoral component [28]. Another biomechanical study using a cadaveric femur revealed that there is a decreased bending strength of 18% and torsional strength of 39% in distal femoral anterior notching [29]. A sharp corner was made in the anterior side of the femoral condyle during total knee arthroplasty. This acts as a stress riser for subsequent fractures.

Specific Consideration: Stress Riser Fractures in Nail Systems

It has been postulated that the causes of stress riser fractures through the end of interlocked nails might be complex. The assumptions include: (1) stress concentration at surgically drilled screw holes; (2) multiple drill passes for interlocking screws because of the difficulty in finding the correct entry point in the cortex; (3) over-tightening of the interlocking bolt can create a hairline crack, especially in fragile bones, and (4) stiffness changes around the interlocked area. Many risk factors such as cortical defects, changes in stiffness, and cracks are interrelated. The third assumption is theoretically possible but has not been proven. The fourth assumption shows that an abrupt change in the modulus of elasticity (“Young’s modulus” fracture) can be a causative factor. The first three assumptions are the most common patterns; the fracture is propagated from the site of interlocking bolts in the early stage of the operation. The fourth assumption addresses stress riser fractures that occur distal or proximal to the tip of the implant, which are more likely to develop because of trauma late in the operation [30]. Libner et al. presented a case report of a femoral fracture at the proximal end of an intramedullary supracondylar nail and hypothesized that this complication may be the result of the cortical holes drilled for the interlocking screws [31]. Jegathesan et al. showed three peri-implant fractures distal to antegrade femoral nails, one of which did not span the entire femoral length and was related to the low-energy peri-implant fracture [30] which supports the fourth assumption. Robinson et al. analyzed femoral implant-related fractures following hip fracture surgery with a relatively high incidence in patients initially treated with a Gamma nail [6]. The fractures progressed distally from the site of insertion of the inferior screw, and the authors assumed that these two cases of stress riser fractures occurred due to the nail system.
Diagnosis

In most cases, patients are relatively asymptomatic before fracture events. Subjective symptoms are sudden and include pain with no history of significant trauma. Studies show that bone scintigraphy, which is the gold standard for diagnosing stress fractures, has clear superiority in the early diagnosis of stress fractures [32] (Fig. 5). Magnetic resonance imaging (MRI) is also highly sensitive and relatively specific for revealing bone injuries. While it is important to diagnose stress fractures as early as possible, orthopedists typically cannot identify early stress fractures on plain X-ray films, although the films can reveal bone risk factors such as holes, sharp corners, tiny cracks, and changes in stiffness. Together with the patient’s symptoms and physical examination, X-ray films can provide a reference for the orthopedist to confirm a diagnosis.

Prevention

Surgeons should focus on prevention of stress riser fractures, which can be more definitive than additional surgeries. If possible, the initial operation should be a minimally invasive osteosynthesis such as an intramedullary nailing or use a less invasive stabilization system. When removing implant plates for any reason, stress riser fractures can be prevented with adequate re-fracture warnings and by carefully protecting the weight-bearing limb postoperatively.

Orthopedic surgeons should be careful to avoid creating local stress elevations that occur because of locally-concentrated loadings, sometimes described as “point loading,” “edge loading,” “line loading,” etc., that occur when bone encounters the tips of implants. This is especially important when nails or prostheses are inserted.

Orthopedic surgeons should minimize the creation of holes in bone (using pins, screws, or drilling). The subtrochanteric area of femur is the most hazardous area. Tensile side of a long bone is more at risk compared to compressive side. Placing resorbable fillers in bone defects after hardware removal can reduce the likelihood of re-fracture [33]. For large diameter tunnels or trephine holes, bone grafts or synthetic bone can accelerate cortical bone healing, which can avoid stress concentrations. Removal of hardware in osteoporotic patients should be performed very carefully.

Based on reports of subtrochanteric fractures after proximal femoral pinning, Karr et al. indicated that when screws are highly clustered or concentrated in the lower lesser trochanter, the pins work as significant stress risers in causing fractures [34]. A vertical pattern of screw insertion is less likely to cause stress riser fractures than a horizontal pattern [35]. Screw configuration, such as a reverse triangle, can also minimize stress concentrations [36–38]. Most importantly, the authors state that it is extremely risky to leave empty holes because of incorrectly positioned guide pins in the subtrochanteric area.

Periprosthetic stress riser fractures most commonly occur around the tip of prostheses; hence, the surgeon should be careful during femur reaming to not penetrate the cortex, especially in the presence of osteoporosis, a very narrow medullary cavity, or a previously unsuccessful prosthesis or osteotomy. The distribution of cement around the tip is also important. It should be even more than 2 cm from the tip [8].

Fig. 5 a An 81-year old woman was fixed with two cannulated screws. b A bone scan was useful to detect the impending stress riser fracture. c The stress riser fracture occurred from the screw hole. d We reduced the fracture gap by the proximal femoral nail
When orthopedic surgeons encounter a revision case, any remaining cortical holes from screw removals or windows in the cortices should be eliminated as stress risers (Fig. 6). If the stress riser already exists or has been missed, the orthopedist should consider altering the patient’s postoperative rehabilitation regimens.

It was reported that the use of cerclage wires was recommended when applying plates to distal femoral fractures to potentially stop the stress concentration effect by altering the regional loading transmission pathway and preventing fractures occurring from the uppermost screw [19]. If surgeons consider “Young’s modulus” stress riser fractures in osteoporotic bones, the use of conventional plates and screws or nonlocking end screws to a locked plate can decrease non-prosthetic peri-implant fractures [39]. For adjacent femoral implants, a technique by Zhiyong et al. showed that a minimum length of two femoral diameters is necessary to bypass the adjacent prosthesis to prevent a stress riser [40]. Connecting the stems together during an adjacent joint replacement is helpful in preventing interprosthetic fractures, especially in the humerus [41]. Lehman et al. studied a biomechanical test with cadaveric femurs and found that two intramedullary implants significantly reduced the fracture strength. If an interprosthetic fracture occurs, sufficient stability can be achieved by a lateral compression plate [42]. Modern biologic plating techniques that span the entire interprosthetic zone to eliminate additional stress risers show reliable results [43]. The authors have already encountered fractures in both types of implants when the distal metal plates are not fixed in an overlapping manner and without removing the proximal metal nail (Fig. 7). In the case of an artificial joint, the importance of the overlapping technique should be applied since fractures have been seen between the long prosthesis and the proximal portion of the long femur prosthesis after a total knee arthroplasty revision. Mark et al. determined that stem tip distances shorter than 110 mm dramatically increase the fracture risk, especially in osteoporotic bone [44]. A stemmed distal femoral component in a total knee arthroplasty would be beneficial if notching of the anterior distal femoral cortex was noted intra-operatively, which would decrease the possibility of periprosthetic fractures after the operation (especially in notches > 3 mm) [28].

**Treatment**

The management of conventional stress fracture may be done using standard management principles. All stress riser fracture treatments are based on creating a satisfactory
environment for healing and preventing further fracture progression. For stress riser fractures without obvious fracture lines after imaging, the best treatment option is the use of crutches to remit pain. Analgesics are appropriate for relieving pain, and pneumatic bracing is also useful for facilitating healing. Patients may gradually increase their level of activity after improvement has been determined by examination, and after pain is relieved. For obvious stress riser fractures, non-operative treatment is not advocated. Stress riser fractures are best managed by secure internal fixation and early ambulation. For interprosthetic and non-prosthetic interimplant fractures, minimally invasive techniques using locking plates are the best solution. Nonlocked plating was associated with an 11.9 times higher risk for nonunion when compared with locked plating in the treatment of periprosthetic hip and interprosthetic femur fractures [45]. The authors reported the usefulness of the Huckstep nail in the treatment of fractures occurring in “kissing” implants in this case report (Fig. 7) [4].

Discussion

Due to the increasing elderly population, weakened bones are more prevalent and vulnerable to stress concentration effects. The increasing use of implants in orthopedics has led to the predisposition for stress riser fractures. Stress riser fractures, although categorized as stress fractures, should be classified as a different disease entirely. The authors encountered several of these cases and realized that treatment was more complicated than just the surgical option. In most cases, prevention was only possible because of the knowledge that existed regarding stress riser fractures. For holes that create a stress concentration, surgical care and consideration are needed during and after the operation. Removal of hardware in osteoporotic patients should be done more carefully. For stiffness changes, new material with a similar elasticity modulus to human bone can prevent “Young’s modulus” fractures. Choosing a very hard implant is not good for a patient with weak bones. Performing surgery to reduce stress concentration at the end of implants in the intramedullary and extramedullary bone is a good way to avoid stress risers. Hairline cracks in vulnerable areas of weight-bearing bones should be diagnosed using a bone scan or MRI. Sharp corners should always be eliminated during operations. With the development of 3D printing technology, a patient-specific implant with the same shape and proper size as the patient’s bone is potentially possible. A patient-specific implant that obtains a maximum contact area can provide a good stress distribution. A personalized implant could also be properly sized, thereby simplifying the operation and allowing it to be minimally invasive. If implants can be produced by 3D printing that accommodates shape and stiffness, orthopedic surgeons can prevent more stress riser fractures in the future.

Summary

In summary, stress riser fractures occur because of multiple factors but cortical perforation (screw holes), changes of stiffness (“Young’s modulus” fractures), hairline cracks (fracture lines), and sharp corners (bone cuts) can act as stress risers, which can develop into secondary fractures in
the clinical setting. This should be a reminder to orthopedists to pay more attention to the above stress risers, which can effectively prevent stress riser fractures. The evolution of 3D printer technology will help overcome this problem.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

References


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30-Day Mortality Rate in Hip Fractures Among the Elderly with Coexistent COVID-19 Infection: A Systematic Review

Prasoon Kumar1 · Karan Jindal1 · Sameer Aggarwal1 · Vishal Kumar1 · Rajesh Kumar Rajnish2

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Abstract

Purpose Hip fractures in the elderly require a multi-disciplinary approach and are associated with increased morbidity and mortality. The current COVID-19 pandemic has affected substantially this high-risk population group. This present review was done to ascertain whether or not the pandemic has affected the 30-day mortality and outcomes of hip fracture in the elderly.

Research Question Does the coexistence of COVID-19 infection and hip fractures in the elderly increase the mortality rates?

Methodology A systematic review and meta-analysis were conducted using three databases (PubMed, EMBASE and SCOPUS) to compare the mortality rates between COVID-19 positive/suspect and COVID-19 negative patients. The secondary outcomes included comparison of in-hospital mortality, complication rate and length of hospital stay. Risk of bias assessment was done using the MINORS tool.

Results The present review included 20 studies. Primary outcome: A significantly higher 30 day mortality rate was seen in COVID-19 positive/suspect patients with an Odds ratio of 6.09 (95% CI 4.75–8.59, \(p < 0.00001\)). Secondary outcome: We observed significantly higher rates of inpatient mortality [OR 18.22, (95% CI 7.10–46.75], complication rate (OR 9.28, 95% CI 4.46–19.30), and length of hospital stay (MD: 4.96, 95% CI 2.86–7.05) in COVID-19 positive/suspect patients as compared to COVID-19 negative patients.

Conclusion COVID-19 has deteriorated the outcomes in elderly patients with hip fractures and associated with higher rates of mortality in the short term. A multidisciplinary approach is needed to contain this “pandemic within a pandemic” and improve the overall outcome to survival.

Keywords COVID-19 · Novel corona virus · Hip fractures · Proximal femur fractures · 30 day mortality · Elderly

Introduction

Hip fractures present as one of the commonest injuries in the geriatric population with a reported incidence between 1 and 2% across Europe and the United States of America [1]. Factors related to increased age; osteoporosis, vitamin D deficiency, and multiple systemic comorbidities, make these patients prone to fragility fractures, as well as increase the associated morbidity and mortality [1, 2]. Surgical management is favoured in these patients for early mobilization to prevent repercussions associated with prolonged bed rest; bed sores, deep vein thrombosis or venous thromboembolism and cardiopulmonary insult [3]. The reported rates of 30 day mortality in operated cases vary between 10 and 15% which increases to 15–35% at 1 year of surgery [1, 4].

COVID-19 infection has currently engulfed the world ever since its origin from Wuhan, China in late 2019. With
high rates of infectivity and transmissibility, the pandemic has been associated with high mortality due to pulmonary complications, especially in the elderly and those associated with systemic co-morbidities like hypertension, diabetes and pre-existent lung diseases [5]. The pandemic required routine patient care and surgeries to be held back, however, the number of trauma and emergency cases including hip fragility fractures have continued to remain more or less similar to pre-COVID-19 era. COVID-19 infection has been shown to increase early mortality (23.8%) in positive patients undergoing major surgeries [6].

With numbers of hip fractures in the elderly increasing and COVID-19 infections multiplying, chances of their co-existence in the same patient is likely, wherein the patient’s age and co-morbidities could increase the morbidity and mortality by manifolds when compared to COVID-19 negative patients presenting with such fractures [7, 8].

Fragility hip fractures are a major geriatric burden which require multi discipline collaboration and advanced implants and postoperative rehabilitation. It is already a trauma subset with a high incidence of complications and deaths, and COVID-19 infection has the potential to worsen it. The present review was conceptualised to ascertain the impact of a co-existent infection on the 30-day mortality and inpatient mortality of patients with hip fractures including neck femur, intertrochanteric and subtrochanteric fractures. Additionally, the number of complications and length of hospitalisation were also compared.

Methodology

Study Design

This systematic review and meta-analysis were performed in accordance with the PRISMA guidelines [9].

Search Strategy

The primary electronic search of the literature was conducted on PubMed, Embase and Scopus databases from the date of inception to 4th February 2021 by two authors (RKR and KJ) using a well-defined pre-formulated search strategy (Table 1), without any initial restriction in the language and country of publication. A secondary search of the reference list of the relevant studies identified from the primary search were also done. Finally, a total number of 598 results were obtained.

Inclusion and Exclusion Criteria

The current review included clinical studies of any design that evaluated at least 10 hip fractures in COVID-19 positive elderly patients and/or compared the same with COVID-19 negative patients, and assessed/compared at least one of the outcomes; 30 day mortality, inpatient mortality, total number of complications and/or length of hospitalization. Exclusion criteria included studies that did not measure the outcomes of interest, included < 10 COVID-19 positive cases, case reports, editorials, review articles, and articles not in the English language.

Study Selection

All the studies were screened based on their titles and abstracts, independently by three authors (RKR, MSD and SA) and those related to the study question were identified. Subsequently, full texts of all the selected articles were accessed, and relevant studies based on the inclusion/exclusion criteria were included in the current review. Discrepancies between the authors were resolved by mutual agreement.

Table 1 Search strategy used for the literature search in PubMed, Embase, and Scopus databases

<table>
<thead>
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<th>Database</th>
<th>Period-inception to 4th February 2021 with keywords</th>
<th>Results</th>
</tr>
</thead>
<tbody>
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<td>PubMed</td>
<td>(((((((&quot;severe acute respiratory syndrome coronavirus 2&quot;[Supplementary Concept] OR &quot;severe acute respiratory syndrome coronavirus 2&quot;[All Fields]) OR &quot;ncov&quot;[All Fields]) OR &quot;2019 ncov&quot;[All Fields]) OR &quot;covid 19&quot;[All Fields]) OR &quot;sars cov 2&quot;[All Fields]) OR ((&quot;coronavirus&quot;[All Fields] OR &quot;coronavirus&quot;[All Fields]) AND 2019/11/01:3000/12/31[Date—Publication]) OR ((&quot;coronavirus&quot;[MeSH Terms] OR &quot;coronavirus&quot;[All Fields]) OR &quot;coronaviruses&quot;[All Fields])) AND (((&quot;hip fractures&quot;[MeSH Terms] OR &quot;hip&quot;[All Fields] AND &quot;fractures&quot;[All Fields]) OR &quot;hip fractures&quot;[All Fields]) OR ((&quot;hip&quot;[All Fields] AND &quot;fracture&quot;[All Fields])) OR &quot;hip fracture&quot;[All Fields])</td>
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<tr>
<td>Embase</td>
<td>(‘covid 19’ OR coronavirus) AND hip AND fracture</td>
<td>110</td>
</tr>
<tr>
<td>Scopus</td>
<td>( ALL ( covid-19) OR ALL ( coronavirus) AND ALL ( hip AND fracture) )</td>
<td>382</td>
</tr>
<tr>
<td>Total</td>
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</table>
Data Extraction

The data extraction was performed by three independent authors (RKR, PK and KJ) from each included article and was entered in a pre-specified data collection excel sheets, mentioning the names of the authors, year of publication, number of COVID-19 positive/suspect and negative patients, relevant demographic parameters, and primary and secondary outcome measures of interest. This was summarized in tabular form (Table 2). All the selected articles were finally reviewed and discussed by all the authors of this study to reduce all possible operator-dependent bias. At the end of this process, 20 publications relevant to this systematic review and meta-analysis at hand were included in this study. Flow chart for the study selection is shown in Fig. 1.

Outcome Measure

The primary outcomes measure of interest was postoperative mortality at 30 days. The secondary outcomes measure of interest were length of hospital stay, number of complications, and in-patient mortality.

Statistical Analysis

Meta-analysis was performed if two or more studies reported the outcome of interest of the current review. The random effect model was used and mean difference was calculated for continuous variables and Odds ratio for dichotomous variables. The statistical heterogeneity was determined by using the I² test. Reasons for clinical heterogeneity, if any, were also explored. The statistical analysis was done by using Review Manager Software version 5.4 (RevMan 5.4) [10].

Risk of Bias Assessment

The risk of bias of the included studies was assessed independently by two observers (RKR and VK) using the MINORS tool for the non-randomized studies [11]. The tool consists of 12 items for the comparative studies, and 8 for the non-comparative study, which was adapted for the current review.

Results

Search and Screening

The PRISMA flowchart for the study has been presented in Fig. 1. A total of 598 records were identified and full texts were retrieved for 37 studies. Seventeen studies were excluded as per the exclusion criteria and a total of 20 studies [1, 8, 15, 16–28] were included for qualitative analysis.

Comparative meta-analysis was performed from 14 studies [1, 8, 15, 16–28] for 30 days mortality, from 4 studies [8, 16, 17, 22] for in-hospital mortality, and 6 each for the length of hospital stay [1, 8, 15, 17, 25, 28] and number of complications [1, 8, 14, 18, 22, 26].

Characteristics of the Studies

A summary of the studies included in the review has been presented in Table 2. Of the 20 studies, 16 were retrospective [1, 7, 13–18, 21–28] and 4 were prospective [8, 12, 19, 20] studies. Nine studies were multicentric trials [1, 7, 15, 17, 19, 21, 23, 25, 28]. A total of 3211 patients were included in the review; of these, the pooled analysis was done for 3157 patients in 18 studies [1, 7, 8, 14–28]. The mean age of patients was 81.79 years with a range from 71.9 to 86.5 years. The review included 925 males and 2028 females reported in 18 studies [1, 7, 8, 12–15, 17–26, 28] and the mean length of hospital stay ranged from 5 ± 2.6 to 24.21 days.

Assessment of Risk of Bias

The overall risk of bias was assessed as low for the included studies as depicted in Figs. 2, 3. There were 15 nonrandomized comparative study [1, 8, 15–20, 22–28] and rest 5 [7, 12–14, 21] were observational studies/case series. MINORS tool Score was ≥ 19 for 13 nonrandomized comparative studies [1, 8, 15–17, 19, 22–28] while ≥ 12 for all 5 noncomparative studies [7, 12–14, 21].

Results of Meta-Analysis Between COVID-19 Positive/Suspects Versus COVID-19 Negative Patients

Primary Outcome

30-days mortality rates: This was compared between the 2 groups in 14 studies [1, 8, 15, 16, 19–28] and showed a significantly high mortality rate in COVID-19 positive/suspect patients with an Odds ratio of 6.09 (95% CI 4.75, 7.81, p < 0.00001) (Fig. 4).

Secondary Outcomes

In-patient Mortality Comparative meta-analysis in 4 studies [8, 16, 17, 22] revealed significantly higher in-hospital mortality rates in COVID-19 positive/suspect patients with an Odds ratio of 18.22 (95% CI 7.10, 46.75, p < 0.00001) (Fig. 5).

Number of Complications The rate of complications like infections, acute renal failure, deep vein thrombosis, myo-
<table>
<thead>
<tr>
<th>Sl no</th>
<th>Author/Year</th>
<th>Type of study</th>
<th>Number of hips</th>
<th>Mean age (years) (SD)</th>
<th>Gender (M/F)</th>
<th>Non operative cases</th>
<th>Mean LOS (days) (SD)</th>
<th>No. of complications</th>
<th>In patient mortality</th>
<th>30 day mortality</th>
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<td>1</td>
<td>Catellani et al. 2020 [12]</td>
<td>Prospective study</td>
<td>16 – –</td>
<td>84.3</td>
<td>10/6</td>
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<td>7.8</td>
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<td></td>
<td>Cheung et al. 2020 [13]</td>
<td>Retrospective study</td>
<td>10 – –</td>
<td>79.7 ± 5.75</td>
<td>2/8</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>Post op:4</td>
</tr>
<tr>
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<td>Prospective study</td>
<td>17 14 107</td>
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<td>CP-12/5</td>
<td>CP-4</td>
<td>CP-9.8 ± 5.2</td>
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<td>CS-80.6</td>
<td>CS-4/10</td>
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<td>CP-7.5 ± 9.9</td>
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<td></td>
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<td></td>
<td>CN-83.4</td>
<td>CN-34/73</td>
<td>CN-0</td>
<td>CP-5 ± 2.6</td>
<td>CN-8</td>
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<td>20 55</td>
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<td>CP-7/13</td>
<td>CP-1</td>
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<td>CP-1</td>
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<td>CP-83.6 ± 11.3</td>
<td>Overall-106/211</td>
<td>CP-11.3 ± 7.5</td>
<td>CP-7.8 ± 4.6</td>
<td>Overall-106/211</td>
<td>CP-11.3 ± 7.5</td>
<td>CP-24</td>
</tr>
<tr>
<td></td>
<td>Kayani et al. 2020 [1]</td>
<td>Retrospective study</td>
<td>82 340</td>
<td>CP-71.9 ± 9.5</td>
<td>CP-31/51</td>
<td>CP-0</td>
<td>CP-13.8 ± 4.6</td>
<td>CP-73</td>
<td>CP-5</td>
<td>CP-25</td>
</tr>
<tr>
<td>7</td>
<td>Konda et al. 2020 [16]</td>
<td>Retrospective study</td>
<td>17 14 105</td>
<td>CP/CS-81.6</td>
<td>–</td>
<td>–</td>
<td>CP/CS-8.9 ± 6.8</td>
<td>CP/CS-72</td>
<td>CP/CS-7</td>
<td>CP/CS-11</td>
</tr>
<tr>
<td>8</td>
<td>LeBrun et al. 2020 [17]</td>
<td>Retrospective study</td>
<td>10 50</td>
<td>CP-86.5 ± 7.9</td>
<td>Overall-81.75±9.74</td>
<td>CP-8-2.25</td>
<td>CP/CN-6±1.75</td>
<td>CP/CN-18</td>
<td>CP-6</td>
<td>CP-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CN-84.7 ± 7.5</td>
<td>Overall-81.75±9.74</td>
<td>CN-0</td>
<td>–</td>
<td>CN-1</td>
<td>–</td>
<td>CN-5</td>
</tr>
<tr>
<td>9</td>
<td>Maniscalco et al. 2020 [18]</td>
<td>Retrospective study</td>
<td>32 89</td>
<td>CP-86.5 ± 7.9</td>
<td>Over all-81.75±9.74</td>
<td>CP-8-2.25</td>
<td>CP/CN-6±1.75</td>
<td>CP/CN-18</td>
<td>CP-6</td>
<td>CP-9 + 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CN-84.7 ± 7.5</td>
<td>Over all-81.75±9.74</td>
<td>CN-0</td>
<td>–</td>
<td>CN-1</td>
<td>–</td>
<td>CN-2 + 1</td>
</tr>
<tr>
<td>10</td>
<td>Narang et al. 2020 [19]</td>
<td>Prospective study</td>
<td>86 596</td>
<td>CP-86</td>
<td>CP-32/54</td>
<td>CP-0</td>
<td>CP-8-2.25</td>
<td>CP/CN-18</td>
<td>CP-6</td>
<td>CP-30/86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CN-83</td>
<td>CN-170/426</td>
<td>CN-0</td>
<td>–</td>
<td>CN-1</td>
<td>–</td>
<td>CN-36/596</td>
</tr>
<tr>
<td>11</td>
<td>Thakrar et al. 2020 [20]</td>
<td>Prospective study</td>
<td>12 31</td>
<td>Overall-81.6±1.3</td>
<td>Overall-23/20</td>
<td>CP-0</td>
<td>Clinical frailty score-4.6±1.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>12</td>
<td>Vives et al. 2020 [21]</td>
<td>Retrospective study</td>
<td>23 113</td>
<td>Overall-85±9</td>
<td>Overall-34/102</td>
<td>12</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>13</td>
<td>De et al. 2020 [7]</td>
<td>Retrospective case series</td>
<td>34 –</td>
<td>Over all 85.9 (SD 7.7)</td>
<td>Over all-12/22</td>
<td>1</td>
<td>22.4 (SD 11.8)-mortality group</td>
<td>16</td>
<td>–</td>
<td>CP-14</td>
</tr>
<tr>
<td>14</td>
<td>Arafa et al. 2020 [22]</td>
<td>Retrospective study</td>
<td>19 78</td>
<td>CP-86.21 (SD 7.71)</td>
<td>CP-9/10</td>
<td>2</td>
<td>CP-24.21 (SD 19.29)</td>
<td>CP-7</td>
<td>CP-2</td>
<td>CP-7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CN: 83.05 (SD 7.64)</td>
<td>CN-21/57</td>
<td></td>
<td>significantly higher than CN</td>
<td>CN-7</td>
<td>CN-3</td>
<td>CN-9</td>
</tr>
<tr>
<td>15</td>
<td>Karayaannis et al. 2020 [23]</td>
<td>Retrospective study</td>
<td>21 182</td>
<td>Overall-81.3 (SD 9.7)</td>
<td>Overall-65/138</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>CP-2</td>
</tr>
<tr>
<td>Sl no</td>
<td>Author/Year</td>
<td>Type of study</td>
<td>Number of hips</td>
<td>Mean age (years) (SD)</td>
<td>Gender (M/F)</td>
<td>Non operative cases</td>
<td>Mean LOS (days) (SD)</td>
<td>No. of complications</td>
<td>In patient mortality</td>
<td>30 day mortality</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------</td>
<td>----------------</td>
<td>----------------</td>
<td>------------------------</td>
<td>--------------</td>
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<td>----------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>19</td>
<td>Mamarelis et al. 2020 [27]</td>
<td>Retrospective study</td>
<td>11 – 26 (and 4 not tested)</td>
<td>–</td>
<td>–</td>
<td>CP-3 CN-3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>CP-6 CN-2</td>
</tr>
<tr>
<td>20</td>
<td>Wright et al. 2021 [28]</td>
<td>Retrospective study</td>
<td>17 – 51</td>
<td>Overall-81.1 (± 11.35)</td>
<td>Overall-18/50</td>
<td>CP-1 CN-1</td>
<td>CP-17 (SD 5.6, range 8–27) CN-10 (SD 8.7, range 1–53)</td>
<td>–</td>
<td>–</td>
<td>CP-5 CN-3</td>
</tr>
</tbody>
</table>

cardiac infarction and acute respiratory failure, was compared between the 2 groups in 6 studies [1, 8, 14, 18, 22, 26] and the number of complications was found to be significantly high in COVID-19 positive/suspected patients with an Odds ratio of 9.28 (95% CI 4.46, 19.30; \( p < 0.00001 \)) (Fig. 6).

Length of Hospital Stay It was compared between the 2 groups in 6 studies [1, 8, 15, 17, 25, 28] and showed that the length of hospital stay was significantly higher in COVID-19 positive patients as compared to COVID-19 negative patients, with a mean difference of 4.96 days (95% CI 2.86, 7.05; \( p < 0.00001 \)) (Fig. 7).
Pooled Analysis

Pooled analysis was done from 17 studies [1, 8, 14–28] for analysing the rates of COVID-19 positive/suspect patients in hip fractures in the elderly. We observed a rate of 19.2%; the heterogeneity for this event was high ($I^2 = 88.98\%$) (Fig. 8).

We also pooled the data for overall mortality in these 626 COVID-19 positive/suspect patients from 18 studies [1, 7, 8, 14–28] and found a mortality rate of 34.7%, the heterogeneity for this event was low ($I^2 = 0$) (Fig. 9).
Discussion

Hip fractures in the elderly are a major group of trauma wherein associated disabilities are significant; prolonged bed riddance and need of mobilizing aids with geriatric care facilities [29]. Over and above this these injuries witness a high rate of early mortality, with reported rate of 30 day mortality being 7–15% [1, 4, 30]. The probable reason for such high rates of death in these patients is the associated acute inflammatory over-activation (increased markers like Interleukins-6,8 and 1; Tumour necrosis factor-alpha and C reactive proteins) resulting in aberrant hyper-coagulability (increased platelet reactivity and Factor VIII) with increased physiological stress (increased cortisol and catecholamines); these induce pulmonary and vascular complications, i.e. myocardial infarction, embolism, stroke etc. [31–33]. This is amplified by the already existing preconditions like hypertension, diabetes, and other cardiorespiratory diseases in this subset of elderly trauma patients [34].

In turn, the COVID-19 infection has also been shown to be resulting in an inflammatory cascade involving what is known as “cytokine storm”, which results from macrophages and neutrophils entering the lung tissue [35]. This deteriorates the prognosis by causing acute respiratory distress...
syndrome (ARDS), leading to increased mortality [35, 36]. Besides this, the co-morbidities have been shown to be independent high-risk factors of worsened outcomes of COVID-19 infections [5].

Thus, in a nutshell both COVID-19 infection and hip fragility fractures could exhibit similar pro-inflammatory pathogenesis, which could lead to devastating outcomes in patients having both pathologies. Older patients are prone to infections and COVID-19 has been shown to demonstrate extreme infectivity and pathogenicity [37]. In terms of overall numbers of COVID-19 infected/suspected elderlies presenting with fragility hip fractures, our pooled analysis across 17 studies showed a positivity rate of 19.2%, which is extremely high and possibly depicts a “pandemic within a pandemic” scenario.

The present review has also shown increased rates of mortality in these infected patients. Our results showed that the rate of 30 day mortality in these patients across 18 studies, was 34.7%, which is 3.5 times the normally reported mortality in patients of hip fractures in the
pre-COVID-19 era [1, 4, 30]. The 1 year mortality in the pre-COVID-19 times had been reported to be between 20 and 35% [1, 4, 29]. These rates convey a very dark picture, wherein the patients with both the pathologies have reported a massive surge in early 1 month mortality, which is even more than what used to be at 1 year earlier.

During the pandemic itself when we compared 30-day mortality between patients with hip fractures, who were negative for COVID-19 infection and those who were either positive or suspected, the results showed a significantly lower mortality rate in COVID-19 negative patients. The total number of deaths in the COVID-19 negative patients was 172/2361, whereas the number of deaths in the other group was 175/530 patients. Interestingly, since the pandemic is on only for a year, the published literature have not shown mortality rates at 1 year or longer periods of time, which could be devastatingly high on longer follow-ups, presenting an even gloomier picture.

Another important aspect in these patients is the frequency of complications like deep infections, acute renal failure, thromboembolism, and myocardial infarction, etc. The review showed that these numbers are significantly higher in the COVID-19 positive/suspect group (138/230 cases) compared to COVID-19 negative patients (159/755), which may be related to the overall pathogenesis of the co-existent infection and the fracture, as discussed above. Some of these complications are life-threatening and could be the probable events leading to increased deaths, which can be during hospitalisation itself or subsequently thereafter.

With more number of complications, the duration of hospitalisation also increases and our results confirm the same, wherein it was significantly longer in infected patients, which could lead to more nosocomial complications, leading to a vicious cycle increasing the number of deaths.

Looking into mortality during index hospitalisation, the meta-analysis of 4 studies comparing these rates between the groups, showed that in-hospital mortality is also extremely high in patients with both the infection and hip fractures. 22/91 patients died in this group whereas deaths in the negative group were only 6/340.

The extreme differences in mortality rates in the present review between the groups, clearly suggest that extra optimization and care are needed in this subset of patients who are anyways at increased risk of early mortality, which can be further compounded by the co-existent COVID-19 infection. One of the limitations of the present review is the relative delay in surgeries in some COVID-19 positive/suspected patients compared to the COVID-19 negative groups in some included studies [27, 28], for preoperative optimization of the patients, which itself may have an effect on overall outcomes and mortality as delaying hip surgeries have been documented to cause inferior outcomes.

Fragility hip fractures are widely considered as an economic burden in view of associated morbidity in the patients and associated costs of geriatric care; superimposed COVID-19 infection worsens the outcomes further and could increase this burden manifold [38]. The present review highlighted the compounded issue with this specific subset of elderly trauma patients in the era of COVID-19 pandemic. A coexistent infection in an already vulnerable group of patients is associated with an exponential increase in the number of complications and deaths. A multidisciplinary approach is needed from the health care providers to contain this “pandemic within a pandemic” and improve the overall outcomes.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by any of the authors.

Informed consent For this type of study informed consent is not required.

References


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Intramedullary Nailing Versus Plating for Proximal Tibia Fractures: A Systematic Review and Meta-analysis

Karan Jindal1 · Deepak Neradi1 · Praveen Sodavarup1 · Deepak Kumar1 · Akshay Shetty1 · Vijay Goni1

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Abstract

Introduction Extra-articular proximal tibia fractures make up to one-tenth of all tibia shaft fractures. Treatment options include conservative, nailing, plating and external fixation. There is no consensus on which method is superior if the patient is to be managed surgically.

Materials and Methods We conducted a systematic review and meta-analysis to know which definitive surgical treatment option (nailing or plating) is better for extra-articular proximal tibia fracture. We used search engines like PubMed, Embase, Scopus, Ovid Medline and Google Scholar to find articles comparing the results of nailing versus plating. We could identify only 4 articles regarding this and data was extracted and meta-analysis was done.

Results Delayed union was common in the nailing group with odds ratio of 8.29 favoring the plating group (95% CI 1.77, 38.80, \( p = 0.007 \)) while malunion showed no difference in both groups. Rate of infection was higher in the plating group while anterior knee pain was common in the nailing group with odds ratio of 5.54 favoring the plating group (95% CI 1.49, 13.88, \( p = 0.008 \)). Range of motion showed no difference between both groups, fractures in the nailing group united early and the difference was significant (\( p = 0.005 \), odds ratio –4.48) (95% CI –8.29, –1.47). The surgical duration was less in the nailing group but was not significant.

Conclusion Considering lesser time for union, early weight bearing, lower chances of infection and lesser surgical duration, nailing seems to be more promising for extra articular proximal tibia fractures. Further research is required on this topic to provide a definitive evidence.

Keywords Extra-articular proximal tibia · Fracture · Nailing · Plating · Malunion · Infection · Knee pain

Introduction

Extra-articular fractures in proximal tibia are seen in up to one-tenth of all tibial shaft fractures and generally result from high-velocity trauma [1]. Non operative treatment of these fractures has frequently resulted in malunion, non-union, or stiffness of adjacent joints [2–4]. Surgical management options for these fractures include intramedullary fixation, plating, mono-lateral or circular external fixation, or a combination of any of these techniques [5]. In recent times, plating and intramedullary nailing have both become the mainstay of treatment for proximal tibial metaphyseal fractures [6, 7], although there is paucity of strong evidence to support the superiority of one modality over the other. Recent modifications to the design of intramedullary nails and supporting fixation techniques have helped in gaining popularity for the use of these devices in this fracture. In the same way, the development of locking plates has allowed
surgeons to reduce and fix such fractures with minimal soft tissue dissection.

Biomechanical studies in cadavers have compared various plating devices and intramedullary nails for these fractures [8, 9] and clinical studies have described the successful use of either intramedullary nailing or proximal locking plating in the treatment of proximal one-third tibial fractures [10–21]. Fixation of these fractures with intramedullary construct can result in malunion with apex anterior and valgus deformities but may have lesser chances of infection [22]. On the other hand, traditional plating techniques require extensive soft tissue stripping and has higher chances of infection which has been overcome by minimally invasive plate osteosynthesis, which may also have lesser incidence of malalignment compared to intramedullary nailing [19, 23]. Studies reporting the comparison between intramedullary nailing and locked plating for these types of fractures have been published but these individual studies had less number of patients [24–28].

As no consensus has been reached regarding the management of these fractures, the optimal treatment option for extra-articular proximal tibial fractures remains questionable and there is not a consistent conclusion about which method is more advantageous. Therefore, we conducted this meta-analysis to provide a more comprehensive and reliable evaluation of plating versus nailing in proximal tibial fractures and analyze the outcomes of fracture fixation with these constructs with respect to malunion, delayed union, nonunion, anterior knee pain, and infection Table 1.

### Methods

#### Search Strategy

Electronic databases including PubMed via Medline, Embase, Scopus and Ovid Medline were searched on 29 March 2019 with the search restricted to publications in English. The key terms for searching were: “proximal”, “tibia™”, “fracture”, “intramedullary fixation or plate or plating” and “nail or nailing”. Additionally, we manually searched the reference lists of the included studies and searched across google and Google Scholar for potentially eligible studies. The reference lists from published original articles and previous reviews were scanned for more relevant studies.

#### Inclusion and Exclusion Criteria

Studies were included if the following criteria were fulfilled:

1. Studies were either randomized controlled trials (RCTs) or comparative studies.
2. The participants in the study were patients with extra-articular proximal tibial fractures, either closed or open;
3. Studies must have had 2 or more groups where one of them must have used plate and another nail to fix the tibial fracture.
4. The assessment indexes included anterior knee pain, malunion, delayed union, nonunion and infection.

On the contrary, studies were excluded if they were:

1. Studies with incomplete data for statistical analysis;
2. Reviews, letters or comments;
3. Duplicated literature
4. Cadaveric studies, conference abstracts, case reports
5. Any studies that included other tibial fractures.

#### Study Selection and Characteristics

The initial search retrieved 559 studies. After examining the titles, abstracts, and full text of the short-listed papers, five were identified as suitable studies. One publication [29] was available only as a conference abstract and hence not included in meta-analysis. The remaining four studies, of which two were randomized controlled trials, one was a retrospective study and one was a prospective study, have

### Table 1 Showing baseline characters of included studies

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Authors</th>
<th>Year</th>
<th>Type of study</th>
<th>Groups (1 = ILN, 2 = PLP)</th>
<th>No. of patients</th>
<th>Percentage of males (%)</th>
<th>Mean age (years)</th>
<th>Mean follow-up (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lindvall et al.</td>
<td>2009</td>
<td>Retrospective</td>
<td>ILN</td>
<td>22</td>
<td>77.3</td>
<td>36.4</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PLP</td>
<td>34</td>
<td>79.4</td>
<td>41.7</td>
<td>2.7</td>
</tr>
<tr>
<td>2</td>
<td>Maharaj et al.</td>
<td>2018</td>
<td>RCT</td>
<td>ILN</td>
<td>10</td>
<td>N/A</td>
<td>N/A</td>
<td>&gt;1 Year</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PLP</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Meena et al.</td>
<td>2014</td>
<td>RCT</td>
<td>ILN</td>
<td>19</td>
<td>73.6</td>
<td>39</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PLP</td>
<td>25</td>
<td>72</td>
<td>36</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Gupta et al.</td>
<td>2018</td>
<td>Prospective</td>
<td>ILN</td>
<td>15</td>
<td>N/A</td>
<td>N/A</td>
<td>14.2 Months</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PLP</td>
<td>15</td>
<td></td>
<td></td>
<td>16.7 Months</td>
</tr>
</tbody>
</table>
been included in the meta-analysis. The literature selection process is illustrated in flow chart below (Fig. 1).

(1) PUBMED ((proximal AND tibia AND fracture) AND English[lang]) -2395 results. ((((proximal AND tibia AND fracture)) AND ("intramedullary fixation" OR nail OR nailing)) AND English[lang]) -416 results.

(2) SCOPUS (TITLE-ABS-KEY (proximal AND tibia AND fracture) AND TITLE-ABS-KEY (intramedullary AND fixation OR nail OR nailing) AND TITLE-ABS-KEY (plate OR plating)) AND (LIMIT-TO (LANGUAGE, "English")) – 181 results.
other co-authors to arrive at a final consensus. Data extracted the two authors were resolved by discussion involving the review for the analysis. Any selection conflicts between the two groups (Group 1—Interlocking nail/ILN and Group 2—plating/PLP). This includes names of the authors and the journal, year of publishing, demographic parameters like age, sex and number of patients, complications like infection, malunion, anterior knee pain. Where there was missing information for studies, we contacted authors of articles. These data are summarized in tabular form (Tables 2, 3).

Data Collection and Analysis

Two reviewers (D.N. and P.S) independently screened the studies. The title of the present study was utilized to assess the articles that appeared to be fit for inclusion, and their abstracts were read. In case of any doubt that arose during abstracts screening, full texts were retrieved and assessed. The articles that pertained to the study question were identified and finally these short-listed articles were included in the review for the analysis. Any selection conflicts between the two authors were resolved by discussion involving the other co-authors to arrive at a final consensus. Data extracted were collected and registered on a structured form under two groups (Group 1—Interlocking nail/ILN and Group 2—plating/PLP). This includes names of the authors and the journal, year of publishing, demographic parameters like age, sex and number of patients, complications like infection, malunion, anterior knee pain. Where there was missing information for studies, we contacted authors of articles. These data are summarized in tabular form (Tables 2, 3).

Quality Assessment

Studies that met inclusion criteria were assessed with Jadad scale scoring system [30]. Studies with a score of 3 were considered as high quality. Of the included studies, all were of medium to high quality. All studies were then assessed by two independent reviewers (DK and KJ) to check the methodological quality of clinical trials using Cochrane Collaboration recommendations. Aspects like random sequence generation, allocation concealment, blinding of outcome assessments, incomplete outcome data, selective reporting and other biases were assessed.

Evidence Grading

Quality of evidences for the outcomes were graded using GRADE system (Grading of Recommendations Assessment, Development and Evaluation). Level of evidence strength was classified as high: further research is very unlikely to change the confidence in the estimate of effect, moderate: further research is very likely to have an important impact on the confidence in the estimate of effect, may change the effect, low: further research is very likely to have an important impact on the confidence in the estimate of effect, likely to change the effect and very low: very uncertain about the estimate. We assessed strength of evidence with the “Grade system pro” and summarized the results (Table 3). Results showed that delayed union, non-union, malunion, infections and anterior knee pain showed low strength, indicating further reasearch in this topic.

Statistical Analysis

We analyzed our data with Review Manager Software (RevMan 5.3). For dichotomous data, odds ratio (OR) and 95% confidence intervals (CI) were calculated. For continuous data, weighted mean difference (WMD) and 95% CI were calculated. We used fixed effects model to estimate overall effect sizes. $I^2$ value and chi-square test were used to assess statistical heterogeneity. $p$ value < 0.05 and $I^2$ value of > 50% were considered as statistical heterogeneity. Sensitivity analysis was carried out to check whether a particular study has larger impact on outcome.

Risk of Bias

Risk of bias of the studies we included were assessed using RevMan software. Parameters like randomization techniques like computer-generation and allocation concealment, blinding were assessed. Risk of bias about methodological quality of the included studies is shown in Figs. 2 and 3.

Study Characteristics

All studies included in the analysis directly compared intramedullary nailing with plating for proximal tibial fractures. Out of the four studies included, two are randomized studies, one is a retrospective study and one is a prospective study. All of them were published in last 10 years. The minimum number of patients included is 10 in nailing group and 15 in plating group [26]. The maximum number of patients in a study were 50 [27]. The studies have mentioned comparability of individual groups in terms of preoperative parameters like age and sex.

Demographic Variables

Age, Sex and Implant

All the included studies have patients of age ranging from 17 to 71 years. All the studies included only skeletally mature patients in the analysis. 3 out of 4 studies have shown that proximal tibial extra articular fractures were more frequent in males compared to their female counterparts [24–26, 28]. Most of the patients have motor vehicle accidents as the cause, hence resulting in a male majority who are more involved in accidents compared to females. Both the groups in all the studies were comparable without any gender bias.
Table 2: Showing operative and post-operative parameters of included studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Study</th>
<th>Groups (1 = ILN, 2 = PLP)</th>
<th>Operative time (mins)</th>
<th>Postoperative data (ambulation time/hospital stay)</th>
<th>Radiological union rates and weeks</th>
<th>Delayed unions and non-unions</th>
<th>Malalignment (Coronal / Sagittal) (in degrees)</th>
<th>Infection</th>
<th>Knee ROM/Anterior knee pain</th>
<th>Authors conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lindvall et al</td>
<td>ILN</td>
<td>N/A</td>
<td>N/A</td>
<td>77%; N/A</td>
<td>0, 5. 2 underwent exchange nailing+BG, 2 had revision plating and 1 exchange nailing only</td>
<td>7 (5 apex anterior with 1 varus; 2 apex posterior)</td>
<td>5 (23%)</td>
<td>N/A</td>
<td>No clear advantage of either technique. Closed fractures had higher union rates than open fractures</td>
</tr>
<tr>
<td></td>
<td>PLP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Maharaj et al</td>
<td>ILN</td>
<td>N/A</td>
<td>Full wt bearing at radiological union / 3 days</td>
<td>90%, 16.4 weeks</td>
<td>2, 1. Dynamization for delayed union and exchange nailing+BG for non-union</td>
<td>2. Varus malalignment in one patient and anterior apex deformity in one</td>
<td>114.5 (range 90–150); 3 (30%)</td>
<td>ILN is superior in terms of hospital stay and speed of union but no advantage of operative time, infection rate, knee ROM, malunion and non union</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Meena et al</td>
<td>ILN</td>
<td>81.57</td>
<td>Partial wt bearing at POD-2 / Full wt at radiological union/4.1 days</td>
<td>94.7%, 18.26 weeks</td>
<td>2, 1. Dynamization for delayed union and exchange nailing+BG for non-union</td>
<td>2.77, 2.57. 4 (one had varus and 3 had anterior apex deformity)</td>
<td>119.7 (90–150); 6 (31.6%)</td>
<td>ILN is superior in terms of hospital stay and speed of union but no advantage of operative time, infection rate, knee ROM, malunion and non union</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PLP</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE: ILN = Intramedullary Nail; PLP = Plates and Screws; POD = Post Operative Day; ROM = Range of Motion; BG = Bone Graft
<table>
<thead>
<tr>
<th>Study</th>
<th>Study Groups (1 = ILN, 2 = PLP)</th>
<th>Operative time (mins)</th>
<th>Postoperative data (ambulation time/hospital stay)</th>
<th>Radiological union rates and weeks</th>
<th>Delayed unions and non-unions</th>
<th>Malalignment (Coronal / Sagittal) (in degrees)</th>
<th>Knee ROM/ Anterior knee pain</th>
<th>Infection</th>
<th>Authors’ conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Gupta et al</td>
<td>ILN</td>
<td>76.7</td>
<td>Partial wt bearing at POD 3/5 Full set at radiological union 3.9/100% 14.2 weeks 100%, 16.7 weeks</td>
<td>100%, 14.2 weeks</td>
<td>2.7; 2.5; 4 (3 anterior apex and 1 varus)</td>
<td>2.7; 2.5; 2.1; 2 (1 anterior apex and 1 varus)</td>
<td>2 (13.3%)</td>
<td>Full ROM in 12 patients; 5 (35.3%)</td>
</tr>
<tr>
<td></td>
<td>PLP</td>
<td>82.57</td>
<td>Partial wt bearing at POD 3/5 Full set at radiological union 7/8 weeks</td>
<td>93.4%, 16.7 weeks</td>
<td>0, 1</td>
<td>2.3; 2.1; 2 (1 anterior apex and 1 varus)</td>
<td>2 (13.3%)</td>
<td>Resolved with debridement and antibiotics</td>
<td></td>
</tr>
</tbody>
</table>

ILN had better outcomes than PLP in terms of hospital stay; time to union; time to infection rate.
with proportional male-to-female ratio between the groups, with males being in majority. Intramedullary nailing consisted of a tibial nail with a proximal Herzog curve. Internal fixation with plating was achieved with a proximal tibial lateral locking compression plate (LCP).

### Outcomes

#### Delayed Union

All four studies mentioned data regarding delayed union. Delayed union was exclusively seen in patients of nailing group with odds ratio of 8.29 favoring the plating group.
(95% CI 1.77–38.80, \( p = 0.007 \)). Dynamization was necessary in such patients who underwent nailing and had delayed union. Although the results favored the plating group with respect to delayed union, the results of non-union were comparable in both groups without any statistically significant difference between them, as mentioned previously. Early dynamization of patients undergoing intramedullary nail fixation is a feasible option to reduce the occurrence of delayed union.

### Delayed union

#### 1 New Outcome

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ILN Events</th>
<th>Total</th>
<th>PLP Events</th>
<th>Total</th>
<th>Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gupta 2018</td>
<td>3</td>
<td>15</td>
<td>0</td>
<td>15</td>
<td>26.0%</td>
<td>8.68 [0.41, 184.28]</td>
<td></td>
</tr>
<tr>
<td>Lindvall 2009</td>
<td>3</td>
<td>20</td>
<td>0</td>
<td>20</td>
<td>27.7%</td>
<td>8.20 [0.40, 169.90]</td>
<td></td>
</tr>
<tr>
<td>Mahara 2018</td>
<td>2</td>
<td>10</td>
<td>0</td>
<td>15</td>
<td>21.0%</td>
<td>9.12 [0.39, 212.66]</td>
<td></td>
</tr>
<tr>
<td>Meena 2014</td>
<td>2</td>
<td>19</td>
<td>0</td>
<td>25</td>
<td>25.3%</td>
<td>7.29 [0.33, 161.20]</td>
<td></td>
</tr>
<tr>
<td><strong>Total (95% CI)</strong></td>
<td><strong>64</strong></td>
<td></td>
<td><strong>75</strong></td>
<td></td>
<td><strong>100.0%</strong></td>
<td><strong>8.29 [1.77, 38.80]</strong></td>
<td></td>
</tr>
</tbody>
</table>

| Heterogeneity: \( \chi^2 = 0.01, df = 3 \) (\( p = 1.00 \)); \( I^2 = 0% \) |

| Test for overall effect: \( Z = 2.68 \) (\( p = 0.007 \)) |

### Non Union

Only two out of four studies mentioned about non-union. Overall, 2 out of 64 patients in ILN group and 3 out of 85 patients in PLP group had the complication of non-union. Nonunion in patients of ILN group were managed by bone grafting and either exchanged intramedullary grafting or plating while nonunion in PLP group were managed by bone grafting leading to fracture union. The odds ratio was 0.94 favoring no group (95% CI 0.17–5.29, \( p = 0.74 \)). The results show that the risk of nonunion was comparable in both ILN and PLP groups.

### Malunion

All 4 studies mentioned about malunion. Malunion was seen in 18 out of 64 patients who underwent nailing and 18 out of 85 patients who underwent plating. Apex anterior malalignment was more commonly seen malreduction than either varus, valgus or recurvatum. The results were comparable between both groups with odds ratio of 1.42 (95% CI 0.67–3.04, \( p = 0.87 \)) favoring plating group but not significant. In a systemic review of 17 studies by Bhandari et al. [5], the authors reported a higher malunion rate in the nailing group (20%) than in the plating group (10%).
Fig. 2 Showing risk of bias graph

Fig. 3 Showing risk of bias summary

3 Malunion

3.1 Malunion

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ILN Events</th>
<th>Total</th>
<th>Weight</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
<th>Odds Ratio M-H, Fixed, 95% CI</th>
<th>Risk of Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gupta 2018</td>
<td>5</td>
<td>15</td>
<td>30.0%</td>
<td>1.00 [0.22, 4.56]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lindvall 2009</td>
<td>7</td>
<td>20</td>
<td>30.0%</td>
<td>2.15 [0.60, 7.77]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maharaj 2018</td>
<td>2</td>
<td>10</td>
<td>17.3%</td>
<td>1.00 [0.14, 7.39]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meena 2014</td>
<td>4</td>
<td>19</td>
<td>24.8%</td>
<td>1.40 [0.30, 6.51]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (95% CI)</td>
<td>64</td>
<td>85</td>
<td>100.0%</td>
<td>1.42 [0.67, 3.04]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total events: 18

Test for overall effect: Z = 0.91 (P = 0.36)

Heterogeneity: Chi² = 0.73, df = 3 (P = 0.87); I² = 0%
Infection

All 4 studies mentioned about infection. Infection was more commonly seen in plating group when compared to nailing group. 3 out of 64 patients had infection in nailing group, and 13 out of 85 patients had infection in plating group. Although the results were not significant, the odds ratio was 0.37 (95% CI 0.12–1.15, p = 0.09) favoring nailing group. Infection was managed by either IV antibiotics and debridement or implant removal whenever necessary. In the study by Lindvall et al. the authors reported significantly higher infection rates: 28% in the nailing group and 24% in the plating group [5]. The likely reason for such outcome is the greater proportion (42.8%) of patients with open fractures in their study.

Anterior Knee Pain

3 out of 4 studies mentioned about anterior knee pain. Anterior knee pain was more commonly seen in patients of ILN group when compared to PLP group with 14 out of 44 patients in ILN group having complaint of knee pain in comparison to 5 out of 55 patients in PLP group. Results showed an odds ratio of 5.54 favoring plating group (95% CI 1.49–13.88, p = 0.008), which was statistically significant. Knee pain was mentioned as occasional in two studies [25, 26]. Hence, even though knee pain was more likely in patients with nailing, significant knee pain which hampers daily activity may be less common.
Range of Motion

Only two studies mentioned data regarding range of motion. The range of motion favored plating group, but the difference was not significant ($p = 0.15$) odd’s ratio 5.54 (95% CI $\pm 1.96$–13.05). This difference may be because of pain and malunion in nailing group.

6 range of motion

6.1 range of motion

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ILN Mean (SD)</th>
<th>PLP Mean (SD)</th>
<th>Total</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>meena 2014</td>
<td>119.7 (15)</td>
<td>115.2 (17.5)</td>
<td>10</td>
<td>5.54 [-1.96, 13.05]</td>
</tr>
<tr>
<td>Total</td>
<td>224 (20.75)</td>
<td>222.55 (17.5)</td>
<td>20</td>
<td>1.56 [-1.5, 4.62]</td>
</tr>
</tbody>
</table>

Surgical Duration

Only two studies mentioned data about surgical duration. Although it favored ILN group, the difference is not significant $p = 0.12$ (95% CI $\pm 13.84$ to 1.50). Correcting deformity and achieving reduction is a difficult task in proximal tibia fractures. There are many techniques that are helpful in attaining reduction. These techniques impact surgical duration. More studies are necessary to know the exact surgical duration.

8 surgical duration

8.1 surgical duration

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>ILN Mean (SD)</th>
<th>PLP Mean (SD)</th>
<th>Total</th>
<th>Mean Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gupta 2018</td>
<td>76.7 (20)</td>
<td>82.57 (15)</td>
<td>15</td>
<td>-5.87 [-18.52, 6.78]</td>
</tr>
<tr>
<td>meena 2014</td>
<td>81.57 (12.5)</td>
<td>87.91 (20)</td>
<td>15</td>
<td>-6.34 [-15.99, 3.31]</td>
</tr>
<tr>
<td>Total</td>
<td>158.27 (12.5)</td>
<td>170.48 (20)</td>
<td>30</td>
<td>-6.17 [-13.84, 1.50]</td>
</tr>
</tbody>
</table>
Discussion

Proximal tibia fractures are defined as those extending from the articular surface up to 1.5 times the medial to lateral width of the articular surface and most commonly occur due to high velocity trauma [14].

Operative management is preferred due to risk of malunion, nonunion or joint stiffness with conservative management. The surgical goal of treatment is anatomic restoration of length, alignment, and rotation of the knee while preventing soft tissue complications. The modalities most commonly used include intramedullary nailing or minimally invasive plate fixation.

Our data showed equivocal results for non-union on comparison between the two groups. This is evident by multiple studies who have shown union in 91–100% of patients treated with these modalities [24–28]. Delayed union was seen exclusively in the nailing group. However, it was seen that dynamization in all these cases led to union. Thus, it is imperative to be watchful and do early dynamization to achieve early union.

Malunion is a common complication associated with both groups. These were defined as those having more than 5° degree of rotational malalignment. The proximal fragment tends to go into valgus and flexion due to the action of the gastrocnemius posteriorly, tibialis anterior muscle anterolaterally and the quadriceps pull anteriorly. Malunion rates are higher in intramedullary nailing owing to the difficulty in controlling the proximal fragment. For this, multiple aids can be used for fracture reduction such as use of blocking screws, femoral distractor, using a semi-extended position, use of a proximal and lateral entry point or a percutaneous anterior plating. However, the current data fails to establish a direct correlation of malunion with functional outcome scores. Thus, there is no definite parameters of malunion which can be said to be associated with a poor functional outcome.

The rate of infection was seen to be higher in the plating group. This is attributable to the opening of the fracture site and more extensive soft tissue stripping. However, with the use of minimally invasive surgery, smaller incisions and indirect reduction techniques are used which result in a decrease in the infection rate. The lower rate of infection in the nailing group is attributed to the sparing of the extra articular blood supply without opening of the fracture site.

Anterior knee pain was more commonly seen with nailing. However, no study reported any association with a poor functional outcome, neither did it affect knee range of motion.

There is no clear consensus regarding the weight bearing protocol after proximal tibia fractures. Most commonly, however, patients are started with knee ROM immediate postoperatively and progressing to partial weight bearing. Full weight bearing was started only after clinical and radiological signs of union.

Our meta-analysis showed no major difference between the two modalities. Lower risk of infection and reduced surgical time slightly favored the nailing group while anterior knee pain and delayed union was seen lesser in the plating group. No difference was observed in the rates of malunion and nonunion.

Limitations

Studies included where observational. Since we didn’t find many randomized control trials on the current topic, we had to use the available observational studies to provide an answer whether to use nail or plate in proximal tibia extra articular fractures. Another limitation of our analysis is fewer studies and a smaller number of patients.

Conclusion

Considering lesser time to union, early weight bearing, low chances of infection and lesser surgical duration our meta-analysis is slightly inclined towards nailing group for extra-articular proximal tibial fractures as compared to plating. However, further studies are required in the form of RCTs comparing both.

Funding  No funding sources for this study.

Compliance with Ethical Standards

Conflict of interest  There is no conflict of interest among the authors.

Ethical standard statement  Our study is a review article and does not include any human or animal participation. So, we didn’t require ethical approval.

Informed consent  Our study doesn’t include human participation hence we didn’t require informed consent.

References


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Complications and Functional Outcome of Femoral Head Fracture-Dislocation In Delayed and Neglected Cases

Ramesh Kumar Sen¹ · Sujit Kumar Tripathy² · Tarun Goyal³ · Sameer Aggarwal⁴ · Sandeep Kashyap⁵ · Prabhudev Prasad Purudappa⁶ · Mallikarjun Honnenahalli Chandrappa⁷

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Abstract
Introduction Delayed reduction of the hip in femoral head fracture dislocation increases the risk of osteonecrosis and adversely affects the functional outcome.

Materials and Methods This retrospective study was designed to evaluate the outcome and complications of 138 patients with femoral head fracture dislocation treated by a single surgeon over a period of 22 years. Only seven patients presented within 24 h of injury and remaining all presented late. The hip joints could be reduced by closed manoeuvre in 105 patients, and 33 patients needed open reduction. The patients were managed conservatively or surgically. The mean follow-up period was 3.57 years (1–18 years).

Results There were 119 males and 19 females. The mean age was 35.71 years (range, 18–70 years). Forty-two patients were managed conservatively, and 96 patients needed surgical treatment. The Kocher-Langenbeck approach was used in 40 patients, the trochanteric flip osteotomy in 14 patients, the Smith-Peterson approach in 31 patients, and the Watson-Jones approach in one patient. The femoral head fragment was fixed in 47.82% patients and excised in 11.59% patients. Primary total hip replacement (THR) was performed in 7.24% of patients through the posterior approach. 24.63% of patients developed complications with 14.49% of hip osteonecrosis, 2.89% posttraumatic osteoarthritis and 2.17% femoral head resorption. 55% of patients who developed osteonecrosis were operated through the posterior approach. Secondary procedures were needed in 14.48% of patients. The clinical outcome, as evaluated using the modified Harris Hip Score, was good to excellent in 52.89% of patients and poor to fair in 47.11% of patients.

Conclusion The incidences of osteonecrosis and secondary procedures are increased in delayed and neglected femoral head fracture dislocation. Osteonecrosis is commonly seen in Brumback 2A injuries and posterior-based approaches. All Brumback 3B fractures in such delayed cases should be treated with THR. Osteosynthesis or conservative treatment should be reserved for other types of injuries. A careful selection of treatment plan in such delayed cases can result in a comparable functional outcome as reported in the literature.

Keywords Pipkin fracture dislocation · Brumback classification · Hip fracture · Hip dislocation · AVN · Osteonecrosis · Harris hip score

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**Introduction**

Femoral head fracture dislocation is an uncommon injury. It is often seen after a high-velocity road traffic accident or after a fall from height. Posterior hip dislocation is usually associated and hence is the eponym ‘femoral head fracture-dislocation’. It has been observed that 4–17% of posterior hip dislocations are associated with femoral head fracture [13, 17, 22].

There have been numerous classification systems proposed for such type of injury, but none of these classifications provides recommendations for treatment, and neither have prognostic values [2, 6, 18]. Pipkin proposed a classification for such injury in 1957 where any femoral head fracture distal to the fovea capitis was labelled as type I and any fracture proximal to the fovea capitis involving the eight-bearing dome was categorized as type II. The fracture with associated femoral neck fracture was labelled as type III, and when it was associated with acetabular wall fracture, it was classified as type IV [18]. However, this classification system did not mention about the cartilaginous or osteochondral injuries of the femoral head. Brumback in 1987 included the indentation and transchondral injuries of the femoral head in his classification system [2].

The management of such injury depends on the reducibility of the hip, fracture location, size of the fragment, displacement, hip stability and associated acetabular fracture [6, 10, 22, 26]. The surgical management of this fracture is still controversial because there is no consensus on the surgical approaches [6, 7, 19]. Regarding the surgical treatment, whether to fix or excise the fragment is debatable. Similarly, the fracture fixation techniques are also not defined [6, 7, 19, 22].

Despite controversies in surgical management, the principle of treatment is clearly defined. An emergent closed reduction of the hip followed by definite treatment either by closed manoeuvre or open reduction with the aim of anatomic restoration of joint and anatomical fracture reduction is the principle of management in such fractures [6, 7, 19]. The common complications such as osteonecrosis of the femoral head (ONFH), posttraumatic osteoarthritis and heterotopic ossifications (HO) make the outcome worse in these young trauma victims. The delay in presentation to the hospital or delay in diagnosis because of associated severe life-threatening injuries has an adverse impact on the outcome [6, 7, 19]. Most of the patients with such injuries present after 24 h of injury in developing countries. The functional outcome and complications in such delayed presenters have been evaluated in this retrospective study.

**Materials and Methodology**

All patients with femoral head fracture dislocation treated by a single surgeon between 1st January 1997 and 31st January 2019 were retrospectively evaluated. The details of the patients as entered into the trauma proforma of the operating surgeon were assessed for their injury pattern and treatment. Patients of more than 18 years of age with at least 1-year follow-up and having all radiological and clinical details were included. Patients with pathological fracture, open injuries and inadequate data were excluded. There were 168 femoral head fracture dislocations that were operated during this period. However, 30 patients were excluded because of inadequate data and follow-up; the remaining 138 patients were included in this study.

All patients received primary emergency care. After that, they were evaluated clinically for their femur head fracture dislocation. The radiological evaluation included the anteroposterior radiograph of pelvis with bilateral hip joints. The injury was classified as per Brumback and Pipkin classification. The hip dislocation was reduced immediately under sedation/general anaesthesia using Alli’s manoeuvre [7]. If it could not be reduced after two to three attempts, immediate open reduction and internal fixation was planned. Patients with combined femoral head and neck fractures or isolated neck fracture with hip dislocation were planned for open reduction without any attempt of closed reduction. The patients were treated conservatively or surgically using the Kocher-Langenbeck approach, Smith-Peterson Approach, trochanteric flip osteotomy or Watson-Jones approach. If there was an anatomic reduction of the hip and femoral head fracture along with the absence of intraarticular fragment and stable joint, nonoperative treatment was adopted (Fig. 1). In the conservatively managed group, postoperative traction was applied in abduction for 6 weeks with regular radiographic follow-up. The surgical treatments adopted were fixation using Herbert screw or small fragment screws/mini-screws (2, 2.5 or 3.5 mm) for large fracture fragments and excision in case of a small fragment, not amenable for fixation. Postoperative traction was used in these patients, but no prophylactic medication was provided to prevent HO. The patients treated until 2006 did not receive any chemoprophylaxis for deep vein thrombosis. However, all patients treated after 2006 received chemoprophylaxis (Low molecular weight heparin, Enoxaparin 40 mg subcutaneous). The hip joint congruity and fracture reduction were assessed with a postoperative/post-reduction radiograph. The computed tomographic scan was performed in 92 patients. These patients were followed-up after 2 weeks, 6 weeks, 3 months, 6 months, 12 months and yearly afterwards. The clinical outcome, complications
and functional outcome were evaluated using the modified Harris Hip Score (HHS) [9, 15]. While the outcome of primary THR was evaluated using modified HHS after the arthroplasty, the outcome in patients needing secondary THR was considered as a poor outcome as THR was the endpoint of treatment. The mean follow-up period in our study was 3.57 years (1–18 years).

Results

There were 119 males and 19 females. The mean age was 35.71 years (range 18–70 years). Only four patients were above 60 years of age. The mode of injury was a road traffic accident in 121 patients, and fall from height in the remaining 17 patients. There were 81 associated injuries in 66 patients. There were 15 head injuries, five pelvic fractures, 51 associated acetabulum fractures, three sciatic nerve injuries, and 7 miscellaneous injuries. None of the patients had a severe head injury. There were 128 posterior hip dislocations, eight anterior hip dislocations and two central fracture dislocations. One hundred twenty-eight patients presented within 6 weeks (mean duration of presentation 4.5 days, range 15 h to 18 days) of injury and ten patients presented after 6 weeks. These ten patients were considered as a “late” presenter, and the injury was labelled as ‘neglected injury’. None of the patients presented within 6 h of injury, and the dislocated hip could not be reduced within the golden hours; hence, these patients were labelled as “delayed presentation”. Of seven patients (0.05%) who arrived at our service within 24 h of injury, the hip joint could be reduced by the closed manoeuvre. In total, the hip dislocation could be reduced by closed manipulation in 105 patients, and the remaining patients needed open reduction.

As per Brumback classification, there were 60 Brumback type 1 injuries (35 type 1A and 25 type 1B, Fig. 1), 54 Brumback type 2 injuries (47 type 2A and 7 type 2B, Figs. 2, 3), 14 type 3 injuries (3 type 3A and 11 type 3B, Fig. 4), 8 type 4 injuries (4 type 4A and 4 type 4B, Fig. 5) and 2 type 5 injuries.

42 (30%) patients were managed conservatively, and 96 (70%) patients needed surgical treatment. The anterior approach (Smith-Peterson approach) was used in 31 patients (Fig. 2), and the anterolateral (Watson-Jones) approach was used in one patient. The posterior surgical approach (Kocher-Langenbeck approach) was used in 40 patients for fixation or excision. The trochanteric flip osteotomy was performed in 14 patients (Fig. 3). The femoral head fragment was fixed in 47.82% (66/138) patients and excised in 11.59% (16/138) patients. In 4 (2.89%) patients with Brumback 1B/Pipkin IV fracture dislocation, the reduction of the femoral head fracture fragment was acceptable; so, it was not fixed, but the associated acetabular fracture was stabilized (Fig. 6). Primary total hip replacement (THR) was performed in 10 (7.24%) patients through the posterior approach. Secondary procedures were needed in 14.48% of patients.

Complications and outcome based on Brumback classification (Tables 1, 2)

34 (24.63%) patients had major complications until the latest follow up, and the most common complication was ONFH (14.49%, Fig. 4). Among patients developing ONFH, the posterior approach was used in 11 patients (55%), trochanteric flip osteotomy in four patients, the Smith-Peterson approach in two patients and non-surgical management in remaining three patients. The ONFH was the most frequent complication in patients with femoral head fracture

---

**Fig. 1** a 47-year female presented with left-sided femoral head fracture (infrafoveal, Pipkin type I, Brumback type 1A) with posterior hip dislocation, (b) Closed reduction was performed, and the postoperative radiograph showed congruent joint with well-aligned fracture fragment, (c) 10-years after surgery, radiograph showed completely healed fracture with no degeneration in the joint (d) Her functional outcome was excellent and she was able to perform the daily activities

---
dislocation without major acetabulum fracture (19/104, 18%) and the femoral head osteolysis or resorption was commonly seen in associated acetabular injuries (3/34, 9%). Only four patients had posttraumatic OA, and one patient developed HO. Secondary procedures were commonly needed in Brumback type 2A and type 3B injuries. The sciatic nerve injury recovered completely in two patients, and only one patient (Brumback 1A) needed sciatic nerve decompression. Overall, the clinical outcome was good to excellent in 52.89% and poor to fair in 47.11%. There was good–excellent outcome in 53.84% of patients with minimal or no acetabular rim fracture and 50% of patients with a major acetabular fracture.

Complications and outcome based on Pipkin’s classification (Table 3)

There was 26 Pipkin’s type I fracture, 39 Pipkin’s type II, 11 Pipkin’s type III and 51 Pipkin’s type IV fracture dislocations. Only 15% of patients had a complication in Pipkin type I fracture dislocation, and 8% of patients needed secondary surgery. About 36% of patients developed
complications in Pipkin type II injuries. The most common complication was the development of ONFH (25.64%). All except one patient with hip dislocation and femoral head–neck fractures (Brumback type 3B/Pipkin III) failed after fixation, and two of them were converted to Girdlestone arthroplasty because of deep infection. Another two needed THR after the development of osteonecrosis. Out of 11 patients of Pipkin III fracture, ultimately ten patients ended up with THR or Girdlestone arthroplasty because of deep infection. Another two patients without acetabular fracture and 41.17% of patients with acetabular fracture.

**Outcome in late presenter (> 6 weeks)**

There were 4 Brumback type 1 injuries (2 type 1A, 2 type 1B), 5 type two injuries (1 type 2A and 4 type 2B) and one type 3B injury. At the time of presentation, the hip joint was in reduced position in four patients, and the remaining six patients had a dislocated hip. Two patients with type 1A injuries were managed conservatively as the reduction was acceptable. The hip joint was reduced, and the fragment was

---

**Fig. 4** a–d Radiograph and CT scan of Brumback type 3B/Pipkin type III fracture-dislocation in a 19-year male. (e) The femoral head was reconstructed on the table and then fixed with neck using large fragment partially threaded screws. (f) Postoperative radiograph shows the anatomi cal reconstruction of the femoral head and neck, (g) 5 years after fixation, there was osteonecrosis with femoral head collapse and healing. (h) 8 years after the fixation, the healed osteonecrosis has progressed to femoro-acetabular impingement with mild osteoarthritis changes in the hip, but the functional outcome of the patient is fair as evaluated using modified HHS.

**Fig. 5** a 24-year male with Right-sided Brumback type 4B injury after closed reduction, (b) Intraoperative picture shows transchondral injury, (c) fixation with multiple mini-screws, (d) 2-years follow up X-ray shows no degeneration in the joint.
excised in one patient. Femoral head allograft was used in one patient, and remaining all patients were advised THR. Three patients were treated with THR, and the remaining three refused for surgery. Overall, three patients had excellent outcome, two had good, two had fair, and three had a poor outcome.

**Discussion**

The surgical complexities, articular part involvement and high-velocity injury with peculiar anatomy of the femoral head (supplied by end artery) make the outcome worse in femoral head fracture dislocations [6, 7, 19]. Delayed presentation and hence, delayed reduction of the hip further worsen the outcome in these young trauma victims. Few patients end up with an unsatisfactory outcome because of the development of osteoarthritis, instability or osteolysis. Giannoudis et al. reported 62.6% good-to-excellent outcome in their review of 11 articles with 155 patients where Pipkin fracture classification was used. In the same review, they reported 54.8% good-to-excellent outcome in 55 patients from 4 articles where the injury was classified using Brumback classification [6]. Henle et al. reported that 56% of patients had good-to-excellent outcome [10]. Of 138 patients in our series, 53% had good-to-excellent outcome whereas 27.53% had fair, and 15.21% had poor outcomes. Despite a delay in presentation, the functional outcome in this series was comparable to that of reported in the literature; this was possible because of a careful selection of treatment plan based on the type of fracture, age of the patients, duration of the delay and hip arthritis status.

The acetabular fracture involvement in Brumback 1B, 2B and 5 include the major acetabular fractures (that make the hip joint unstable) and the central fracture dislocation of the hip. However, Pipkin IV fracture dislocation includes minor rim fractures to major acetabular fractures. Based on both the classifications, it was observed that the outcome

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**Fig. 6** a 59-year old male with Brumback type 1B/Pipkin type IV fracture-dislocation, (b) Axial cut section of CT scan shows femoral head fracture and posterior wall acetabulum fracture, (c) The femoral head fragment was excised, and acetabulum fracture was fixed with 3.5 mm reconstruction plate and lag screw, (d, e) 11-years after surgery, the X-ray showed the hip joint degeneration, but the patient had fair outcome.
was worse when there was associated acetabulum fracture. Another observation was that the rate of good–excellent outcome declined with the increasing severity of fractures. There was 77% of good-to-excellent outcome in Pipkin I injury and only 41% good–excellent outcome in Pipkin IV fracture.

Table 1  Complication and clinical outcome of femoral head fracture dislocation with minimal acetabular rim fracture/without acetabular fracture (n = 104)

<table>
<thead>
<tr>
<th>Brumback</th>
<th>Conservative</th>
<th>FH fixation</th>
<th>FH excision</th>
<th>THR</th>
<th>Complications</th>
<th>Secondary procedure</th>
<th>Outcome (Harris Hip Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>24</td>
<td>7</td>
<td>4</td>
<td></td>
<td>1 nonunion</td>
<td></td>
<td>4 poor</td>
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<td></td>
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<td></td>
<td></td>
<td>3 osteonecrosis</td>
<td></td>
<td>9 fair</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 malunion causing FAI</td>
<td></td>
<td>12 good</td>
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<td></td>
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<td></td>
<td></td>
<td>1 sciatic nerve decompression</td>
<td></td>
<td>10 excellent</td>
</tr>
<tr>
<td>2A</td>
<td>6</td>
<td>41 (1 allograft)</td>
<td></td>
<td></td>
<td>14 osteonecrosis, 1 HO, 3 OA, 1 posttraumatic femoral neck fracture</td>
<td>1 neck fixation</td>
<td>11 poor</td>
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<td></td>
<td></td>
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<td></td>
<td>1 OA</td>
<td></td>
<td>14 fair</td>
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<td>4 CD/stem cell</td>
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<td>12 good</td>
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<td>5 THR</td>
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<td>10 excellent</td>
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<td>3A</td>
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<td></td>
<td>2</td>
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<td></td>
<td></td>
<td>1 excellent</td>
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<td>2 good</td>
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<td>3B</td>
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<td></td>
<td>6</td>
<td></td>
<td>2 infection</td>
<td></td>
<td>2 Girdlestone arthroplasty</td>
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<td></td>
<td>2 osteonecrosis</td>
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<td>1 THR</td>
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<td></td>
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<td>1 OA</td>
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<td></td>
<td></td>
<td>25 excellent</td>
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<tr>
<td>Total</td>
<td>35 (25.36%)</td>
<td>56 (40.57%)</td>
<td>5 (3.62%)</td>
<td>8 (5.79%)</td>
<td>29 (21.01%)</td>
<td></td>
<td>18 (13.04%)</td>
</tr>
</tbody>
</table>

FH femoral head, FAI Femoro-acetabular impingement, HO heterotopic ossification; OA osteoarthritis, CD Core decompression, THR total hip replacement

Table 2  Complication and clinical outcome of femoral head fracture dislocation with major acetabular fracture (n = 34)

<table>
<thead>
<tr>
<th>Brumback (both FH and Ac)</th>
<th>Conservative</th>
<th>FH fixation, Ac fixation</th>
<th>FH excision, Ac fixation</th>
<th>FH Closed reduction, Ac fixation</th>
<th>THR</th>
<th>Complications</th>
<th>Sec procedures</th>
<th>Outcome (Harris Hip Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B</td>
<td>4</td>
<td>4</td>
<td>11</td>
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<td>2 femoral head resorption</td>
<td>1 THR</td>
<td>4 poor</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1 osteonecrosis</td>
<td></td>
<td>8 fair</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>1 hip instability</td>
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<td>8 good</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>4 femoral head resorption</td>
<td>1 THR</td>
<td>5 excellent</td>
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<tr>
<td>2B</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
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<td>1 hip instability</td>
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<td></td>
<td></td>
<td>1 femoral head resorption</td>
<td>1 THR</td>
<td>1 excellent</td>
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<tr>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 good</td>
</tr>
<tr>
<td>Total</td>
<td>7 (5.07%)</td>
<td>10 (7.24%)</td>
<td>11 (7.97%)</td>
<td>4 (2.89%)</td>
<td>2</td>
<td>2 (1.44%) complications</td>
<td>2 (1.44%)</td>
<td>6 poor</td>
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<td></td>
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<td></td>
<td>7 excellent</td>
</tr>
</tbody>
</table>

FH femoral head, Ac acetabulum, THR total hip replacement
Table 3  Outcome evaluation as per Pipkin’s fracture dislocation (n = 127)

<table>
<thead>
<tr>
<th>Pipkin</th>
<th>Conservative</th>
<th>FH fixation</th>
<th>FH excision</th>
<th>FH Closed reduction, Ac fixation</th>
<th>THR</th>
<th>Complications</th>
<th>Secondary procedures</th>
<th>Outcome (Harris hip Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>19</td>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
<td>1 nonunion</td>
<td>1 CD/stem cell</td>
<td>2 poor</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>2 osteonecrosis</td>
<td>1 THR</td>
<td>4 fair</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1 malunion</td>
<td>2 osteonecrosis</td>
<td>10 poor</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>causing FAI</td>
<td>1 OA</td>
<td>10 good</td>
</tr>
<tr>
<td>Type II</td>
<td>3</td>
<td>36 (1 allograft)</td>
<td></td>
<td></td>
<td></td>
<td>10 osteonecrosis, 1 HO, 2 OA, 1 posttraumatic femoral neck fracture</td>
<td>1 neck fixation</td>
<td>9 poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 malunion</td>
<td>3 CD/stem cell</td>
<td>10 fair</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>causing FAI</td>
<td>3 THR</td>
<td>11 good</td>
</tr>
<tr>
<td>Type III</td>
<td>5</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td>2 infection</td>
<td>2 Girdlestone arthroplasty</td>
<td>4 poor</td>
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<td></td>
<td>2 osteonecrosis</td>
<td>2 THR</td>
<td>1 fair</td>
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<td></td>
<td></td>
<td>1 OA</td>
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<td>2 osteonecrosis</td>
<td>4 excellent</td>
<td>4 excellent</td>
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<tr>
<td>Type IV</td>
<td>15</td>
<td>17 (10 Ac fixation)</td>
<td>13 (11 Ac fixation)</td>
<td>4</td>
<td>2</td>
<td>3 femoral head resorption</td>
<td>1 sciatic nerve decompression</td>
<td>10 poor</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>6 osteonecrosis</td>
<td>4 THR</td>
<td>20 fair</td>
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<td></td>
<td></td>
<td></td>
<td>1 OA</td>
<td>2 CD/stem cell</td>
<td>13 good</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 hip instability</td>
<td>8 excellent</td>
<td>8 excellent</td>
</tr>
<tr>
<td>Total</td>
<td>37 (29.13%)</td>
<td>63 (49.6%)</td>
<td>15 (11.81%)</td>
<td>4 (3.14%)</td>
<td>8 (6.29%)</td>
<td>34 (26.77%)</td>
<td>20 (15.74%)</td>
<td>25 poor</td>
</tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>31 excellent</td>
</tr>
</tbody>
</table>

FH femoral head, Ac acetabulum, FAI Femoro-acetabular impingement, HO heterotopic ossification; OA osteoarthritis, CD Core decompression, THR total hip replacement
Femoral head fracture dislocation needs urgent hip reduction [6, 7, 19]. Unfortunately, we could not reduce any patient within the golden period of 6 h because of late arrival or missed initial diagnosis. This late reduction had an adverse consequence on the outcome as a significant proportion of these patients ended up with ONFH (14.5%) [11, 12, 20, 30]. Again, the success of closed reduction in our series (76%) was also less than the average success rate of 84% as reported by Giannoudis et al. It is a norm that immediately after reduction, the joint congruity and fracture reduction should be assessed using Computed tomography (CT) [6, 16]. As the patients recruited in this series were since 1997, only 92 patients could be evaluated using CT after reduction.

While conservative treatment was the mainstay of treatment in Brumback 1A/ Pipkin type I injury. open reduction and internal fixation was needed in Brumback 1B, 2 and 5/ Pipkin II and IV injuries. The Brumback 3B/Pipkin type III injuries failed after ORIF and invariably needed THR.

Nonoperative treatment was adopted in 30.43% of patients, and it was slightly more than that reported in the literature (22.9%). However, joint stability and restoration of the joint congruity along with the reduction of the fracture fragment was confirmed before embarking on the nonsurgical treatment [6, 7, 19]. It has been well documented that Pipkin type I fracture can be managed conservatively, but it is difficult to maintain the reduction and delay the rehabilitation in patients with fracture fragment extending above fovea or in associated significant acetabular fractures [3]. Thirteen patients in this series (Brumback 2A, IB and 2B) were maintained in a strict bed rest protocol with traction along with frequent serial radiographs for confirmation of maintained reduction.

Regarding surgical approaches, the trochanteric flip osteotomy and anterior Smith Peterson approach have shown better outcome and minimal morbidity [4, 8, 14, 19, 22, 23, 25, 28]. The anterior approach provides excellent exposure with minimal blood loss and shorter operative time, but there is increased risk of HO. Contrary to it, the posterior approach does not allow access to the anterior fracture fragment because of the interposition of the femoral head [5, 8, 14, 23, 25]. With the trochanteric flip osteotomy and anterior hip dislocation, there is adequate exposure and access to all the parts of the femoral head and acetabular rim for fixation [4, 5, 14, 28]. It is considered as a safe approach having all the advantages of anterior approach with minimal risk of HO because of less retraction or damage to the abductor muscles [4, 5, 14, 28]. We used the posterior approach in 40 patients during our initial period as we did not have sufficient training on trochanteric flip osteotomy. Of 86 patients who went for surgical fixation or excision, we adopted the anterior approach or trochanteric flip osteotomy in 54 patients (63%). Among patients who developed ONFH (20 patients), the posterior approach was used in 11 patients (55%).

Although fragment excision provides a better outcome than fixation in Pipkin I injury [6, 7, 19], it is difficult to draw any conclusion from this series as very few patients have been treated surgically. However, the complication rate and secondary intervention were minimal in this group. The complication rate and secondary interventions in Pipkin II fracture were more than Pipkin IV injuries in our patients. Because of delayed reduction of the hip, a majority of the Pipkin type II fractures in our series developed ONFH and hence there was increase in complication rate and secondary procedures. Pipkin type III fracture was least common with an incidence of 8.7%. Although ORIF has been the standard of care in young trauma victims and THR is reserved for elderly individuals [13], our observation is not in support of this perception. Four of five patients in this series failed after fixation and ultimately ended up with THR or girdlestone arthroplasty. A recent article by Scolaro and his team reported a 100% failure rate after internal fixation of Pipkin III injuries, and that was the largest study in the world till date [28]. With the availability of good implant having better survivorship, probably THR is a better option even in young individuals [6, 21, 27]. However, if the artificial prosthesis cannot fulfi l the functional demands of the patient, open reduction and internal fixation is justifi ed but with a risk of failure [27]. We observed good outcome in the indentation and transchondral injuries of the femoral head. However, with a small number of patients, the treatment outcome is difficult to judge.

The incidence of ONFH was relatively high in this series (14.5%) compared to the literature. There were 8.7% and 11.8% of ONFH in femoral head fracture dislocation as reported by Scolaro et al. and Giannoudis et al., respectively [6, 21]. Even Tonetti and his associates reported only 8% of ONFH in their series [26]. The relatively high incidence of ONFH in our series was probably because of delayed hip reduction and posterior based approaches. Previous studies have shown that the posterior surgical approach is associated with 3.2 times increased risk of osteonecrosis [8, 23, 25]. Another frequent complication, as reported in the western literature, is HO. In the systematic review, Ginnadious et al. reported 35.6% HO [6]. Scolaro et al. also reported a 40% incidence of HO in their series [21]. Only one patient of Brumback type 2A or Pipkin type II developed HO in our series, and that was of Brooker type I severity without functional limitation. Unlike western literature, HO is not a major problem in the Indian subcontinent. None of the patients in our series received prophylaxis to prevent HO. However, none of these patients had a severe head injury that warranted a prolonged immobilization/intensive care management. A typical complication that we observed in our series was the development of femoral head osteolysis or resorption. We noted four patients with femoral head resorption mainly with the associated acetabular fracture; probably,
significant trauma to the osteoarticular cartilage induces the osteolysis process. There is no consensus on the outcome evaluation in patients treated with THR for femoral head fracture dislocation. While evaluating the outcome using Thompson and Epstein score or Merle d’Aubigne and Postel score, the previous studies reported the outcome of primary THR patients either as poor or good [6, 13]. Few authors believed that THR below 60 years of age is not justifiable and hip joint preservation should be the aim. Hence, they considered the outcome as poor [13]. With the current treatment protocol, THR is a well-accepted treatment for Pipkin type III injuries, elderly individuals and in neglected cases where reconstruction is not feasible or joint is arthritic [6, 21, 27]. We evaluated the outcome using HHS in such primary THR after the arthroplasty procedure. However, patients needing secondary THR for arthritis after initial conservative or surgical treatment in Pipkin fracture dislocation denote the “complication” or “treatment failure”; hence, the clinical outcome (HHS) in such patients were evaluated before the arthroplasty procedure (invariably it was poor). We chose the Harris hip score for outcome evaluation in our study, because it is used extensively worldwide, it is more familiar, and there is no validated clinical score available for treatment evaluation of femoral head fracture dislocation [14]. Many recent studies have evaluated the functional outcome of Pipkin fracture dislocation using HHS as it has been validated to evaluate multiple hip pathologies [14, 24, 29]. If we consider THR as the endpoint of treatment, 20 (14.49%) patients ultimately needed this procedure, including 10 primary and 10 secondary procedures. The need for THR as primary and secondary intentions were more in our study compared to the available literature [6, 14].

There are a few limitations in this study. Being retrospective study few data might have lost. As the patients were recruited since 1997, some patients might not have received the current standard treatment regime. Despite the development of arthritis, few patients did not opt for arthroplasty, and hence a relatively poor outcome was inevitable. The strength of this study is that this is the largest series of femoral head fracture dislocation with more than one-year follow up having detailed information of the complications and clinical outcome.

To conclude, the incidence of hip osteonecrosis and the need for total hip replacement is increased when the reduction of femoral head fracture dislocations is delayed. Osteonecrosis in these patients is usually seen in Brumback 2A injuries and posterior based approaches. However, heterotopic ossification is not a common problem in the Indian subcontinent. A primary osteosynthesis of fracture must be attempted in Brumback 1B, 2 and 5 injuries and few type 1A injuries. However, total hip replacement should be the primary treatment for all Brumback 3B fracture dislocations in such delayed/neglected cases. Femoral head fracture with infrafoveal involvement has good prognosis even with nonoperative treatment. The fractures involving suprafoveal femoral head and associated acetabular fracture have a worse prognosis. A careful selection of treatment plan in such delayed or neglected cases may provide a comparable outcome as that reported in the literature.

Compliance with ethical standards

Conflict of interest The authors of this manuscript declare that they have no conflicts of interest to disclose.

Ethical standard This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

References


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CT Based Analysis of Acetabular Morphology in Northern Indian Population: A Retrospective Study

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Abstract

Purpose The acetabular morphology has shown to differ among different regions of the world. Multiplanar evaluation by computed tomography (CT) scan is the key to assess acetabular depth, version, and inclination at the same time which have been rarely explored before in the Indian population. We present an anthropometric study of the native acetabulum by CT based coronal, sagittal, and axial parameters in the Northern Indian population.

Methods The acetabular anteversion (AA), acetabular angle of sharp (AAS), sagittal acetabular angle (SAA), lateral center edge angle (LCEA), acetabular depth (AD), acetabular horizontal offset (AHO), extrusion index (EI) and acetabular depth ratio (ADR) was measured in CT scans of 122 patients (244 hips) without any bony pathologies. LCEA < 20°, ADR < 250, AD < 9 mm, AAS > 43°, and EI ≥ 25% were taken as criteria for dysplastic acetabulum.

Results There were 62 males and 60 females included in the study with a mean age of 63.8 ± 17.2 years (21–98 years). In this study, females were having significantly lower ADR (p = 0.002) and higher EI (p = 0.01) than males. The prevalence of dysplasia was 3.2% according to LCEA and 1.6% while combining all of the criteria.

Conclusion There are prominent differences in acetabular depth in the Indian population compared with the population of Western countries or other parts of Asia. Females were shown to have shallower acetabulum than males. The comparative analysis of radiographic parameters obtained from our study with the data available on different country-based studies can help better understanding the acetabular morphology of Indian as well as the worldwide population.

Level of Study Retrospective cross-sectional study.

Keywords Acetabulum · Anthropometric study · Acetabular dysplasia · CT scan · North India

Introduction

Acetabular orientation carries the utmost importance in hip reconstruction surgery. Acetabular retroversion or abnormal depth is known to cause an increased incidence of femoroacetabular impingement and osteoarthritis of the hip [1–3]. Moreover, knowledge of the spatial orientation of the native acetabulum can prevent malposition of the acetabular component which can lead to increased wear and instability in cases of total hip arthroplasty (THA) [4–6].

Anthropometric studies can help to identify the normal range of acetabular parameters for a region. The available literature has shown high variability of acetabular orientation and depth across different populations [3, 7–13]. Acetabular depth can be assessed by multiple parameters such as centre edge angle, acetabular depth ratio, and extrusion index [7, 10, 14, 15]. But computed tomography (CT) based analysis of acetabular depth has rarely been explored in the Indian population before [15, 16]. Acetabular anteversion and inclination can be assessed from a different perspective in different planes as described by Murray [17]. Different signs of acetabular retroversion in plain radiograph have been described in the literature. However, these signs provide us with only a 2-dimensional perception of the acetabulum [18]. Multiplanar evaluation by computed tomography (CT) scan is the key to assess all of these parameters at the same time [19], which have been rarely explored before in the Indian population.

We present an anthropometric study of the native acetabulum by CT based coronal, sagittal, and axial parameters in the Northern Indian population. The aim of the study was to...
find out the difference in native acetabular parameters of the people of northern India and the data available from other parts of India and worldwide.

**Materials and Methods**

Non-contrast computed tomography (NCCT) scan of B/L hips of these patients were used for assessment which were already done for some other unrelated pathologies. A total of 122 NCCT scans (244 hips) without any bony pathologies in hip joint were evaluated over a period of 2 years (July 2017–August 2019). Patients with a previous history of hip or pelvis trauma or surgery were excluded.

There were 62 males and 60 females included in the study with a mean age of 63.8 ± 17.2 years (21–98 years). These patients were mainly belonging to the sub-Himalayan region of Northern India including patients from Uttar Pradesh district as well as the planes of Uttar Pradesh district of India with different ethnic backgrounds. We measured seven parameters using different views of CT scans. The CT scan was performed in the supine position with hip, knee extended, and ankle in the neutral position. We used a multislice CT scanner (128 slice Siemens scanner) with 1 mm thickness cuts. RadiAnt DICOM Viewer 5.5.1 was used for the calculation of all parameters. Informed consent was obtained from all of the patients.

A transparent plastic sheet marked with concentric Moose circles was used to determine the center of the femoral head. The parameters assessed were: (1) acetabular anteversion (AA) which was measured by the method described by Reikeras et al. [1] (Fig. 1), (2) acetabular angle of sharp (AAS) which is the angle between line joining tip of two teardrops and edge of the acetabulum [20] (Fig. 2), (3) sagittal acetabular angle (SAA) which is the angle between the line joining anterior and posterior edges of the acetabulum in a sagittal section and the horizontal reference line [21] (Fig. 3) (4) lateral center edge angle (LCEA) that is angle between the line joining center of the femoral head to the anterior edge of the acetabulum and another vertical line drawn through center of femoral head [22] (Fig. 2) (5) acetabular depth (AD) which is denoted by distance of a vertical line drawn from the center of acetabulum to a line joining

![Figure 1](image1.png)  
*Fig. 1* Figure showing measurement of acetabular anteversion, a = acetabular anteversion angle

![Figure 2](image2.png)  
*Fig. 2* Figure showing measurement of lateral center edge angle and acetabular angle of sharp (a = lateral center edge angle, b = acetabular angle of sharp)

![Figure 3](image3.png)  
*Fig. 3* Figure showing measurement of sagittal acetabular angle (a = sagittal acetabular angle)
teardrop and lateral edge of the acetabulum [23] (Fig. 4) (6) acetabular horizontal offset (AHO) which is denoted by the horizontal distance from the teardrop from the center of femoral head [24] (Fig. 5), (7) acetabular depth ratio (ADR) which is calculated by dividing the depth of the acetabulum by the length between the inferior point of the teardrop and the lateral edge of the acetabulum and then multiply by 1000 [23] (Fig. 4), and (8) extrusion index (EI) which is the ratio of horizontal length of femoral head uncovered by acetabulum and total horizontal length or width of femoral head [25, 26] (Fig. 5). LCEA less than 20° was considered as criteria for dysplastic hip and angle between 20° and 25° was taken as borderline dysplasia [22]. Whereas ADR < 250 [19], AD < 9 mm [10], AAS > 43° [27], and EI ≥ 25% [27] were taken as other criteria for dysplasia. Prevalence was defined as acetabular dysplasia in at least one hip of any patient.

We analysed the variability between sexes and sides of the same patient. Continuous variables were expressed in mean, standard deviation, and confidence intervals. As the data was found to be normally distributed independent sample $T$ test was used to compare between groups. Statistical analysis was performed by SPSS 26.

**Results**

A total of 244 hips were analyzed to note the mean, standard deviation of all parameters which has been summarized in Table 1. Comparison of all parameters between both sides of the same patient revealed no significant difference in any parameters (Table 2). There was a significant difference in acetabular horizontal offset (< 0.001) and acetabular depth ratio (0.002) between males and females. A comparison of all parameters between different sexes has been summarized in Table 3. We found a positive correlation between age and acetabular depth ratio ($r = 0.18$, $p = 0.01$), but no correlation was found between age and the rest of the parameters. We assessed dysplasia of the hips with AAS, AD, ADR, LCEA, and EI based criteria separately and also by combining all of them. Only four patients had dysplastic hips according to criteria given by Wiberg (CE angle < 20°) [21]. However, there were 11 patients (9.01%) who had a CE angle less than 25° suggestive of borderline dysplasia. There were 7 females (5.7%) and 4 males (3.3%) among these patients. Bilateral involvement was seen in 86.1% of all these patients. Other

![Figure 4](image1.png) Figure showing measurement of acetabular depth and acetabular depth ratio ($a =$ acetabular depth, $(a/b) \times 1000 =$ acetabular depth ratio)

![Figure 5](image2.png) Figure showing measurement of extrusion index $(a/b)$ and acetabular horizontal offset $(c)$

**Table 1** Table showing all computed tomography-based parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean ± SD</th>
<th>Range</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetabular angle of sharp</td>
<td>36.2 ± 2.35</td>
<td>30.5–51.7</td>
<td>45.9–46.5</td>
</tr>
<tr>
<td>Sagittal acetabular angle</td>
<td>28.9 ± 2.4</td>
<td>16.6–36.3</td>
<td>28.6–29.2</td>
</tr>
<tr>
<td>Acetabular anteversion</td>
<td>17.52 ± 2.7</td>
<td>9.8–28.3</td>
<td>17.1–17.9</td>
</tr>
<tr>
<td>Acetabular depth (mm)</td>
<td>23.9 ± 4.7</td>
<td>8.7–34.5</td>
<td>23.5–24.3</td>
</tr>
<tr>
<td>Center edge angle</td>
<td>33.5 ± 4.8</td>
<td>18.6–61.8</td>
<td>32.9–34.2</td>
</tr>
<tr>
<td>Acetabular horizontal offset (cm)</td>
<td>2.92 ± 0.24</td>
<td>2.29–3.56</td>
<td>2.88–2.95</td>
</tr>
<tr>
<td>Acetabular depth ratio</td>
<td>341.4 ± 27.6</td>
<td>241.4–453.7</td>
<td>337.6–345.2</td>
</tr>
<tr>
<td>Extrusion index (%)</td>
<td>16.3 ± 2.1</td>
<td>11.3–25.9</td>
<td>14.5–21.6</td>
</tr>
</tbody>
</table>

$SD$ standard deviation, $SEM$ standard error of mean, $CI$ confidence interval
The prevalence of dysplasia was 1.6% while combining all of the criteria. All data was observed and analysed by a single observer.

**Discussion**

Variations in the acetabular parameters across different countries or ethnicities necessitate the synthesis of data from every region for better understanding the anatomy of that group of population. We compared all of the acetabular parameters of the North Indian population with the rest of the world to note that the acetabular depth and acetabular depth ratio were more than other parts of the world (Table 4). This is probably the causative factor behind the high prevalence of asymptomatic femoroacetabular impingement in the Indian population [30]. This finding has not been shown in any of the previous studies based on the Indian population. In our study, the prevalence of acetabular dysplasia was 1.6% while considering all the criteria (AAS, AD, ADR, LCEA, and EI) with no difference between males and female dysplasia prevalence. Prevalence of acetabular dysplasia has been rarely discussed in studies on the Indian population [31].

Reikeras et al. [1] highlighted the role of mismatch of acetabular and femoral anteversion in the development of osteoarthritis. The mean AA was $17° \pm 6°$ in their study on the population of Norway. The mean AA in our study was $17.52° \pm 2.7°$ which are comparable to studies conducted on the Northeastern Indian population by Saikia et al. [15] (mean AA $18.2° \pm 5.6°$), Western Indian population by Jogani et al. [32] (mean AA $18.13°$) and Southern Indian population by Sengodan et al. [16] (mean AA $18.64°$). Although Maheshwari et al. [33] reported a median AA $27°$ in another study conducted on the Indian population.

CT based studies performed worldwide show anteversion

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Right side</th>
<th>Left side</th>
<th>p value</th>
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<tbody>
<tr>
<td>Acetabular angle of sharp</td>
<td>Mean ± SD 36.2 ± 2.3</td>
<td>Range 31.2–51.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Sagittal acetabular angle</td>
<td>Mean ± SD 28.9 ± 2.4</td>
<td>Range 21.1–35.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Acetabular anteversion</td>
<td>Mean ± SD 17.3 ± 2.6</td>
<td>Range 12.1–27.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Acetabular depth (mm)</td>
<td>Mean ± SD 23.7 ± 4.3</td>
<td>Range 8.8–34.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Center edge angle</td>
<td>Mean ± SD 33.6 ± 4.9</td>
<td>Range 18.7–61.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Acetabular horizontal offset (cm)</td>
<td>Mean ± SD 2.91 ± 0.24</td>
<td>Range 2.29–3.54</td>
<td>0.7</td>
</tr>
<tr>
<td>Acetabular depth ratio</td>
<td>Mean ± SD 341.03 ± 29.6</td>
<td>Range 243.5–453.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Extrusion index (%)</td>
<td>Mean ± SD 16.1 ± 2.19</td>
<td>Range 11.3–25.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

$SD$ standard deviation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Male ($n = 62$)</th>
<th>Female ($n = 60$)</th>
<th>p value</th>
</tr>
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<tbody>
<tr>
<td>Acetabular angle of sharp</td>
<td>Mean ± SD 36.3 ± 2.01</td>
<td>Range 31.6–48.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Sagittal acetabular angle</td>
<td>Mean ± SD 29.06 ± 2.1</td>
<td>Range 16.6–36.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Acetabular anteversion</td>
<td>Mean ± SD 17.2 ± 2.7</td>
<td>Range 11.1–28.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Acetabular depth (mm)</td>
<td>Mean ± SD 24.1 ± 4.7</td>
<td>Range 8.8–34.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Center edge angle</td>
<td>Mean ± SD 33.6 ± 4.07</td>
<td>Range 19.7–61.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Acetabular horizontal offset (cm)</td>
<td>Mean ± SD 2.9 ± 0.23</td>
<td>Range 2.41–3.56</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Acetabular depth ratio</td>
<td>Mean ± SD 347.4 ± 29.06</td>
<td>Range 248.1–453.7</td>
<td>0.002</td>
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<tr>
<td>Extrusion index (%)</td>
<td>Mean ± SD 16.1 ± 1.9</td>
<td>Range 11.3–25.1</td>
<td>0.03</td>
</tr>
</tbody>
</table>

$SD$ standard deviation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>p value</th>
</tr>
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<tbody>
<tr>
<td>AAS $&gt; 43°$</td>
<td>1/62 (1.6%)</td>
<td>1/60 (3.33%)</td>
<td>2/122 (1.6%)</td>
<td>1</td>
</tr>
<tr>
<td>AD $&lt;9$ mm</td>
<td>1/62 (1.6%)</td>
<td>2/60 (3.33%)</td>
<td>3/122 (2.4%)</td>
<td>0.61</td>
</tr>
<tr>
<td>ADR $&lt;250$</td>
<td>2/62 (3.2%)</td>
<td>6/60 (4.9%)</td>
<td>6/122 (4.9%)</td>
<td>0.43</td>
</tr>
<tr>
<td>LCEA $&lt;20°$</td>
<td>2/62 (1.6%)</td>
<td>4/60 (6.67%)</td>
<td>4/122 (3.2%)</td>
<td>1</td>
</tr>
<tr>
<td>EI $&gt;25%$</td>
<td>1/62 (2.4%)</td>
<td>2/60 (1.67%)</td>
<td>3/122 (2.4%)</td>
<td>0.61</td>
</tr>
<tr>
<td>Combined</td>
<td>1/62 (1.6%)</td>
<td>1/60 (1.67%)</td>
<td>2/122 (1.6%)</td>
<td>1</td>
</tr>
</tbody>
</table>

parameters were also used to calculate the separate prevalence of dysplasia which have been summarized in Table 4. The prevalence of dysplasia was 1.6% while combining all of the criteria. All data was observed and analysed by a single observer.

<table>
<thead>
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<th>Criteria</th>
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<th>Female</th>
<th>Total</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2/122 (1.6%)</td>
<td>1</td>
</tr>
<tr>
<td>AD $&lt;9$ mm</td>
<td>1/62 (1.6%)</td>
<td>2/60 (3.33%)</td>
<td>3/122 (2.4%)</td>
<td>0.61</td>
</tr>
<tr>
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</tr>
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<td>1</td>
</tr>
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<td>1/62 (2.4%)</td>
<td>2/60 (1.67%)</td>
<td>3/122 (2.4%)</td>
<td>0.61</td>
</tr>
<tr>
<td>Combined</td>
<td>1/62 (1.6%)</td>
<td>1/60 (1.67%)</td>
<td>2/122 (1.6%)</td>
<td>1</td>
</tr>
</tbody>
</table>
comparable to our data like studies conducted on the German population by Wassilew et al. [34] and American population by Tannenbaum et al. [35] revealed a mean AA of 18°± 4.7° and 17°± 9°, respectively.

Acetabular sagittal orientation and horizontal offset can be of help in preoperative planning and intraoperatively understanding the depth of reaming in total hip replacement [24]. There are no data available on the normal Indian population in these parameters. Mean SAA was not significantly different (p=0.5) among different genders. However, females were shown to have significantly lower (p < 0.001) acetabular horizontal offset which has been reported by Merle et al. [24] before on an X-ray based study. The knowledge about these parameters can help surgeons determine the correct plan for various acetabular surgeries as well as the position of shell in total hip replacements.

Lateral CEA is a well-established parameter for the assessment of acetabular dysplasia. It has shown to vary from 28° to 42° in the Indian population [31]. The mean lateral CEA in our study was 33.5° which are comparable to previous Asian studies (31.69° in Malaysian [12], 32.5° in Korean [9], 31.25° in Singaporean population [10], 32.7° in northeastern India [15] but varying largely from the western population (41° in Finland [8], 36° in British [14], 39.2°± 3.2° in white racial groups [7]. This finding points towards a higher degree of acetabular over coverage in all of these populations.

The acetabular angle of sharp is one of the commonly used parameters for categorizing dysplastic hip, which was first described by sharp [20]. The mean AAS was 36.2°± 2.35° in our study. Saikia et al. [15] reported a mean of 39.2°± 4.9° acetabular angle in the Northeastern Indian population. Studies conducted in western [32] (mean AAS 35.1°) and southern [16] (mean AAS 35.5°) parts of India have also shown comparative values. Other Asian studies have shown mean AAS to range from 38° in Japanese studies [36], 39.46° in Singaporean population [10] to 42.35° in Malaysian population [12], which is quite high compared to the normal range described by Sharp (33°–38°) [20]. The variation brings us to the question of difference in acetabular anatomy in different zones which needs exploration of the acetabular anatomy of the northern region of India.

Acetabular depth is one of the most reliable predictors for joint incongruity and arthritic change in the hip [2]. We observed a mean AD of 23.9± 4.7 mm in our study which is comparable to Saikia et al. (25 mm) [15]. The acetabulum has shown to be much deeper in Indian studies comparative to other Asian studies like the study conducted on Malaysian [12], British [37], and Korean [9] population have shown AD to be 15 ± 1.7 mm, 14.4 ± 3.1 mm and 10.9 ± 2.7 mm AD, respectively. However, most of these studies are X-ray based unlike our CT based study. The same findings were observed with the acetabular depth ratio which was 341.4 ± 27.6 in our study compared to 308.3 ± 47.9 in a Japanese study by Mimura et al. [19]. Another study performed on the population of Denmark [25] has shown mean ADR to be comparatively lower than Indian value (Table 4). The ADR has shown the ability to detect dysplasia better than other parameters in the same group of patients. Similar findings have been shown in another CT based study by Mimura et al. [19]. Further studies will be needed to confirm the higher sensitivity of this parameter.

Extrusion index has ranged from 12.99% in German population [38] to 18% in Singaporean population [10] and 13% in South-Asian population [13]. Our study shows a mean EI of 16.3%. In our study, females were having significantly lower ADR (p= 0.002) and higher EI (p= 0.01) than males. These findings suggest a shallower acetabulum in females compared to males. Increased prevalence of acetabular dysplasia in females has been reported before in the Asian population [19] as well as a study from Denmark [25], but there isn’t any Indian data available.

The prevalence of dysplasia ranges from 1.8 to 15% in the Korean population using lateral center edge angle (sourcil as an edge) in studies by Han et al. [9] and Kim et al. [39], respectively. Whereas Croft et al. [37], Aktas et al. [40], Engesaeter et al. [41], Umer et al. [10], and Mimura et al. [19] studied British, Turkish, Japanese, Norwegian and Singaporean population to note the prevalence of dysplasia measured by Lateral CEA to be 1%, 2.4%, 3.3%, 7.3%, and 11.5%, respectively. Our findings of 3.2% prevalence are comparable to the Asian data published before. However, while considering all the parameters there was only one male (1.6%) and one female patient (1.67%) found to be having a dysplastic acetabulum. The combined prevalence of 1.6% is closer to the studies conducted in the Korean population (1.8%) by Han et al. [9] or the Chinese population (1.1%) by Lau et al. [3]. However different studies from the same country also have reported different prevalence of dysplasia (Table 5). There isn’t any Indian data for the prevalence of acetabular dysplasia in the adult population available yet. Looking at the variations in the ethnic and cultural background of India our study conducted on the Northern of India can be a valuable addition to the existing literature highlighting on acetabular morphology.

The limitation of our study is the lack of calculation of prevalence on a population sample instead of a hospital cohort. However, the study was conducted on patients without any hip pathologies. A multicentric study conducted with the population from different corners of the country would give a better idea about the acetabular morphology of India.
Table 5  Table showing comparative analysis of all acetabular parameters across different countries

<table>
<thead>
<tr>
<th>Variables</th>
<th>Sex</th>
<th>North India (current study) (M ± SD)</th>
<th>Japan (Mimura) [19] (M ± SD)</th>
<th>Malay (Bahiruddin) [12] (M ± SD)</th>
<th>Finland (Tallroth) [8] (M ± SD)</th>
<th>Singapore (Umer) [10] (M ± SD)</th>
<th>Korea (Park) [28] (M ± SD)</th>
<th>Africa (Lavy) [11] (M ± SD)</th>
<th>Korean (Han) [9] (M ± SD)</th>
<th>Japan (Yoshimura) [14] (M ± SD)</th>
<th>Britain (Yoshimura) [14] (M ± SD)</th>
<th>South Asia (Umer) [13] (M ± SD)</th>
<th>Serbia (Jeremic) [29] (M ± SD)</th>
<th>China (Lau) [3] (M ± SD)</th>
<th>North East India (Sai-kia) [15] (M ± SD)</th>
<th>Denmark (Jacon-sen) [25] (M ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>M</td>
<td>17.2 ± 2.7</td>
<td>14.81 ± 5.45</td>
<td>17.0 ± 6.0</td>
<td>15.17 ± 4.67</td>
<td>39.85 ± 6.0</td>
<td>37.4 ± 3.8</td>
<td>36.9 ± 4.0</td>
<td>36.5 ± 3.5</td>
<td>37.31 ± 4.27</td>
<td>37.5 ± 3.6</td>
<td>37.0 ± 3.5</td>
<td>37.0 ± 3.5</td>
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<td>F</td>
<td>17.7 ± 2.6</td>
<td>15.17 ± 4.67</td>
<td>23.0 ± 7.0</td>
<td>24.0 ± 3.7</td>
<td>37.4 ± 3.8</td>
<td>36.9 ± 4.0</td>
<td>36.5 ± 3.5</td>
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<td>37.0 ± 3.5</td>
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<td>18.4 ± 6.2</td>
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</tr>
<tr>
<td>AAS</td>
<td>M</td>
<td>36.3 ± 2.01</td>
<td>39.7 ± 4.2</td>
<td>41.79 ± 3.23</td>
<td>37.48 ± 5.4</td>
<td>39.85 ± 6.0</td>
<td>37.4 ± 3.8</td>
<td>36.9 ± 4.0</td>
<td>36.5 ± 3.5</td>
<td>37.31 ± 4.27</td>
<td>37.5 ± 3.6</td>
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<td>38.28 ± 4.43</td>
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<td>39.4 ± 3.2</td>
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<td>AD</td>
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<td>2.41 ± 0.47</td>
<td>1.617 ± 0.15</td>
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<td>1.15 ± 0.26</td>
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<td>1.44</td>
<td>1.25 ± 0.27</td>
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<td>1.02 ± 0.26</td>
<td>0.89</td>
<td>1.41</td>
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<td>AHO (cm)</td>
<td>M</td>
<td>2.9 ± 0.23</td>
<td>347.4 ± 29.06</td>
<td>305.6 ± 43.2</td>
<td>319</td>
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<tr>
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<td>F</td>
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<tr>
<td>EI</td>
<td>M</td>
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<td>13.0</td>
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<tr>
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<td>F</td>
<td>16.9 ± 2.1</td>
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</table>

$M$ mean, $SD$ standard deviation, $AA$ acetabular anteversion, $AAS$ acetabular angle of sharp, $SAA$ sagittal acetabular angle, $LCEA$ lateral centre edge angle, $AD$ acetabular depth, $AHO$ acetabular horizontal offset, $ADR$ acetabular depth ratio, $EI$ extrusion index, $M$ male, $F$ female-right, $L$ left
Conclusion

The comparative analysis of radiographic parameters obtained from our study with the data available on different country-based studies can help better understanding the acetabular morphology of Indian as well as the worldwide population. There are prominent differences in acetabular depth in the Indian population compared with the population of Western countries or other parts of Asia. Females were shown to have shallower acetabulum than males. The rest of the acetabular parameters were comparable with data from other countries.

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Compliance with Ethical Standards

Conflict of interest The author(s) declared no potential conflicts of interest with respect to the research authorship, and/or publication of this article.

Ethics standard statement This study was approved by the institutional review board. Ethics approval for the study had been taken from the institutional ethics committee before starting the study.

Informed consent Informed consent was obtained from all individual participants included in the study.

References


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Coexistence of Osteomalacia in Osteoporotic Hip Fractures in More Than 50 Years Age Group

Karmesh Kumar1 · Himanshu Bhayana1 · Kim Vaiphei2 · Devendra Chouhan1 · Rajendra Kumar Kanojia1 · Sanjay Bhadada3

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Abstract

Introduction Osteomalacia is a hitherto common orthopaedic condition and is commonly coexists with osteoporosis. However, the identification of osteomalacia always slips under the radar and more emphasis is given to diagnosis and management of osteoporosis. Identification of osteomalacia is equally relevant as management of the osteoporotic fractures is different with or without osteomalacia.

Methods This was a prospective study design that included patients 50 years or above of either sex presented with proximal femur fractures. Osteoporosis was identified by DEXA scan of hip and lumbar spine. Metabolic tests including serum calcium, phosphorus, ALP and vitamin D levels were done. Histopathological diagnosis of osteomalacia was performed on bony tissues that were taken during surgery from a site adjacent to the fracture and histological examination was performed on non-decalcified paraffin sections using special stains.

Results A total of 45 patients was included in study. Mean age was 68.7 years (53–85 years). Abnormal values of serum calcium, phosphorus, ALP, vitamin D were noted in 44.4%, 22.2%, 53.3% and 48.9% patients, respectively. On histopathology, 73.17% patients showed osteomalacia. No significant correlation was found between serum biochemical markers and histopathology except with serum Vitamin D (p value −0.004).

Conclusion The majority of patients with osteoporotic hip fractures had coexisting osteomalacia. Abnormal biochemical values were not significantly associated with osteomalacia. Hence, histopathology remains the gold standard for the diagnosis of osteomalacia. Further research is needed to identify a biomarker that may enable the clinician to diagnosis and treat osteomalacia well in time.

Keywords Osteomalacia · Osteoporotic hip fracture · Vitamin D deficiency · Bone mineral density · Bone health

Introduction

Osteomalacia is characterized by defective or delayed bone mineralization [1] resulting in low bone mineral density (BMD). It is mainly due to Vitamin D deficiency [2] (VDD) and is widely prevalent in countries such as India where majority of population receives suboptimal nutrition [3]. High prevalence of VDD has been reported in healthy Indian subjects among all age groups [4]. This includes both urban and semi-urban Indians, postmenopausal women, pregnant
women, school children and newborns [5, 6]. A prospective observational study was carried out from July 2006 to March 2008 by Khadgawat et al [7] on Indian patients with osteoporotic hip fractures. The authors reported all patients (n = 43) except one had VDD.

Another metabolic disease common in India is osteoporosis. In 2013, around 50 million people in India were reported to have osteoporosis [8]. Fractures of femur neck and intertrochanter region were the most commonly reported osteoporotic fractures and add significant health burden [9]. Various studies have documented that osteomalacia and osteoporosis coexist especially in elderly population [10, 11].

Identification of osteomalacia is a challenging situation especially if it coexists in the setting of osteoporosis. The symptoms, such as bone pain, decreased bone radio-density and increased risk of bone fractures mimic each other [12]. Secondly, for diagnosis of osteomalacia, blood tests alone are not sufficient [13], and the gold standard is bone histopathology [14]. Indeed, identification of osteomalacia cannot be overemphasised especially in patients with fracture because correction of osteomalacia component promotes fracture healing [15, 16]. Yet the orthopaedic community do not stress on identification of osteomalacia despite its significance. The aim of this study was to identify the coexistence of osteomalacia in osteoporotic hip fracture patients in more than 50 years age group.

Methods

Patient Selection

This was a prospective study conducted at Level 1 trauma centre in North India done in July 2015 to June 2016. Patients 50 years or above of either sex, who presented to the orthopaedics department with hip fractures, i.e., fracture neck of femur and intertrochanteric having a t score of less than −2.5 based on DEXA scan was considered for the study. Prior institutional clearance was obtained from IRB (institutional review board) vide infra: NK/2255/MS/10823-24.

Histopathological Examination

Samples for histopathology were collected at the time of operation from the affected site and adjoining area of the size of around 1 cm in separate vials containing absolute alcohol. All biopsies were processed as such without decalcification after overnight fixation. Sections of 3- to 5-micron thickness were stained with routinely with H&E, toluidine blue at pH 2.8, elastic von Gieson, Masson’s trichrome and Solochrome cyanine R. Biopsies were assessed by (a) studying overall contour of bony trabeculae, i.e., normal thickness or thinning of trabeculae. If thinning of the trabeculae was observed, grading as mild, moderate, or gross/extensive was done subjectively and also extent of involvement of the bony areas, i.e., focal/patchy or diffuse/extensive was documented. (b) Reduced calcification of the bony trabeculae was graded into mild, moderate and severe. Comments were also made for non-calciﬁed osteoid front of bony trabeculae, osteoblastic and osteoclast giant cells, inter-trabecular areas for ﬁbrosis and granulation tissue. A biopsy showing mainly collagenised tissue was not graded. Histological parameters were interpreted in context to normal bone section obtained along the resection margins of limb amputation for fresh traumatic injury or malignancy.
Statistical Analysis

The investigation parameters were analysed by statistical software SPSS 22.0 version. Mean and standard deviation of variables were calculated, and the correlation to histopathology was done using Pearson’s correlation method. Statistical significance was set at \( p < 0.05 \). For the calculation of sample size, we used statistical formula. In the previous studies, prevalence of osteomalacia in osteoporotic hip fractures among more than 50 years age of population was from 30 to 65% [10, 11]. In the current study, we recruited 45 patients (sample size using below formula was 42.68) assuming that prevalence of osteomalacia in osteoporotic hip fractures among more than 50 years age of population as 50% at our setting and absolute precision as 15% with 95% confidence interval.

\[
n_0 = \frac{(1.96)^2 PQ}{D^2}.
\]

Here \( n_0 \) is the sample size, \( P \) is the prevalence of osteomalacia in osteoporotic hip fractures among more than 50 years age population, i.e., 50% = 0.50, \( Q = 1 - P = 1 - 0.50 = 0.50 \), \( D \) is the Absolute precision, i.e., 15% = 0.15.

Results

A total of 45 patients was included in the study. The demographic and fracture characteristics are shown in Table 1. 84.4% patients (\( n = 38 \)) sustained fracture at home with fall/slip in the bathroom or wet floor. As per dietary habits, 75.6% patients (\( n = 34 \)) were vegetarian and 24.4% (\( n = 11 \)) were non-vegetarian. 13.3% patients (\( n = 6 \)) were smokers and 20% patients (\( n = 9 \)) were chronic alcoholic. Only 42.2% patients (\( n = 19 \)) had history of sufficient sunlight exposure. No patients were family history of congenital or genetic disorders. Among co-morbidities 64.4% patients (\( n = 29 \)) were hypertensive while 40% (\( n = 18 \)) were diabetic. Mean BMD value at spine was 0.700 ± 0.148 g/cm\(^2\) and mean value at hip was 0.594 ± 0.156 g/cm\(^2\). 4 (8.9%) patients were presented with a history of calcium and vitamin D supplements and 7 (15.6%) patients were history of previous osteoporotic fracture, but not on anti-resorptive medications like bisphosphonates.

Low values of serum calcium, phosphate, Ca × PO\(_4\) product and Vitamin D was found in 44.4% (\( n = 20 \)), 22.2% (\( n = 10 \)), 42.2% (\( n = 19 \)) and 53.3% (\( n = 24 \)) patients, respectively. Serum ALP level found high in 53.3% (\( n = 24 \)) patients (Table 2).

Osteomalacia was established on histopathological analysis in 30/41 (73.2%) cases, of these, 3/30 (10%) cases had mild, 8/30 (26.7%) cases had moderate and rest 19/30 (63.3%) cases had severe osteomalacia (Fig. 1). 4 cases biopsy specimen showed dead or fibrous tissues.

For correlation, we excluded those four cases and the histopathological and biochemical correlation was obtained for the remaining 41 patients (Table 3). No significant correlation was found with serum biochemical markers except with serum Vitamin D (\( p \) value = 0.004) (Fig. 2). Out of 29/41 (70.7%) intertrochanteric fractures patients, osteomalacia were established in 22 (53.6%) patients while patients with neck femur fractures (\( n = 12 \); 29.3%), osteomalacia were established histopathologically in 8 (19.5%) patients. Amongst 78.1% vegetarian patients (\( n = 32 \)), 63.4% patients (\( n = 26 \)) had osteomalacia. (\( p = 0.042 \)) and amongst 56.1% female patients (\( n = 23 \), 46.3% patients (\( n = 19 \)) had osteomalacia (\( p = 0.164 \)).

Discussion

Osteomalacia is defined as defective mineralization of bone matrix. The main cause of osteomalacia is vitamin D deficiency that can be due to nutritional deficiency, reduced cutaneous production, malabsorption, chronic liver diseases and long-term anticonvulsive therapy [18]. Several studies have showed that bone mineral density (BMD) is markedly reduced in osteomalacia bone [19, 20] and display similar clinical features, such as bone pain, decreased bone radio density and increased risk of bone fractures, as seen in osteoporosis. Histopathological diagnosis is essential to

<table>
<thead>
<tr>
<th>Type of fracture</th>
<th>H/O previous osteoporotic fractures</th>
<th>H/O calcium and vitamin D supplementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intertrochanteric fracture</td>
<td>7 (15.6%)</td>
<td>4 (8.9%)</td>
</tr>
<tr>
<td>Neck of femur</td>
<td>29/41 (70.7%)</td>
<td>22/29 (75.9%)</td>
</tr>
</tbody>
</table>

Table 1 Patients demographic data and fracture characteristics

| Total no. of patients | 45 |
| Mean age | 68.7 ± 8.5 years (53–85 year) |
| Mean BMI | 21.7 ± 3.2 kg/m\(^2\) |
| Sex | Male 20 (44.4%) Female 25 (55.6%) |
| Type of fracture | Neck of femur Intertrochanteric fracture |
| Sid of fracture | Left 28 (62.2%) Right 17 (37.8%) |
| Dietary habits | Vegetarian 34 (75.6%) Non-vegetarian 11 (24.4%) |
| H/O calcium and vitamin D supplementation | 4 (8.9%) |

\(^a\)Intertrochanteric fracture
\(^b\)Neck of femur
differentiate between osteoporosis and osteomalacia because no other single blood screening test is sufficient for establishing the diagnosis. In our study, osteomalacia was established in 30 out of 41 cases (73.2%). Tucker et al. [10] in 1988 found that amongst osteoporotic hip fractures, osteomalacia was found in 65.4% (n = 17/26) patients. Another study by Hordon et al. [11] showed that overall 12% (n = 9/72) prevalence of osteomalacia in elderly femoral neck fracture patients. Several other studies also showed the presence of osteomalacia in bone biopsies from proximal femur fracture patients [21, 22].

Serum calcium and vitamin D level plays an important role in finding out status of bone health [23]. Serum 25 [OH] D levels is most practical and widely used parameter to assess vitamin D status of an individual. There is no generally accepted criteria on optimal levels of serum 25[OH] D level, VDD is defined [2] as serum vitamin D level < 20 ng/ml. Using this cutoff value, we found 80% patients had VDD, and we found 53.3% patients below 10 ng/ml (severe VDD). A study by Peacey et al. [13] reported that relying solely on routine biochemical laboratory tests like serum calcium, phosphate and alkaline phosphatase can lead to missed diagnosis of osteomalacia in about 20% of cases. In our study, low level of serum calcium, serum phosphorus and Ca x P product was found in 44.4%, 22.2% and 42.2% patients, respectively. Raised level of serum ALP was found in 53.3% patients.

The majority of patient’s dietary habits were vegetarian and amongst female patients, many were post-menopausal. Body weight, age, menopause and calcium intake are important determinants of BMD and healthy lifestyle (such as diet, exercise and sunlight exposure) plays an important role [24]. Adequate intake of calcium and vitamin D increases bone mass and prevents long-term fracture risk in postmenopausal women [25]. Only 8.9% of our study patients were taking regular vitamin D and calcium supplementation at the time of sustaining hip fracture.

The treatment approach for patients suffering from these two similar types of metabolic bone diseases is different. Osteoporosis treatment mainly aims about removing all risk factors, supplementing vitamin D3 (600-800 IU/day), calcium (dietary calcium 1200 mg/day) and anti-resorptive therapy [26]. The main aim of osteoporosis treatment is decreasing fracture risk, which can be achieved by bisphosphonates, anti-resorptive drugs so these called gold standard for treating osteoporosis [27]. However, management of osteomalacia involves giving vitamin D3 and calcium for at least 1 or 2 years [28]. It is noted that with proper treatment of osteomalacia, normalization of BMD of vertebrae and hip is expected to be reached in up to 12 months [29]. Some studies suggest that increasing doses of Vitamin D for treatment of patients with osteoporosis [23, 28, 30], is also useful for accompanying some cases of subclinical osteomalacia.

Our study is not without its share of limitations. We do not have a very large sample size, so it may not truly be a reflection of actual incidence of whole Indian population, besides we did not study for any relevant haematological markers of bone formation and resorption.

<table>
<thead>
<tr>
<th>Biochemical markers</th>
<th>Number of patients</th>
<th>Mean ± SD</th>
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<tr>
<td>Serum calcium (8.8–10.2 mg/dl)</td>
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<tr>
<td>Normal/high</td>
<td>25 (55.6%)</td>
<td>8.7 ± 0.45 mg/dl</td>
</tr>
<tr>
<td>Low</td>
<td>20 (44.4%)</td>
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<tr>
<td>Serum phosphorus (2.7–4.5 mg/dl)</td>
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<tr>
<td>Normal/high</td>
<td>35 (77.8%)</td>
<td>3.2 ± 0.56 mg/dl</td>
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<tr>
<td>Low</td>
<td>10 (22.2%)</td>
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<tr>
<td>Serum ALPb (42–128 U/L)</td>
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<tr>
<td>Normal</td>
<td>21 (46.7%)</td>
<td>133.6 ± 49.97 U/L</td>
</tr>
<tr>
<td>High</td>
<td>24 (53.3%)</td>
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<tr>
<td>Ca x P product (27–32 mg/dl)</td>
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<tr>
<td>Normal/high</td>
<td>26 (57.8%)</td>
<td>28.45 ± 5.59 mg/dl</td>
</tr>
<tr>
<td>Low</td>
<td>19 (42.2%)</td>
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<tr>
<td>Corrected calcium (8.8–10.2 mg/dl)</td>
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<tr>
<td>Normal/high</td>
<td>25 (55.6%)</td>
<td>9.2 ± 0.67 mg/dl</td>
</tr>
<tr>
<td>Low</td>
<td>20 (44.4%)</td>
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<tr>
<td>Serum vitamin D (10.0–42.9 ng/ml)</td>
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<tr>
<td>Normal/high</td>
<td>21 (46.7%)</td>
<td>13.23 ± 9.64 ng/ml</td>
</tr>
<tr>
<td>Low</td>
<td>24 (53.3%)</td>
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</table>

*a* Standard deviation

*b* Alkaline phosphate
Conclusion

Based on our study findings, we can say that in most of osteoporotic hip fracture patients, osteomalacia can coexist. Bone histopathology is gold standard to determine the presence of osteomalacia but is impractical especially if we are looking to screen the patient or if patient does not suffer from fracture. Biochemical findings may not give true picture of the disease so there is need to identify a biomarker or panel of markers that may correlate well with osteomalacia so that clinicians can screen, diagnose and provide adequate treatment of osteomalacia well in time before major fracture occurs.
**Table 3** Correlation of biochemical markers and histopathology in 41 patients

<table>
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<th>Variables</th>
<th>No. of patients</th>
<th>Histopathology</th>
<th>p value</th>
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<td></td>
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<td>Osteomalacia</td>
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<tr>
<td>Serum calcium</td>
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<tr>
<td>Normal/high</td>
<td>23 (56.1%)</td>
<td>8 (19.5%)</td>
<td>15 (36.6%)</td>
</tr>
<tr>
<td>Low</td>
<td>18 (43.9%)</td>
<td>3 (7.3%)</td>
<td>15 (36.6%)</td>
</tr>
<tr>
<td>Serum phosphorus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal/high</td>
<td>33 (80.5%)</td>
<td>9 (21.8%)</td>
<td>24 (58.5%)</td>
</tr>
<tr>
<td>Low</td>
<td>8 (19.5%)</td>
<td>2 (4.9%)</td>
<td>6 (14.6%)</td>
</tr>
<tr>
<td>Serum P ALPa</td>
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<td></td>
</tr>
<tr>
<td>Normal</td>
<td>21 (51.2%)</td>
<td>3 (7.3%)</td>
<td>18 (43.9%)</td>
</tr>
<tr>
<td>High</td>
<td>20 (48.8%)</td>
<td>8 (19.5%)</td>
<td>12 (29.3%)</td>
</tr>
<tr>
<td>Corrected calcium</td>
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<tr>
<td>Normal/high</td>
<td>23 (56.1%)</td>
<td>7 (17.1%)</td>
<td>16 (39.0%)</td>
</tr>
<tr>
<td>Low</td>
<td>18 (43.9%)</td>
<td>4 (9.7%)</td>
<td>14 (34.2%)</td>
</tr>
<tr>
<td>Serum vitamin D</td>
<td></td>
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</tr>
<tr>
<td>Normal/high</td>
<td>22 (53.7%)</td>
<td>10 (24.4%)</td>
<td>12 (29.3%)</td>
</tr>
<tr>
<td>Low</td>
<td>19 (46.3%)</td>
<td>1 (2.4%)</td>
<td>18 (43.9%)</td>
</tr>
<tr>
<td>Ca × P product</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal/high</td>
<td>26 (63.4%)</td>
<td>8 (19.5%)</td>
<td>18 (43.9%)</td>
</tr>
<tr>
<td>Low</td>
<td>15 (36.6%)</td>
<td>3 (7.3%)</td>
<td>12 (29.3%)</td>
</tr>
</tbody>
</table>

*a Alkaline phosphate, significant p value < 0.05

**Fig. 2** Correlation between serum vitamin D values and histopathology grading (1—Normal, 2—mild, 3—moderate and severe)

**Funding** None.

**Compliance with Ethical Standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical standard statement** This article does not contain any studies with human or animal subjects performed by the any of the authors.

**Informed consent** For this type of study informed consent is not required.

**References**


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Treatment of Traumatic Femoral Neck Fractures with an Intramedullary Nail in Osteoporotic Bones

Tim Friedrich Raven\textsuperscript{1} · Wilhelm Friedl\textsuperscript{2} · Arash Moghaddam\textsuperscript{1}

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Abstract

\textbf{Purpose} Sufficient anchoring of intramedullary osteosynthesis in the femoral head in a femoral neck fracture is a challenge with increasing age of the patients and decreasing bone quality. For older patients with inferior bone quality, it has not been investigated whether the application of an intramedullary force carrier, as a minimally invasive and rapid intervention, can provide a considerable benefit and reduce the postoperative complication and lethality rate. This retrospective study aimed to investigate the stability and functionality after the acute treatment of a femoral neck fracture in osteoporotic bone using an intramedullary force carrier even with higher grade fracture types.

\textbf{Material and Methods} The retrospective analysis was based on a collective of 82 patients over 60 years of age with a femoral neck fracture treated with a gliding nail in our centre between 1999 and 2006.

\textbf{Results} The average time to follow-up was 69.05 months (median 71.0; minimum 27.0–maximum 108.0). Female patients made up more than two-thirds of the patient collective at 63 of the 82 patients (76.83%). The average age of the patients was 77.76 years (median 78.00; range 60.00–93.00).

In 66 patients (80.49%), the implantation showed good results and no complications or further treatments. 24/82 patients of our collective had died in our re-evaluation. In no case, a pseudarthrosis or severe impaction with neck shortening occurred (loss of offset).

11/82 patients had femoral head necrosis which led to total hip replacement in 8 cases, a hemiarthroplasty in 2 cases and in 1 case a remaining Girdlestone situation because of a deep infection. Another five patients also had to undergo a total hip replacement because of a central perforation of the blade in one case, breakout of the blade after another fall in another two cases and a lateral dislocation of the blade in two cases.

\textbf{Conclusion} The use of an intramedullary force carrier in the osteoporotic bone can mean distinct advantages for the selected patient as a minimally invasive and rapid surgical method compared to extensive surgery, even in the case of severe injuries. However, the advantages and disadvantages for the patient should be considered critically.

\textbf{Keywords} Gliding nail · Intramedullary nail · Femur nail · Osteoporosis · Femoral neck fracture · Femoral neck nail

\section*{Introduction}

Femoral neck fracture is one of the most common fractures in older people, with an incidence of around 100,000 per year in Germany, and approximately 30\% of all the women are affected [1, 2]. Due to an increase in the elderly population, there is an associated increase in osteoporosis and subsequent loss of stability in the proximal femur, hence, this injury will increase in importance in the coming years [3–5].

To the best of our knowledge, femoral neck fracture has always been one of the most problematic fractures; therefore, research is continuously focused on its adequate therapy. The goal of such therapy is a fast, load-bearing, anatomical...
restoration of hip joint functionality, as well as early mobilisation to avoid immobility and the consecutively increasing risk of further illness. Even though there are modern treatment methods, postoperative complications are still prevalent, and there still remains an applicable rate of postoperative mortality which increases with any delay in the operative treatment [6–11]. For this reason, within the quality management criteria in Germany there is a recommendation that a patient who is to receive treatment with osteosynthesis should be operated on within the first 24 h.

It was already demonstrated in the past century that the correct surgical therapy is superior to non-operative therapy for proximal complex fractures of the femur [12–15]. There is a consensus that less displaced fractures and femoral neck fractures with less displacement in younger patients and patients with a high activity level should receive treatment with osteosynthesis, while preserving the head. In recent decades, various implants have been developed and continuously improved upon for this purpose. Noteworthy implants in recent years are dynamic hip screws (DHSs) and intramedullary implants with neck screws [16–20] and these have been established as effective and safe implants for the treatment of femoral neck fractures. However, complications are also known regarding these implants; e.g. femoral head necrosis, non-unions, and displacements, as well as implant-specific and biomechanical complications.

Alternatively, as early as 1992, the gliding nail (GN) with the unique feature of an impacting blade was introduced as an intramedullary top weighting arm with increased surface area and rotational stability using a double-T cutting edge. The advantages of a higher load capacity, combined with higher rotational stability and a lower cut-out rate than the gamma nail, should lead to the optimal treatment of patients and a lower postoperative rate of complications and mortality [21]. This advantage of the gliding nail has already been demonstrated in per- and subtrochanteric fractures and in experimental settings [21, 22].

For this reason, the following questions arise: (1) can the indication for the use of an implant, with such high rotational stability and impact, also be extended to the femoral neck fracture in older patients and osteoporotic bone after individual consideration; (2) what outcome can be expected?

Patients and Methods

82 patients over 60 years of age with a femoral neck fracture were treated with a gliding nail in our centre between 1999 and 2006 and they were eligible for inclusion in this retrospective study. The re-examination was in 2008. The average time of follow-up was 69.05 months (median 71.0; minimum 27.0–maximum 108.0). Out of 82 patients, 63 were female thus constituting the majority portion of the patient collective (76.83%). The average age of the patients was 77.76 years (median 78.00; range 60.00–93.00). Of the total data, parts were previously published in 2005 during an earlier study [23].

Criteria for Inclusion

Criteria for inclusion in the study were the following: all patients over 60 years of age who were treated with an intramedullary nail with Garden I and II fractures; as well as Garden III and IV fractures [24, 25]. Patients with cervical base fractures, lateral femoral neck fractures, and femoral neck non-unions were also included. Patients who had contraindications against a therapy to preserve the femoral head via treatment with osteosynthesis were not included. All patients were asked for their permission regarding the evaluation of their data, and they all gave their approval. All data were archived anonymously.

Indication

In our trauma centre, patients over 65 years of age, or elderly patients having an assessment of their biological age, receive surgical treatment for a femoral neck fracture according to their individual injury, their individual state of health, and their activity level. Usually, active elderly patients with a non- or slightly displaced fracture were treated with osteosynthesis. Elderly patients with a displaced fracture were usually treated with a hemi- or total endoprosthesis. If the patient is at the age limit or biologically younger (i.e. very good general condition, few previous illnesses, and good mobility), in some cases we also use the intramedullary nail for impacted and non-displaced medial femoral neck fractures (Garden I and II). In the case of a non-active patient in combination with a displaced medial femoral neck fracture (Garden III and IV), we use the intramedullary nail only as a stabilising operation if a major operation, such as implantation of a prosthesis, would be detrimental to a patient’s health or the surgical risk is too high; so that stability in the bone is achieved and the patient can be properly positioned and provided with healthcare.

Data Evaluation and Ethical Approval

Data evaluation in 2008 was performed based on collected patient data, such as medical history, imaging results, anaesthesia protocols, surgery reports, nurse reports, physiotherapy protocols, and the corresponding admission notes. Patients were also contacted after treatment and asked to participate in a standardised questionnaire which included questions about their daily life activities, pain, mobility, other operations, or medication.
Due to the international usage of these systems, fractures were classified according to Garden [24, 25] and Pauwels [26]. Displacement in the frontal and sagittal plane was evaluated using deep pelvis radiography and axial hip radiography. A supplementary CT scan was only necessary in a few cases.

This study was approved by the Ethics Committee of the Medical Faculty at the University of Heidelberg, Germany. Hence, the study was approved by the review board and conducted according to the review board guidelines and within the bounds of good clinical practice, according to the ethical principles that have their origin in the Declaration of Helsinki in its current form. As aforementioned, all patients were asked for permission for evaluation of their data, and they all gave their approval. All data were archived anonymously. Data analyses were performed using IBM SPSS® Statistics 25.

Implants Used

The gliding nail (GN) is an implant that combines: (1) the advantages of the locking nail system and the flap gliding principle, and (2) the dynamisation in the thighward direction as well as in the direction of the femoral shaft, with (3) the advantages of the double-T profile of the femoral neck load bearer (Figs. 1a, b, 2). The double-T profile of the blade has the highest moment of resistance for a given cross-sectional area (Fig. 2). Further, the rotation of the head-neck fragment with a screw breakout from the cranial fragment is effectively prevented by the double-T profile of the blade design; in that, a rotation of the proximal fragment around the blade is not possible. A further decisive advantage is that the blade, in a similar manner to a nail, is driven into the bone. This results in additional bone impaction and thus there is no loss of bone substance in a similar manner to local spongiosaplasty.

Postoperative Rehabilitation Protocol

On the first day after the surgery, physiotherapy under full load was started for all patients with a Garden I or II fracture. According to the current therapy recommendation of a relief in displaced femoral neck fracture in younger patients, we also recommend a temporary partial load of 20 kg in the first 6 weeks for patients with Garden III and IV fractures. Complete healthcare and bedding were permitted for those patients requiring comprehensive nursing care.

Results

Fracture and Age Distribution

In our collective of 82 patients, the mean age of patients was 77.76 years (median 78.00, range 60.00–93.00); as aforementioned, female patients made up the majority of the collective with 63 out of a total of 82 patients. We divided our collective into three groups based on their injuries: group A corresponds to Garden I and II (Pauwels 1/2) fractures, group B corresponds to Garden III and IV (Pauwels 2/3), and group C corresponds to base cervical/lateral femoral neck fractures. Distribution of patients in the groups was as follows: group A included 69 patients with an average age of 77.64 years (median 78.00, range 62.00–93.00), of whom 14 were male and 55 were female. Group B consisted of eight patients with an average age of 75.38 years (median 76.50, range 60.00–92.00) and gender distribution of three men and five women. Group C consisted of five patients with an average age of 83.20 years (median 83.00, range 77.00–90.00) and gender
distribution of two men and three women. The characteristics of the collective are provided in Tables 1 and 2.

Complications

In 66 patients (80.49%), the implantation showed good results and no complications or further treatments. In none of the cases, a pseudarthrosis or severe impaction with neck shortening had been detected (i.e. loss of offset). 24/82 patients of our collective had died, according to our re-evaluation in 2008.

11/82 patients had femoral head necrosis which led to total hip replacement in 8 cases, a hemiarthroplasty in 2 cases, and in 1 case a remaining Girdlestone situation because of a deep infection.

Another five patients also had to undergo a total hip replacement because of a central perforation of the blade in one case, breakout of the blade after another fall in another two cases, and a lateral displacement of the blade in two cases.

Regarding the three individual groups, the following distribution was observed:

In group A, 21/69 patients (30.4%) had died; 9/69 patients developed femoral head necrosis, which led to a total hip replacement in 8 cases and a hemiarthroplasty in 1 case; 3 further patients also had to undergo total hip replacement, 1 patient because of a breakout after a new fall and 2 patients because of a lateral blade displacement.

In group B, 1/8 patients (12.5%) had died; 2/8 patients developed a femoral head necrosis, which led to a hemiarthroplasty in one case and one further patient was left with a Girdlestone situation because of a deep infection after an arthroplasty was attempted; one patient received a total hip replacement because of a breakout of the blade after another fall.

In group C, 2/5 (40%) patients had died at the time of follow-up; one patient required a total hip replacement due to a central blade perforation.

Detailed characteristics are given in Table 3 and Fig. 3.

Discussion

Medial femoral neck fractures have always been problematic. The general medical consensus is to conserve the femoral head, in the case of impacted and non-displaced medial femoral neck fractures (Garden I and II) as well as displaced medial femoral neck fractures in younger patients. Non-displaced fractures of the elderly can be treated in individual cases with head-preserving therapy whereas an intramedullary treatment for older patients with displaced fractures is not recommended by some authors [27–29]. It is recommended by some authors that an endoprosthetic restoration should, not only be sought at some stage for fractures of the femoral neck of a higher degree, but that this should actually occur right from the start.

As early as 2002, McKinley et al. were able to show that patients with primary endoprosthetic treatment had a better outcome than patients who had undergone joint conserving surgery and subsequently received endoprosthetic replacement [30]. Osteosynthesis is not recommended and especially if the patient is already suffering from severe osteoarthritis. After an endoprosthetic restoration, the patient can be fully loaded again after a brief time and can also be fully mobilised. This makes it easier to prevent subsequent complications such as pneumonia or a similar condition.

However, there are also borderline cases in which a comprehensive intervention with prolonged anaesthetic guidance and increased blood loss must be critically evaluated. This raises the question of whether the use of an intramedullary force carrier such as the gliding nail (GN) can create a better perioperative outcome for the patient. The gliding nail (GN) is an implant that can be inserted quickly and with minimum invasion. The operation has a significantly lower blood loss than an endoprosthetic replacement operation and even after this the patient can again fully load. It must also be taken into account that there are frail patients who have already undergone nursing case before their injury or who

### Table 1 Fractures and age distribution

<table>
<thead>
<tr>
<th>Patients</th>
<th>Age</th>
<th>Female</th>
<th>Male</th>
<th>Died</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
<td>77.76 (78; 60–93)</td>
<td>63</td>
<td>19</td>
<td>24</td>
</tr>
</tbody>
</table>

### Table 2 Group distribution

<table>
<thead>
<tr>
<th>Type</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garden I and II</td>
<td>69</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Garden III and IV</td>
<td>77.64 (78; 62–93)</td>
<td>75.38 (77; 60–92)</td>
<td>83.20 (83; 77–90)</td>
</tr>
<tr>
<td>Cervical base and lateral femoral neck fractures</td>
<td>55</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Died</td>
<td>21</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 3 Complications

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck necrosis in general</td>
<td>9</td>
<td>2</td>
<td>–</td>
</tr>
<tr>
<td>Total hip arthroplasty</td>
<td>11</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hemi hip arthroplasty</td>
<td>1</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>Lateral dislocation of the blade</td>
<td>2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Central perforation of the blade</td>
<td>–</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>Breakout after fall</td>
<td>1</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>Girdlestone</td>
<td>–</td>
<td>1</td>
<td>–</td>
</tr>
</tbody>
</table>
have only been able to lie in bed. For these patients, it may be favourable to have a smaller and rapid intervention for the perioperative outcome, rather than an extensive endoprosthetic treatment, hence the patients can be safely positioned and cared for again.

Generally, the use of an intramedullary implant, firm fracture impaction, tilting of the femoral head, and implant breakouts have led to a high rate of implant failure rates of up to 30% [31]. Furthermore, 10–15% of cases develop femoral head necrosis or non-union, caused by the initial damage to the vascularisation, perhaps also because the instability of the osteosynthesis [32, 33]. Those cases can be recognised by the often very strong impaction with protruding screw heads and corresponding high bone resorption in the fracture zone.

Our results show that the majority of fractures that are treated with a GN, heal without complications (see Figs. 4a, b, 5a–d). None of the cases has a pseudarthrosis or severe impaction with neck shortening occurred (i.e. loss of offset). The overall rate of the secondary prosthesis was 15/82 in total (18.29%). But, prosthesis implantations after another fall were also counted (2 patients), but this should not be considered as implant failure.

Dividing information into the three collectives has shown that 12/69 of patients in group A, 2/8 of patients in group B, and 1/5 patients (20.0%) in group C required hip replacements.

However, if we take a closer look at the corresponding prosthetic indications, it can be seen that there is a significantly lower number of femoral head necrosis cases in our collective than in the comparative literature [31–34]. The main indication for hip replacement in group A was femoral head necrosis in nine cases. Three further patients also had to undergo total hip replacement, one patient because of a breakout after a new fall and two patients because of a lateral blade displacement. Our results show an overall rate of femoral head necrosis of 9/69 in group A (13.04%) and 1/8 in group B (12.5%). Lu-Yao et al. describe a non-union rate of 33% and a rate of femoral head necrosis of 16% in the results of their meta-analysis of displaced femoral neck fractures [34].

In group C, 1/5 patients required a total hip replacement due to a central blade perforation. Similarly, the other authors also note 10–20% of avascular femoral head necrosis cases after displaced femoral neck fractures [32, 33]. Some authors even note <30% of femoral head necrosis cases [31].
Regarding our collective, we also recorded avascular necrosis—the incidence is lower than the risk described by the other authors; but the small collective of group B must be taken into account. This also reflects the consensus to treat higher grade femoral neck fractures with a prosthetic device.

To prevent femoral head necrosis, a fast operation within the “6-h window”, as an emergency operation in younger patients with a displaced fracture, is recommended; if it is not possible to treat a patient within 6 h or at least within 24 h, an endoprosthetic treatment is also recommended [6–8, 35–37].

An operative treatment and an urgent operation according to the above criteria will not only improve the local outcome of the fracture but will also lower the in-hospital mortality of the patients and the postoperative mortality, in general, as the other authors have shown in their respective studies [15, 38].

Our collective showed a total complication rate of 12/69 (17.4%) for fracture healing and fracture stabilisation in group A. Group B showed a total complication rate of 3/8 (37.5%). The size of the collective, especially regarding group B, is also a limiting factor here. Eschler et al. reported a “Cut-Out” (i.e. femoro-acetabular penetration) in 8 patients (32%) treated with a DHS and 4 patients (15%) treated with a Targon®-FN in a study of 52 patients [39]. In our collective, none of the patients showed signs of a typical “Cut-Out.”

Using a very stable implant, such as the GN, which allows an impaction of the fracture while eliminating rotational movements, which minimises the risk of breakout, results in a lower rate of complication in the femoral head, thus conserving treatment of medial femoral neck fractures. The danger of femoral head necrosis is not only dependent on the age of the patient and the resulting remaining vascularity and bone quality, but also is also especially dependent on trauma-induced damage. In our collective, group A had an incidence of femoral head necrosis of 9/69, compared to 1/8 in group B. Sometimes it is stated that medial femoral neck fractures are nothing but a sign of physical deterioration. Since our data show that patients over 60 years of age also develop femoral head necrosis in cases of a simple, non-displaced fracture, there must be various influencing factors. The solid, rotation-free fracture retention of the GN enables a revitalisation of the femoral head, and even in patients with vascularisation damage caused by the fracture.

Generally, a low rate of complication and early fully load-bearing treatment should be the goal. Moreover, older patients often have a significant number of additional risk factors, often due to pre-existing comorbidities, all of which affect outcome and postoperative mortality [40]. Medial femoral neck fractures should only be treated with an osteosynthesis in the case of fracture impaction, non-displacement, and younger patients. In older patients with a higher grade of displacement, in general, treatment with osteosynthesis is not recommended; the other authors agree [27]. However, the advantages and disadvantages for the patient should be critically considered. Thus, the life situation before the fracture event, as well as the individual state of health and the associated surgical risk, must be taken into account. Therefore, every decision should take into account not only the risk of the operation but also the risk of postoperative complications and, as aforementioned, the risk of the care of these.

**Strengths and Limitations**

One strength of this study is the detailed clinical documentation and data collection as well as the large size of the patient collective. However, a small number of patients in the individual groups can be considered a weakness. Other weaknesses of the study are a missing prospective collective...
for comparison, the single-centre study, and the retrospective design.

Conclusion

The treatment of displaced medial femoral neck fractures in older patients is generally the domain of treatment with endoprosthesis. However, there are also borderline indications where rapid, minimally invasive surgery is required to stabilise the fracture.

The use of a very stable implant, such as the GN, which enables impaction of the fracture with the elimination of rotational movements and minimises the risk of an outbreak, leads to a lower complication rate in the femoral head and thus to gentle treatment of medial femoral neck fractures. The GN is a safe, easy-to-use implant with a low perioperative lethality that provides a major benefit to patients in the treatment of femoral neck fractures. However, its application must be critically considered and the individual risk and benefit of each patient must be taken into account.

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Author Contributions All the authors, TFR, WF and AM, declare that they have made a substantial contribution to the collection of data, the evaluation and the preparation of the manuscript.

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Compliance with Ethical Standards

Conflict of interest Dr. med. Tim Friedrich Raven and Prof. Dr. Arash Moghaddam declare that they have no conflict of interest. The presentation of the topic is independent and the presentation of the contents product-neutral. One of the authors. Prof. Dr. med. Dr. h.c. mult. Wilhelm Friedl, is the inventor of the gliding nail and works as a development consultant for Intercus GmbH.

Ethics approval This study was approved by the Ethics Committee of the medical faculty Heidelberg. Hence, the study was approved by the review board and conducted according to the guidelines of the review board and within the bounds of good clinical practice according to the ethical principles that have their origin in the Declaration of Helsinki in its current form.

Consent to participate All the patients were asked for permission for data evaluation and they gave their approval. All data were archived anonymously.

Consent for publication All the patients were asked for permission for data evaluation and they gave their approval. All data were archived anonymously.

Availability of data and material All data were archived anonymously.

Code availability Not applicable.

References


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The Cost and Consequences of Failed Osteosynthesis of Intertrochanteric Femur Fractures: A Matched Cohort Study

Erdi Özdemir1 · Mustafa Caner Okkaoglu1 · Ali Teoman Evren1 · Yuksel Ugur Yaradilmis1 · Ahmet Ates1 · Murat Altay1

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Abstract
Background  We aimed to evaluate the cost and consequences of failed osteosynthesis of intertrochanteric femur fracture (ITFF) patients and compare with primary ITFF patients.
Methods  We retrospectively evaluated 689 patients who underwent surgery due to ITFF via cephalomedullary nail. 31 patients (5.8%) had revision surgery because of osteosynthesis failure of ITFF. Each revision case included in the study was matched with four primary ITFF cases as control group based on age, gender, year of operation, type of fracture and American Society of Anesthesiologists (ASA) grade. Total cost for the admission that patients underwent surgery, mortality rate at first year, infection rate, length of stay at hospital, length of stay at intensive care unit, and erythrocyte transfusion amounts were recorded from hospital registry records. Tip apex distances (TAD) were noted.
Results  The mean total cost of the revision cases and primary cases was 10,027 ± 6387 and 5261 ± 1773 Turkish Liras, respectively (p < 0.001). TAD was ≥ 20 mm in 32.3% (10/31) of patients in revision group while 2.4% (3/124) of the patients in control group (p < 0.001). The mean length of stay at hospital, length of stay at intensive care unit, erythrocyte transfusion amounts, infection rate and mortality rate at first year were significantly higher in revision cases compared to matched primary control cases (p < 0.05).
Conclusion  Revision surgeries due to failed osteosynthesis of ITFFs with cephalomedullary nail have at least two times higher mean total cost than primary cases. The awareness of the cost, morbidity and mortality of the revision surgeries may reduce the modifiable risk factors of osteosynthesis failure including maintenance of TAD below 20 mm, obtaining optimal lag screw position and reduction quality.
Level of Evidence  Level 3, retrospective cohort study.

Keywords  Cost · Morbidity · Mortality · Intertrochanteric femur fracture · Revision

Introduction

Osteoporotic hip fracture in the elderly population is a common injury with a reported annual incidence of 1.6 million in worldwide [1, 2]. Approximately, 45% of these fractures are intertrochanteric femur fractures (ITFF) [1]. The optimal treatment method for the ITFF remains controversial [3]. Most of the ITFF could be treated with osteosynthesis utilizing dynamic hip screws or cephalomedullary nails. In the recent literature, osteosynthesis with cephalomedullary nail has been intensively used in the treatment of ITFF [4]. Failure of osteosynthesis of ITFF following treatment with cephalomedullary nail is an important concern for orthopedic surgeons since it could lead to severe morbidities for the patients [5].

Failure rate of osteosynthesis of ITFF has been reported 4.7–8% in the literature [5, 6]. Although the cost and complications of primary osteosynthesis of ITFF have been studied well [7], there are only a few studies concerning the failed cases [8, 9]. In this matched control study, we aimed to evaluate the cost and consequences of failed osteosynthesis of ITFF patients and compare with primary ITFF patients.
Materials and Methods

We retrospectively evaluated patients who underwent surgery between January 2010 and June 2019 in our clinic due to an ITFF after obtaining local ethics council approval (no: 43278876-929). A written informed consent was obtained from each patient. Patients with pathological fractures, periprosthetic fractures, initial osteosynthesis performed with an implant other than cephalomedullary nail, who had follow-up < 12 months and lost during follow-ups were excluded. Patients who were treated with cephalomedullary nail were identified. Patients who had ITFF and underwent revision surgery because of osteosynthesis failure following treatment with cephalomedullary nails were included in the study (Fig. 1).

Total cost of the patients for the admission that patients underwent surgery (revision or primary surgery) was obtained from the local finance department of our hospital and given with Turkish Liras (TL). Patients’ age, gender, American Society of Anesthesiologists (ASA) grade, mortality rate at first year, infection rate, length of stay at hospital, length of stay at intensive care unit, and erythrocyte transfusion amounts were recorded from hospital registry records. ITFFs of the patients were classified based on AO classification system [10]. Mode of failure of osteosynthesis, type of implants used during revision, complications were noted. Tip apex distance (TAD) was measured on early postoperative radiographs as previously described [11]. TAD ≥ 20 mm was considered as a risk factor for failure of osteosynthesis [12] (Fig. 2).

For the revision cases, the types of arthroplasty components were decided based on bone quality, bone loss of the patient, and surgeons’ preference. Patients were followed at least 1 year. Absence of callus or bony bridge on at least three cortices at anteroposterior and lateral radiographs at 6 months follow-up was considered to be non-union [13].

We decided to compose a matched control group to make a valid comparison in homogenous groups. The primary outcome considered the total cost of the admission that patients had their surgeries. The priori power analysis revealed that control group requires four times more patients than the revision group (n=31) to satisfy the 0.05 significance level and 80% statistical power. Thus, each revision case included in the study was randomly matched with four control cases (primary ITFF cases treated with cephalomedullary nail) based on age, gender, year of operation, fracture type, and ASA grade. Revision cases and matched primary control cases were compared using the aforementioned parameters.

Descriptive statistics were expressed as mean ± standard deviation for continuous numerical variables, categorical variables were expressed as number of patients and percentage. Distribution of variables was measured with the Kolmogorov–Smirnov test. Statistical analysis was performed with Mann–Whitney U test to compare mean values. Categorical variables were compared with Pearson Chi-square test. Analyses of the data were performed using the IBM SPSS Statistics 23.0 (IBM Corporation, Armonk, NY, USA).

Fig. 1 Flowchart showing the patient population included

<table>
<thead>
<tr>
<th>Intertrochanteric femur fractures (n=689)</th>
<th>Exclusion (n=162)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary osteosynthesis with cephalomedullary nail (n=527)</td>
<td>Follow-up &lt;12 months (n=56)</td>
</tr>
<tr>
<td></td>
<td>Used implant other than cephalomedullary nail (n=43)</td>
</tr>
<tr>
<td></td>
<td>Lost during follow-up (n=38)</td>
</tr>
<tr>
<td></td>
<td>Periprosthetic fractures (n=16)</td>
</tr>
<tr>
<td></td>
<td>Pathologic fractures (n=9)</td>
</tr>
</tbody>
</table>

| Failed osteosynthesis group (n=31) | Matched control group (n=124) |

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The results were considered statistically significant when the p value was < 0.05.

**Results**

A total of 689 patients with ITFF were evaluated. 527 ITFF patients met the inclusion criteria and were included in the study. There were 31 (5.8%) ITFF patients who had revision surgery due to failed osteosynthesis. Demographics of the patients regarding age, gender, year of operation, fracture classification, ASA grade were similar between revision
(n = 31) and matched primary control cases (n = 124) (p > 0.05) (Table 1). 48% (n = 15) of the revisions were performed during the first postoperative month and 74% (n = 23) during the first 3 months.

The mode of failure of osteosynthesis was mechanical failure of the implant (11 cut-outs, 16 cut-throughs) in 87% (27/31) of the patients and non-union in 13% (4/31) of the patients. All the mechanical failures were treated with arthroplasty. Two non-union patients were also treated with arthroplasty and the other two non-union patients were treated with autografting and refixation with cephalomedullary nails. Hemiarthroplasty was performed in 77.4% (n = 24) of the patients, total hip arthroplasty was performed in 16.1% (n = 5) of the patients. Primary femoral stems were used in ten patients, long femoral stems were used in 13 patients, calcar replacement femoral stems were used in 6 patients. 4 patients had an infection following revision with hemiarthroplasty. Three of the infections occurred in revisions that were performed within the first month of initial fixation. During the revision cases, two intraoperative femoral fissures were observed and treated with cerclage wires. 1 patient had dislocation of the hemiarthroplasty during follow-up and treated with revision total hip arthroplasty.

The mean total cost of the revision cases and primary cases was 10,027 ± 6387 TL and 5261 ± 1773 TL, respectively (p < 0.001). In the revision group, 32.3% (10/31) patients had TAD ≥ 20 mm while 2.4% (3/124) of the patients in control group (p < 0.001). The mean length of stay at hospital, length of stay at intensive care unit, erythrocyte transfusion amounts, infection rate, and mortality rate at first year were significantly higher in revision cases compared to matched primary control cases (p < 0.05) (Table 2).

**Discussion**

ITFFs have been an important health problem in elderly owing to increased life expectancy [1]. As the number of operated ITFFs increases, the failed osteosynthesis of ITFFs has been observed more frequently [14]. There are a few studies examining the impact of osteosynthesis failure on the health system as well as patients [8, 9]. We investigated the cost and impact of failed osteosynthesis of ITFFs in a matched control study and demonstrated that revision cases are significantly associated with higher cost, morbidity, and mortality rates.

Mechanical failure of the intramedullary nail is one of the most feared complications following internal fixation of ITFFs. Failure rates of osteosynthesis due to mechanical failure have been reported 4.7–8% in the literature [5, 6]. Risk factors of mechanical failure have been intensively investigated. TAD, position of lag screw or blade,
and postoperative reduction quality were reported as the most important factors to prevent mechanical problems [5, 11]. These risk factors could be considered as modifiable risk factors for failure. In the current study, we observed 5.8% osteosynthesis failure following ITFF treatment with cephalomedullary nail and 87% of our failed osteosynthesis occurred because of mechanical failures. TAD of ≥ 20 mm was observed 32.3% (10/31) in revision group and 2.4% (3/124) in control group. 48% (n = 15) of the revisions were performed during the first postoperative month and 74% (n = 23) during the first 3 months. Considering the percentage of early mechanical failures and higher percentage of patients with TAD of ≥ 20 mm in the current study, we believe a remarkable percentage of mechanical failures could be prevented hence revision surgeries could be avoided by reducing the risk factors.

Arthroplasty has been commonly used as a salvage procedure for failed osteosynthesis of ITFF. The choice of hemiarthroplasty versus total hip arthroplasty is commonly made based on patients’ comorbidity and functional status in addition to the arthritis grade in the hip joint at revision [15]. Various femoral stem types have been used based on bone quality and femoral canal geometry. Considering the poor bone quality of the patients, long stems or calcar-replacement stems are often required to achieve adequate bone fixation. Cho et al. reported that long stems or calcar-replacement femoral stems were used in 89% of the patients who were operated after failed internal fixation of ITFF [16]. Haidukewych et al. used long stems or calcar-replacement femoral stems in 51 of their 60 salvage arthroplasties for failed internal fixation of ITFF [17]. In our approach during revision cases, we do not remove the implants as the initial step of the surgery if the lag screw is within the femoral head and there are no broken implant parts. We slightly adjust the failed lag screw to its original position because subluxation of the hip joint is easier when fractured segments move in single piece. We consider that metaphysial fixation of femoral stems may not have adequate strength, we mostly prefer longer stems which pass the distal locking screw of the nail especially in osteoporotic patients. In the current study, 19 of 31 patients underwent arthroplasty utilizing long stems or calcar replacement femoral stems.

Arthroplasty could be an option for the primary treatment of ITFFs. It may reduce implant-related complications, reoperation rates, and immobilization period; however, it could increase intraoperative blood loss compared to cephalomedullary nailing [18]. In a recent meta-analysis, Ju et al. recommended hip arthroplasty in selected elderly patients with unstable ITFFs who have several risk factors of mechanical complications. Nevertheless, the authors stated that further high-quality randomized controlled trials are needed to determine the optimal treatment options for ITFFs [19]. We believe arthroplasty could be used in selected patients who are prone to complications related to prolonged immobilization and mechanical failure. More evidence is required for the utility of arthroplasty as a primary treatment option in ITFFs.

Revision of a failed osteosynthesis of ITFF is a challenging procedure. Some problematic situations could be encountered during the surgery including femoral and acetabular bone defects, osteopenic bone, removal of the nail or its broken parts, presence of a scar tissue due to previous surgery, and bone loss from previous fractures [20]. Morazavi et al. evaluated both femoral neck fracture and ITFF conversions to arthroplasty and they stated that intramedullary nail conversions could be considered in the complex case group in which also there are cases required an extended trochanteric osteotomy [21]. Pui et al. reported 3 intraoperative femur fractures in 31 patients who underwent total hip arthroplasty after failed ITFF [22]. Lee et al. had 5 intraoperative femur fractures in 33 patients who underwent conversion to total hip arthroplasty following failed ITFF fixation [23]. In the current study, 2 of our 31 patients had intraoperative femur fractures and were treated with cerclage wiring.

Revision surgeries secondary to failed osteosynthesis of ITFFs commonly lead to high rates of morbidity and mortality. Tetsunaga et al. reported 6.3% infection rate following the conversions of failed ITFFs to total hip arthroplasty [24]. In a meta-analysis conducted by Luthringer et al. including failed internal fixation of ITFFs, 2 of 55 hemiarthroplasty and 3 of 71 total hip arthroplasty patients had infection after surgery [15]. In the current study, we had 12.9% (4/31) infection rate. As revision cases have high risk of infection, intraoperative and postoperative precautions should be taken to minimize the risk of infection. Thakar et al. stated that the strongest predictor of postoperative complications was the need for postoperative erythrocyte transfusion [8]. In the current study, primary cases had a mean of 1.4 ± 1.3 units transfusion and revision cases had a mean of 4.3 ± 3.4 units erythrocyte transfusion. Transfusion has been shown to cause a reduction in the patient’s immune response [25]. This significant difference in transfusion amounts could have been contributed to the higher infection rate in revision cases. To reduce the erythrocyte transfusion rate following revision cases, careful coagulation control and utility of tranexamic acid during surgery would be beneficial.

Dislocation is not an infrequent problem following the revision of failed osteosynthesis of ITFF. Smith et al. reported 8.1% dislocation rate after the revision of failed osteosynthesis of ITFF with total hip arthroplasty [26]. Luthringer et al. compared hemiarthroplasty with total arthroplasty as a salvage procedure after failed osteosynthesis of ITFF regarding dislocation rate and they reported 10.4% dislocation rate after total hip arthroplasty and 5% after hemiarthroplasty [15]. We observed only one
dislocation during follow-up which was occurred in a hemi-
arthroplasty patient.

Mortality is a major issue even for primary ITFF cases. In a systematic review containing 36 studies, the average 1-year mortality rate after hip fractures has been reported as 22% [27]. There are controversial studies in the literature reporting various mortality rates of revision cases compared to primary cases. Soreide and Lillestol reported that mortality rate was higher in the first 6 months in revision cases [28]; however, Palmer et al. noted no overall difference in mortality between primary and revision cases [29]. In the current study, 1-year mortality was significantly higher in revision cases (38.7%) compared to primary cases (17.7%). As the mortality rate of revision cases even higher, patients may benefit from close follow-ups by means of a multidisciplinary approach.

It is not hard to predict that revision cases would have higher costs than primary cases. However, less is known about how many times revision cases cost more compared to primary cases. Few studies investigated the economic burden of secondary surgeries due to failed osteosynthesis of ITFFs [8, 9]. Tiihonen et al. reported that the mean cost of primary cases was €7481 and revision cases was €9791 in Finland. Their mean length of stay at hospital was 9 days for primary cases and 16.2 days for revision cases [9]. Thakar et al. stated that mean cost of primary cases was £8610 (£918.54–£45 601.30) and the mean cost of secondary surgeries was £18 709 (£2606.30–£60.827.10) in the United Kingdom. Thakar et al. concluded that revision cases after failed osteosynthesis of ITFFs doubled the costs [8]. In the current study, the mean cost of primary cases was 5261 ± 1773 Turkish Liras and the mean cost of revision cases was 10,027 ± 6387 Turkish Liras. The mean length of stay at hospital and at intensive care unit was 7.0 ± 3.7 days and 1.5 ± 2.0 days for primary cases, 17.6 ± 21.5 days and 2.4 ± 1.3 days for revision cases, respectively. Our results demonstrated that revision cases double the mean total cost, mean length of stay at hospital and intensive care unit.

The strength of this study is the 4:1 matching of age, gender, ASA, type of fracture and year of the operation that allowed a valid comparison between the two groups. There are also some limitations of our study. The current study was a retrospective study thus had all of the drawbacks associated with that method. Further studies examining the functional status of primary and revision cases would be beneficial.

In conclusion, revision surgeries due to failed osteosynthesis of ITFFs with cephalomedullary nail at least double the mean total cost, the mean length of stay at hospital, the mean length of stay at intensive care unit, erythrocyte transfusion amounts, infection rate and mortality rate at the first year. The awareness of the cost, morbidity, and mortality of the revision surgeries may reduce the modifiable risk factors of osteosynthesis failure including maintenance of TAD below 20 mm, obtaining optimal lag screw position and reduction quality. In addition, arthroplasty might be an option for the primary treatment of patients with unstable ITFFs or patients with poor bone quality to eliminate the catastrophic consequences of osteosynthesis failure.

**Compliance with Ethical Standards**

**Conflict of interest** The authors declare that they have no conflicts of interest.

**Ethical standard statement** This study was ethically approved by the Keçiören Health Practice and Research Center Council (date: 06/07/2020, documents number: 43278876-929).

**Informed consent** A written informed consent was obtained from each patient.

**References**


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Management of Refractory Aseptic Subtrochanteric Non-union by Dual Plating

Krishna Kumar Mittal¹ · Apoorva Agarwal² · Nishant Raj²

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Abstract
Background Subtrochanteric fractures are challenging to treat because of their anatomical and biomechanical behaviours. Non-unions of this region become much more difficult to treat because of the previous surgical scar, fibrosis, mal-reduction, presence of an implant, compromised soft tissue, and osseous vascularity, bone-mass loss etc. The aim is to provide a stable mechanical environment by PF-LCP, augmented by LCP (dual plating) where biology can work uneventfully. Biology is re-initiated by decortication (shingling) and autologous cancellous bone graft.

Methods Twelve cases of failed aseptic subtrochanteric non-union either with intact or broken implant were included in this study in a period of 3 years from August 2016 to July 2019. The interposing fibrous tissue resected in patients with mal-aligned fragments. The mechanical stabilization is achieved by orthogonal dual plating. PF-LCP on lateral and 4.5 mm LCP anteriorly, decortication, and cancellous graft applied before applying for the anterior plate. Patients were encouraged for a toe-touch walk with walking-frame from 3rd post-operative day. Functional outcomes were assessed using Parker Mobility Score (PMS).

Results All fractures united in 7 ± 1.53 months. ROM at the knee remained unchanged but improved at the hip after revision surgery. Average PMS improved to 7.58 from pre-revision 1.75 validating the efficacy of this protocol.

Conclusion Adequate stability by dual-plate construct and re-initiation of cellular and biochemical processes by decortication and cancellous bone-graft reunited ununited subtrochanteric fractures. This particular combination of plates and decortication has not been employed earlier as per our review of the literature.

Aim To offer a new paradigm for the management of surgically failed subtrochanteric non-unions.

Keywords Non-union subtrochanteric fractures · Decortication · PF-LCP · Augmentation by LCP

Introduction
Non-union is an irreversible stage in the cascade of fracture healing devoid of all potentials of regeneration. Non-union of subtrochanteric fracture reflects either inadequate stability or poor biology or both. Favorable biological and mechanical environments are pre-requisites for uneventful and uncomplicated fracture healing. Subtrochanteric zone is the most highly stressed zone of the body, the level of stress can go up to six times of body weight [1]. Thick cortical bone, tenuous blood supply, cantilever anatomy of head and neck with high unequal biomechanical stress, compressive forces on posterio-medial cortices more by 20% as compared to the tensile surface creating varus tendency, cortico-cancellous junction make the fractures of this zone more susceptible to non-union [1, 2]. Implant failure is a consequence, not a cause of non-union. Failed post-ossynthesis non-unions following once/multiple surgical interventions is challenging due to previous fibrous and scar tissues, osteoporosis, compromised vascularity of bone and soft tissues, dormant infection, and presence of the failed implant. This study aims to propose a treatment protocol for refractory non-unions of subtrochanteric fractures with co-morbidities optimization.
The options for primary fixation in fresh fracture are cephalomedullary nails (CMN), blade plate, DCS, DHS, and PFLCP. CMNs are the most preferred implant. Post-surgical causes for nonunion are mainly loss of initial reduction—varus or procurvatum, misplaced implant, wrong entry point, excessive soft tissue stripping, and selection of the wrong implant. The various procedures tried to treat non-union after nailing are dynamisation of nail, exchange nailing, bone grafting, augmentative plating, nail conversion to the plate or prosthetic replacement. The length of the proximal fragment, deformity, bone defect, bone stock, age, presence of implant, and surgeon’s preference help in decision making [3].

The healing time is more in non-unions hence the implant has to bear stresses for a longer duration of time. Moreover, the earlier failed implant is indicative of a slower pace of healing than stress accumulation on the device leading to failure. Osteo-periosteal decortication and cancellous bone graft re-initiates and expedites the process of fracture healing. The “Diamond Concept” clearly gives importance to both mechanical and biological factors in addressing associated comorbidities. Physiology works in stable anatomical conditions otherwise it becomes pathological.

Materials and Methods

Twelve patients of failed osteosynthesis of subtrochanteric non-union were included in the study. The inclusion criterion was patients above 18 years of age, fractures with lapse of 9 months from index surgery without any radiological evidence of union or non-progressive reparative status for last three consecutive months, failed implant at any point of time, without any obvious infection on clinical, hematological and radiological examinations. Pathological, atypical and infected fractures were excluded from this study. The age ranged from 18 to 65 years the average being 42.83 ± 13.38 years. The average operating time was 128.33 ± 17 min. The average time between index and revision surgery was 12.5 ± 7.69 months ranging from 6 to 36 months. The necessary demographic observations are summarized in tabular form (Table 1).

The possibility of dormant infection is excluded by carefully detailed history and clinical, hematological (CBC, CRP, ESR) and radiological examinations (Lysis around screws, resorption of bone, sequestrum and involucrum formation). Per-operative tissue from the non-union site was sent for culture and histopathological examination for further confirmation of infection.

With all clearances, informed consents, and optimization of co-morbidities, all surgeries were done under spinal anesthesia on a traction table in the supine position. Tranexamic acid 15 mg/kg body weight half an hour
before surgery is given routinely to every patient unless contraindicated and repeated 6 h after the initial dose. Local infiltration of lignocaine with adrenaline diluted to 1:600,000 ratio done in the proposed line of the incision with the intention to minimize blood loss and to have better post-surgical analgesia.

In all cases, the non-union site and implant approached through a previous surgical incision extending as per need. Implants removed, intervening fibrous tissue resected in five patients to bring fragments in alignment retaining maximum peri-osteal attachment. Resection of intervening fibrous tissue and freshening of bone ends was necessary for obtaining a stable end to end alignment in five patients, the remaining seven patients needed no resection and freshening of ends as stable alignment was secured after removal of the implant. Anatomic alignment obtained and fixed by PFLCP in compression mode. At this stage decortication 20 mm on either side of the fracture in all approachable areas done by a sharp and narrow blade chisel or osteotome till fresh bleeding from parent bone visualized. Sufficient cancellous bone graft taken from same iliac crest applied over the decorticated surface and all around the fracture. An orthogonal 4.5 mm LCP was applied on the anterior aspect again in compression mode. Alignment of fragments and placement of screws in head checked under fluoroscopy in more than two planes to avoid the possibility of error. Standard norms of dual plating were followed to avoid stress risers.

Postoperative follow up was on 1st, 2nd weeks and on monthly interval till fracture united based on radiological evidence and afterwards also. All patients were encouraged to toe touch walking with a walking frame and to undergo physical therapy from 3rd post-operative day, and load-bearing gradually increased as per tolerance retaining the walking frame.

Healing of non-union assessed on clinical and radiological parameters. Painless full weight-bearing walking was a clinical parameter of the union. Reborne Bone Healing Score [4] for radiological consolidation was used and evaluated by two orthopaedic surgeons (Table 2).

### Results

We classified the results as a. Excellent with no decline in Parker Mobility Score (PMS), b. Good with a decline of 1 point c. Fair with a decline of 2 points and d. Poor with a decline of 3 or more points as compared to their pre-injury values or requiring further revision surgery (Table 3).

All patients followed till osseous union and even afterwards, the range of follow-up was from 10 to 18 months the average being 14.25 ± 2.08 months. The average time to heal was 7 ± 1.53 months ranging from 4 to 9 months. 6 patients out of 12 (50%) presented with a broken implant and remaining six with intact implant with varus malalignment.

Parker Mobility Score (PMS) improved in every patient as compared to pre-revision status. On comparison to pre injury PMS Three patients regained full points. Five patients lost one point with PMS 8 had good functional results and three patients had decline of two points to pre-injury level were placed in fair category. None had poor results or required re-revision. Chart with average PMS at three different stages i.e. pre-injury, pre-revision, and last follow-up shows an encouraging result validating the success of this procedure (Fig. 1). A patient (P11) with low pre-injury PMS of 4 declined to zero before revision surgery but at last follow-up, her PMS was two labelling her recovery as fair. Four patients reported painless lurch, one patient with low pre-injury PMS continued her walking frame and two patients needed a walking stick for outdoor movements. The average pre-injury PMS was 8.58 which declined to 1.75 just before revision surgery and improved to 7.58 at last follow-up with 25% patients excellent, 50% good and 25% had fair results.

All culture reports were negative and histopathology did not reveal anything significant. The range of motion at the hip improved but the knee remained in the same range as before revision surgery. No correlation in result could be established with co-morbidity as they were optimized before and during the course of treatment. Tobacco chewing/smoking was discouraged during the course of treatment. There was no loss of reduction in any of our patients till

### Table 2 Reborne Bone Healing Score

<table>
<thead>
<tr>
<th>Cortical score</th>
<th>Stage</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>Non-interpretable/non-visible. Hidden by plate</td>
</tr>
<tr>
<td>1</td>
<td>Fracture unchanged</td>
</tr>
<tr>
<td>2</td>
<td>Callus present but not continuous</td>
</tr>
<tr>
<td>3</td>
<td>Callus continuous but fracture still visible</td>
</tr>
<tr>
<td>4</td>
<td>Callus with same density as cortex</td>
</tr>
</tbody>
</table>

### Table 3 Criteria for evaluation of result based on Parker Mobility Score

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Decline in Parker Mobility Score W.R.T Pre-injury level</th>
<th>Grading of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No decline</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>Decline by 1 point</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>Decline by 2 points</td>
<td>Fair</td>
</tr>
<tr>
<td>4</td>
<td>Decline by 3 or more points, re-revision</td>
<td>Poor</td>
</tr>
</tbody>
</table>
bony union. No incidence of plate or screw breakage was observed. None of the patients till last follow-up presented sign of avascular necrosis of head of femur. (Figs. 2, 3, 4, 5 show pre-revision status of non-union with a failed implant, post revision and at follow up.)

Discussion

An uneventful fracture healing requires favorable biological and mechanical environments, imbalance leads to failure. Mechanical instability initiates biological failure which leads to implant failure. Vice-versa, failing biology creates undue stress on fracture mechanics causing the implant to fail. No earlier author has used PFLCP and LCP combinations to provide mechanical stability. There are reports of exchange nailing with bone graft, blade plate, augmentation [5], DCS and LCP combinations [6] or PFLCP alone [7]. There are various publications to manage non-union of subtrochanteric fractures but the sample size in these reported publications is small [3]. The overall fixation failure rate was 12% with a reoperation rate of 6% by one year as reported by Parker et al. [8].

The Parker Mobility Score is a composite measurement of a patient’s mobility indoors, outdoors and during shopping [9]. We used it in our study like others [10] to measure mobility as an outcome of revision surgery. In our context, outdoor walking is like going to a neighborhood and shopping is like going to the vegetable market and alike.

Orthogonal dual plating is a strong and stiff construct. Torsional stress is completely obliterated by PF-LCP’s proximal multiplanar screws in head and neck at 95°, 120° and 135°. Axial and bending stiffness also increases many folds because of PFLCP and LCP act as a single beam construct which is 4 times stronger than conventional plating like DCS [11]. The anterior plate being nearer to the mechanical axis increases its endurance to stresses. Hence, a more favorable mechanical environment is created by reducing stress on the implant. PF-LCP and LCP provide tension band effect as both are applied on the convex surface of the femur.

Judet in 1963 pioneered osteoperiosteal decortication for non-union of diaphyseal fractures, claiming good results. Guyver et al. [12] published his article in 2012 stating excellent results by obtaining a 99% union rate yet this technique is not popularized. He further emphasized that osteoperiosteal decortication remains a highly effective surgical technique in the management of failed fracture healing. Some authors have also reported excellent results [13, 14]. Decortication is like ploughing a field, the harder you plough better you sow and reap.

Decortication up to a minimum of 20 mm on each side of the fracture, proximally and distally, provides a pink vascular bed for the cancellous graft to get vascularised by the process of angiogenesis. Decortication is a time tested procedure but ignored due to over-reliance on mechanical stabilisation and biological reactivation by bone graft alone. Decortication may help to physically interlock bone graft with recipient’s bone with new bone formation [15]. The cancellous bone graft helps in obtaining osseous union by osteoconduction, osteoinduction, and osteogenesis. Decortication helps as viable raised osteoperiosteal flakes increase raw fracture area which stimulates fracture healing. The multiple mini fractures in the outer layer of cortex created by decortication, initiate a hypoxia driven signaling pathways. The decreased perfusion concurrent with increased metabolic demand of repair leads to hypoxia near fracture site [16]. As a result, there is the restoration of blood flow due to stimulated angiogenesis which is a key component in fracture healing. Cellular response releasing vascular endothelial growth factor (VEGF-A) which is a proangiogenic factor.
stimulates angiogenesis. Hematoma formation from bleeding periosteal and cortical vessels provides necessary biochemicals to stimulate progenitor cells to form osteoblasts which are essential in fracture healing cascade, converting an established non-union fracture to start afresh for healing. Tall et al. [17], could achieve union in all fifty patients of nonunion of diaphyseal fracture of long bones with osteoperiosteal decortication and internal fixation alone without cancellous bone graft even in atrophic non-unions.

Sebastian et al., reported re-revision surgery for the non-union subtrochanteric fracture to be 32.5% [18]. Haidukewych et al. reported bone stock from prior attempts can compromise stable fixation [3]. Dual plating overcomes this deficiency as proximal screws of PFLCP are multi-planar and multi-directional gaining purchase in the subchondral bone. Kang et al. [19], in his series of 19 patients showed an exchange of previous implant and removal of fibrous tissue was better than in those retained in the treatment of

Fig. 2  A Broken PFN with atrophic non-union, eleven months after index surgery.  B Immediate Post-operative-dual plate and bone graft.  C Osseous union at 6 months, alignment maintained
non-unions of subtrochanteric fractures, 10 versus 9. In the present study, the author removed fibrous tissue only when reduction is to be achieved. We believe, by avoiding resection of intervening fibrous tissue, time and blood-loss are saved, without affecting the ultimate healing process in fracture with stable end-to-end reduction.

The exchange nailing for non-union of diaphyseal fractures of femur/tibia supports this concept. The compression at the fracture site generated by Tension Band Effect of these orthogonal plates stimulates mesenchymal stem cells to proliferate and differentiate into osteoblasts due to Piezo-electric effect converting fibrous tissue into osseous tissue [20]. Giannoudis et al. [21], used blade plate with enhancing biological and mechanical preconditions on “diamond” concept treated fourteen subtrochanteric non-unions but in one case further revision surgery was required due to blade plate failure. In our study, no patient required revision surgery.

Fig. 3  A 2 years after index surgery, treated by reverse LCP non-union subtrochanteric with varus deformity. B Post Operative dual plate fixation and bone graft. C Osseous union at 40 weeks, alignment maintained
Dietmar et al. [22], in their study of 17 patients of non-union of subtrochanteric fractures concluded that all three factors for subtrochanteric non-union were mechanical parameters. They identified risk factors either result of increased load on the implant (varus mal-alignment), reduced intrinsic stability of fracture (lack of medial support) or reduced stability of overall mechanical construct (auto dynamization). It is therefore reasonable to assume there is a summation effect. The spectrum of stability: absolute stable/rigid fixation permits 2% strain, relative stable fixation permits 2–10% strain and unstable fixation permits beyond 10% strain which leads to non-union. Relative stable fixation is for acute fractures which have the potential to repair itself as micromotion helps in angiogenesis and subsequently osteogenesis but in the case of non-union all biological processes of healing come to a complete halt. They are reinitiated by decortication and bone grafting effectively only in a stable mechanical environment provided by

Fig. 4 A Patient presented subtrochanteric non-union with broken barrel plate 9 months after index surgery. B Immediate post-operative X ray showing dual fixation and bone graft. C Bony healing evident at 26 weeks
rigid fixation which prevents micromotion across the fracture line. The failed implant is indicative of undisputable defeat in the race between process of fracture healing and stress concentration on a point of implant making it vulnerable to failure. Non-unions even after revision take a longer time to heal. The orthogonal plates provide a stronger and stiffer construct enduring larger stresses for a much longer time. Murray et al. [23], in 1964 started the concept of dual plating for non-unions. Egol et al. [24], raised a theoretical concern for the amount of soft tissue stripping and delayed revascularization jeopardizing vascularity. Although, this concern in the treatment of acute fractures is justifiable but not in non-unions as wide exposure and dissection are required. Rubel et al. [25], concluded that the addition of another plate doesn’t increase failure rate. Moreover, the locking plate provides fixation without undesirable effect on periosteal vascularityization and mechanical drawbacks associated with conventional locking plates.

Fig. 5 A Non-Union subtrochanteric fracture treated by long PFN showing loss of reduction. B Immediate post-operative showing fixation by dual plating and bone graft. C At 36 weeks, signs of radiological healing present
In revision surgeries, we believe more strong and rigid fixation is required, which is adequately provided by dual plating. The surgical technique for non-union surgery requires more extensive dissection, debridement of fibrous tissue, and shortening to bleeding bone.

This often results in irregular bone ends not providing enough stability because of poor contact. Longer healing times are also common, requiring implants to bear more stress for a longer period of time.

The limitation of our study is the small sample size and no control group but the strength of the study is that all surgeries performed by a single surgeon following a standard protocol.

Conclusion

Favorable mechanical and biological environments provided by orthogonal dual plating, decortication and autogenous cancellous bone graft reunited ununited subtrochanteric fractures. With this protocol, large number of patients should be studied before final verdict. We conclude, strict application of basic non-union principles can result in a successful salvage of subtrochanteric non-unions in patients with one or multiple failed prior surgical interventions, stability being the most important. Once a wise man said, “Stability is success”.

Compliance with Ethical Standards

Conflict of interest The authors hereby, declare that there is no conflict of interest in this study. This study is not sponsored/funded by any institution. All patients were admitted and operated by the authors only.

Ethical standards statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent All patients were operated upon after taking their informed consent. Nowhere in this study, identity/ethnicity/gender of patient is disclosed.

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Comparing Intramedullary Nailing Versus Locked Plating in the Treatment of Native Distal Femur Fractures: Is One Superior to the Other?

Jaclyn M. Jankowski1 · Patrick F. Szukics1 · Jay K. Shah1 · David M. Keller1 · Robinson E. Pires2 · Frank A. Liporace1 · Richard S. Yoon1

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Abstract
Introduction Distal femur fractures make up < 1% of all fractures and 3–6% of all femur fractures. In the literature, both intramedullary nailing (IMN) and locked plating (LP) have shown favorable results, but there is no consensus on a gold standard. The purpose of this systematic review is to compare outcomes of native distal femur fractures treated via IMN versus LP in an effort to determine if one is superior to the other.

Methods Systematic review of MEDLINE, EMBASE, and Cochrane Library databases was conducted according to PRISMA guidelines. Only articles published within the last ten years were included. Evidence and study quality were evaluated with the MQOE and Oxford Criteria.

Results Forty-six articles were included in the review. Fractures treated with IMN were found to have a 93.9% union rate, an average time to union of 19.2 weeks, an average arc of motion of 105.1 degrees, with an average of 14.4 degrees of malalignment. Fractures treated with LP were found to have a 90.2% union rate, an average time to union of 20.5 weeks, an average arc of motion of 104 degrees, with an average of 12.6 degrees of malalignment.

Conclusion Compiled data comparisons revealed no differences in union rate, malalignment, time to union, average arc of motion, or complication rates requiring a return to the operating room. Until higher level randomized data is available, either IMN or LP are acceptable methods of treatment for native distal femur fractures.

Keywords Distal femur fracture · Intramedullary nail · Locked plating · Retrograde intramedullary nail

Introduction Distal femur fractures make up < 1% of all fractures and 3–6% of all femur fractures [1]. Excessive deforming forces cause significant deformity, making this fracture clinically challenging to treat [2]. Improper restoration of distal femoral anatomy can cause significant disability due to significant shifts in the anatomic and mechanical axis of the affected limb.

With rare indications for non-operative treatment, the majority of distal femur fractures are treated operatively via either intramedullary nailing (IMN) or locked plating (LP). IMN typically is performed in the retrograde fashion, while LP can be performed via a midline or minimally invasive lateral approach [3, 4]. Continued understanding of surrounding anatomy, along with the concurrent metallurgical and biomechanical evolution of both IMN and LP technologies, results for both treatment modalities have been favorable in the recent literature [1–57]. However, while proponents of each treatment modality will debate on pros and cons of both IMN and LP, there is still no clear consensus on a gold standard when it comes to treating distal femur fractures. In this systematic review, a step-wise methodical approach is performed to compare outcomes of distal femur fractures treated with either IMN or LP.
Methods

Search Strategy

A systematic review was conducted according to PRISMA guidelines. The following search terms were used in MEDLINE, EMBASE, and the Cochrane Library databases. Only studies published within the last ten years were included in this systematic review (Fig. 1).

Eligibility Criteria

Two independent reviewers performed the literature search and reviewed the results. The titles and abstracts were reviewed, and potentially eligible studies received a full-text review. Inclusion criteria consisted of: cohort studies comparing LP to IMN or combined LP/IMN, articles published in peer-reviewed journals, articles published from 2007 to 2019, articles published in English, and availability of full-text studies. Exclusion criteria consisted of: non-cohort studies, review studies, cadaver studies, and basic science studies. The reference lists of all included studies, and all literature reviews found in the search results, were manually screened for additional articles that met the inclusion criteria.

Data Extraction/Analysis

The data from each clinical study were extracted using a standardized datasheet. The following information was collected: patient age, gender, length of follow up (in months), union rate, time to union (weeks), range of motion, functional scores, and complications. The level of evidence (LOE) was evaluated based on previously published criteria by Wright et al. [5]. The methodological quality of the evidence (MQOE) was assessed for randomized control trials using the Oxford Criteria. The MQOE was assessed for the non-randomized cohort studies using the Minors Criteria. The data from each clinical study were then extracted using a predetermined datasheet.

Fig. 1 Flow chart illustrating study selection process
Results

Out of 1942 articles reviewed, 46 articles were included in our review series [6–51]. There were 6 randomized prospective studies, 34 retrospective case series, 6 prospective observational cohorts, 1 retrospective cohort, and 1 retrospective case–control (Table 1). Due to the overall heterogeneity of the data presented, an unbiased, accurate meta-analysis could not be performed. To overcome the overall heterogeneity of the compiled data, similarly reported variables were analysed and reported as pooled means to provide a head-to-head comparison between the two treatment modalities.

Fifteen studies were included for IMN analysis with a total of 493 patients. The mean age was 55.1 years and the patient population was 53% female. The mean follow-up was 18.4 months. Results exhibited that those treated via IMN were found to have a 93.9% union rate, with an average time to union of 19.2 weeks. Average range of motion was found to be 105.1 degrees, and there was an average of 14.4 degrees of malalignment (Table 2).

A total of 39 studies were included for LP analysis with a total of 2841 patients. The mean age was 57.8 years and the patient population was 32.6% female. The mean follow-up was 21.3 months. Those treated with LP were found to have a 90.2% union rate, with an average time to union of 20.5 weeks. Average arc of motion was found to be 104 degrees, and there was an average of 12.6 degrees of malalignment (Table 2).

Discussion

Screening and analysing over a decade of literature, combined data regarding the use of IMN and LP for the treatment of distal femur fractures has shed a favourable light on the evolution of the operative treatment of a classically difficult to treat fracture pattern. Improved understanding of surrounding anatomy combined with improved metallurgy and implant technology has led to significant advancements in the operative treatment of distal femur fractures. This is highlighted by our summarized results from the literature which exhibit reliable bony union and restoration of function without gross malalignment and/or failure, regardless of implant selection (IMN vs. LP). Despite the robust results, however, one can argue that there still is room for improvement.

In other words, despite a robust 90% union rate, some may argue that a 10% non-union or failure rate is still too high in the realm of modern healthcare. A closer look, however, at the evolution and understanding of treating operative distal femur fractures, paints a more interesting picture. Earlier studies, highlighting all LP constructs (i.e. LISS) plates, exhibited unacceptably high non-union/failure rates of 20–40%, depending on the report [53]. However, these outcomes improved with time, as the risk factors for failure became apparent; preserve the blood supply and periosteum, do not use a too rigid of a construct, and increase fracture and implant working length whenever possible [47].

Here, proponents of IMN will champion the slightly higher rate of union found in our data (93% vs. 90%, Table 1). Increased flexibility due to relative stability, combined with minimally invasive (tissue/blood supply sparing) techniques likely are the reasons for slightly higher union rates, however, what are the reasons for the other 7% of failures? Summarized systematic review could not come to a consensus, where some reports cited initial injury (i.e. high-energy open fracture causing infection), and others cited comorbidities (i.e. smokers, diabetics, obesity) [54]. Heterogeneity amongst all reports in the literature, made formulating consensus statements on reasons for treatment failure an extremely difficult task.

Within heterogeneity, lies the inherent limitation encountered in this study. Despite utilizing strict inclusion criteria for analysis, the mere lack of high-level randomized data hindered the ability to perform a true meta-analysis. However, the sheer volume of data available did allow for pooled mean data analysis, which does provide important outcomes in this challenging clinical arena. In other words, our pooled data reports that reliable, promising outcomes can and have been established. The next step, however, may be to further isolate and analyse by specific characteristics (i.e. patient age, open fracture, bone quality, fracture pattern and subsequent implant type/construct), to tease out specific risk factors for negative outcomes. Further understanding of the specific cohorts may push our outcomes closer to the desired 100%.

In conclusion, in today’s modern health care arena, both RIMN and LP have become reliable treatment modalities for distal femur fractures. Touting over a 90% union rate, while

| Table 1 Pooled mean comparisons between IMN and LP cohorts compiled from included studies |
|---------------------------------|-----|-----|
|                                | IMN | LP  |
| Mean follow-up (months)        | 18.4| 21.3|
| Total studies included         | 15  | 39  |
| Total patients                 | 493 | 2841|
| Mean age (years)               | 55.1| 57.8|
| % Female                       | 53  | 32.6|
| Union rate                     | 93.9| 90.2|
| Time to union (weeks)          | 19.2| 20.5|
| ROM                            | 105.1| 104|
| Malalignment                   | 14.4| 12.6|
Table 2  Study characteristics of articles included for analysis

<table>
<thead>
<tr>
<th>Article</th>
<th>Total n</th>
<th>Mean age</th>
<th>Percent female</th>
<th>Mean follow up (Months)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gill et al. 2017</td>
<td>42</td>
<td>Nail 36 Plate 38.7</td>
<td>31%</td>
<td>Nail 27.8 Plate 29.2</td>
<td>Nailing proved to be more cumbersome intraoperatively but showed an inclination towards earlier union, while LISS plating showed technical errors to be more common and less forgiving</td>
</tr>
<tr>
<td>Demirtas et al. 2014</td>
<td>28</td>
<td>Nail 31.1 Plate 36</td>
<td>14%</td>
<td>Nail 26.7 Plate 31.3</td>
<td>Bridge plating and RIMN showed similar results in the treatment of extra-articular distal femur fractures</td>
</tr>
<tr>
<td>Gao et al. 2013</td>
<td>36</td>
<td>Nail 50.6 Plate 54.7</td>
<td>31%</td>
<td>Nail 26.9 Plate 31.3</td>
<td>The overall nonunion rate in the locked plating group was higher than in the RIMN group, though likely due to surgical technique rather than the choice of implant</td>
</tr>
<tr>
<td>Henderson et al. 2010</td>
<td>24</td>
<td>Nail 63 Plate 65</td>
<td>71%</td>
<td>Nail 15.42 Plate 13.12</td>
<td>Significantly less periosteal callus formed in fractures stabilized with locking plates than with IM nails</td>
</tr>
<tr>
<td>Hierholzer et al. 2011</td>
<td>115</td>
<td>Nail 54 Plate 54</td>
<td>–</td>
<td>Nail 13 Plate 15</td>
<td>Both retrograde IM nailing and angular stable plating are adequate treatment options, but clinical outcome largely depends on surgical technique rather than on the choice of implant</td>
</tr>
<tr>
<td>Hoskins et al. 2016</td>
<td>297</td>
<td>Nail 57 Plate 62</td>
<td>56%</td>
<td>Nail 6 Plate 12</td>
<td>IMN may be a superior treatment compared with anatomical locking plates for fractures of the distal femur</td>
</tr>
<tr>
<td>Pean et al. 2015</td>
<td>555</td>
<td>Nail 74.5 Plate 71.2</td>
<td>76%</td>
<td>Nail 0.23 Plate 0.21</td>
<td>DF fractures treated with IMN have equivalent short-term outcomes compared to those treated with plate fixation</td>
</tr>
<tr>
<td>Thomson et al. 2008</td>
<td>22</td>
<td>Nail 50.5 Plate 49.9</td>
<td>45%</td>
<td>80</td>
<td>Less invasive techniques decreased the need for delayed bone grafting and decreased the malunion rate in this study</td>
</tr>
<tr>
<td>Intramedullary nail only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No implant or surgical technique is superior to any other under all circumstances for distal femur fractures. RIMSN is standard care, yet the biological osteosynthesis using DCS is a very good alternative for the treatment of distal femur fractures</td>
</tr>
<tr>
<td>Dar et al. 2009</td>
<td>37</td>
<td>47</td>
<td>38%</td>
<td>30</td>
<td>Treatment of distal femur fractures with retrograde locked IMN yields satisfactory results in adults</td>
</tr>
<tr>
<td>Gurkan et al. 2009</td>
<td>16</td>
<td>45</td>
<td>31%</td>
<td>32.6</td>
<td>Retrograde femoral nailing is commonly used in elderly patients due to reliable bone healing, minimal soft tissue damage, and immediate full weight bearing</td>
</tr>
<tr>
<td>Neubauer et al. 2012</td>
<td>35</td>
<td>81.3</td>
<td>77%</td>
<td>16.5</td>
<td>RIMN of open distal femur fractures allows for early rehab of the affected joint and helps to reduce primary deformities and secondary degenerative lesions for a good treatment outcome</td>
</tr>
<tr>
<td>Cieslik et al. 2007</td>
<td>39</td>
<td>38</td>
<td>44%</td>
<td>6</td>
<td>Distal femoral nailing provides a good fixation method allowing immediate mobilization for elderly patients</td>
</tr>
<tr>
<td>Giddie et al. 2015</td>
<td>54</td>
<td>80.6</td>
<td>98%</td>
<td>4.1</td>
<td>RIMN is a good surgical option for distal femur fractures with osteoporosis as it promotes fracture healing and allows early mobilization</td>
</tr>
<tr>
<td>Kim et al. 2012</td>
<td>13</td>
<td>79</td>
<td>100%</td>
<td>30</td>
<td></td>
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</table>
Table 2 (continued)

<table>
<thead>
<tr>
<th>Article</th>
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<th>Mean follow up (Months)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wu 2015</td>
<td>21</td>
<td>39</td>
<td>19%</td>
<td>40.8</td>
<td>RIMN for aseptic supracondylar femoral nonunions following failed locked plating achieved a high union rate</td>
</tr>
<tr>
<td>Plate only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottlang et al. 2014</td>
<td>29</td>
<td>57</td>
<td>52%</td>
<td>17</td>
<td>Absence of implant and fixation failure suggests that dynamic plating of distal femur fractures with far cortical locking screws provides safe and effective fixation</td>
</tr>
<tr>
<td>Ehlinger et al. 2014</td>
<td>92</td>
<td>64.2</td>
<td>59%</td>
<td>6</td>
<td>Neither the type of the construct nor the hardware used influenced radiologic and clinical outcomes</td>
</tr>
<tr>
<td>Erhardt et al. 2014</td>
<td>25</td>
<td>53</td>
<td>44%</td>
<td>36.5</td>
<td>Modern locked implants achieved high union rates with a good clinical function and patient satisfaction when respecting biologic and biomechanical principles</td>
</tr>
<tr>
<td>Hanschen et al. 2014</td>
<td>27</td>
<td>69.01</td>
<td>70%</td>
<td>12</td>
<td>Noncontact bridge plating by Zimmer had better functional and radiological outcomes than LISS by Synthes</td>
</tr>
<tr>
<td>Jain et al. 2013</td>
<td>20</td>
<td>37.05</td>
<td>25%</td>
<td>12</td>
<td>LCP is one of the best available options for management of peri and intraarticular fractures around the knee</td>
</tr>
<tr>
<td>Khursheed et al. 2015</td>
<td>25</td>
<td>66.5</td>
<td>76%</td>
<td>12</td>
<td>Minimally invasive fixation of extra-articular distal femur fractures with locking plates in patient aged 60 years and above show high union rates despite high prevalence of communication and osteoporosis</td>
</tr>
<tr>
<td>Pascarella et al. 2014</td>
<td>89</td>
<td>62</td>
<td>61%</td>
<td>19.25</td>
<td>Distal femur fractures treated with polyaxial locking plates have a high union rate and good clinical outcomes</td>
</tr>
<tr>
<td>Pwasuttikul et al. 2014</td>
<td>40</td>
<td>48.7</td>
<td>40%</td>
<td>18.35</td>
<td>The indirect reduction technique for the treatment of comminuted distal femur fractures provides satisfactory results when combined with LCP fixation</td>
</tr>
<tr>
<td>Virk et al. 2016</td>
<td>25</td>
<td>36.64</td>
<td></td>
<td>24</td>
<td>Positive results can be obtained by locked plating alone for DF fractures of all varieties as long as technique is appropriate</td>
</tr>
<tr>
<td>Adams et al. 2015</td>
<td>15</td>
<td>58</td>
<td>73%</td>
<td>8</td>
<td>Far cortical locking screws may provide the answer to the high nonunion rate associated with distal femur fractures treated with traditional locked constructs</td>
</tr>
<tr>
<td>Barei et al. 2012</td>
<td>34</td>
<td>45</td>
<td>32%</td>
<td>13</td>
<td>Fixed Angled Screw/plate implants may decrease the need for staged bone grafting while maintaining alignment, even in situations with metaphyseal bone loss, provided that viable posterior and/or osseous fragments exist</td>
</tr>
<tr>
<td>Batchelor et al. 2014</td>
<td>27</td>
<td>64.7</td>
<td>70%</td>
<td>30</td>
<td>The trends towards the benefits of the LISS procedure when correctly applied would suggest that not only should the LISS procedure be performed for distal femur fractures, but the correct principle of insertion is important in improving the patient’s outcome</td>
</tr>
</tbody>
</table>
Table 2 (continued)

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</thead>
<tbody>
<tr>
<td>Chung et al. 2016</td>
<td>80</td>
<td>74</td>
<td>83%</td>
<td>14</td>
<td>Performing MIPO using positional screws to sustain the reduced interfragmentary gap after fracture reduction will be helpful in the treatment of simple femoral fracture</td>
</tr>
<tr>
<td>Doshi et al. 2013</td>
<td>24</td>
<td>73.08</td>
<td>92%</td>
<td>15.3</td>
<td>Locking plates inserted using MIPO techniques in elderly patients with distal femur fractures appear to be promising based on clinical outcome measurements</td>
</tr>
<tr>
<td>Gardner et al. 2008</td>
<td>31</td>
<td>57.6</td>
<td>71%</td>
<td>41.5</td>
<td>Distal femoral nonunions may be treated successfully with correction of deformity, stable fixed-angle internal fixation, lag screw placement, and supplemental bone grafting</td>
</tr>
<tr>
<td>Hart et al., 2017</td>
<td>28</td>
<td>82</td>
<td>93%</td>
<td>12</td>
<td>Nearly 1 in 5 patients older than 70 years developed a nonunion after ORIF of an intraarticular distal femur fracture</td>
</tr>
<tr>
<td>Harvin et al. 2017</td>
<td>96</td>
<td>61</td>
<td>64%</td>
<td>19.46</td>
<td>Plating constructs with all locking screws used in the diaphysis when bridge-plating distal femur locking plates were 2.9 times more likely to incur a nonunion. However, other factors associated with more flexible fixation constructs such as increased working length, decreased proximal screw number, and decreased proximal screw density were not significantly associated with union in this study</td>
</tr>
<tr>
<td>Henderson et al. 2011</td>
<td>70</td>
<td>60.8</td>
<td>–</td>
<td>50.4</td>
<td>A high rate of nonunion was found in distal femur fractures treated with locking plates. Nonunion presented late without hardware failure and with limited callus formation suggesting callus inhibition rather than hardware failure is the primary problem</td>
</tr>
<tr>
<td>Kumar et al. 2014</td>
<td>46</td>
<td>35</td>
<td>22%</td>
<td>12.3</td>
<td>Use of standard lateral approach for simple intra-articular distal femoral fractures (C1) and transarticular/minimally invasive techniques for complex intraarticular fractures (C2/C3) results in improved exposure of the knee joint and better union rates with a low incidence of bone grafting</td>
</tr>
<tr>
<td>Kolb et al. 2008</td>
<td>31</td>
<td>49</td>
<td>52%</td>
<td>29</td>
<td>The LISS promotes early mobilization and rapid rates of bony and clinical healing without bone grafting with low rates of infection</td>
</tr>
<tr>
<td>Linn et al. 2015</td>
<td>17</td>
<td>59</td>
<td>–</td>
<td>12</td>
<td>Overdrilling the near cortex in metaphyseal bridge plating can be adapted to standard implants to create a dynamic construct and increase axial motion. This technique seems to be safe and leads to increased callus formation, which may decrease nonunion rates seen with standard locked plating</td>
</tr>
<tr>
<td>Liu et al. 2009</td>
<td>85</td>
<td>49</td>
<td>–</td>
<td>27</td>
<td>Fixation with LISS plating is adequate to maintain alignment and obtain union with a low incidence of complications even in patients with osteoporotic bone</td>
</tr>
</tbody>
</table>
exemplary, also highlights room for improvement in both clinical outcomes and furthering the understanding of the injury. Higher-level randomized trials along with specific studies focused on studying modes and causes for treatment failure should be performed to continue to improve on prior successes.

**Author Contributions** JJ- study design, literature search, data analysis, manuscript draft. PFS- literature search, manuscript draft. JKS- study design, literature search, data analysis, manuscript draft. DMK- manuscript draft. REP- study design, execution, data interpretation/analysis, manuscript fixation FL- study design, execution, data interpretation/analysis, manuscript fixation. RY- study design, execution, data interpretation/analysis, manuscript fixation. All authors read and approved the final manuscript.

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**Data Availability** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.
Compliance with Ethical Standards

Conflict of interest Authors have no relevant conflicts of interest or funding to disclose in the preparation and completion of this manuscript.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

References


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Outcome Analysis of Fixed Angle Locking Plate in Patella Fractures: A Single Centre Experience from North India

Saurabh Singh · Rishabh Surana · Alok Rai · Divyansh Sharma

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Abstract

Background  Tension band wiring supposedly is the most commonly used technique for displaced patella fractures, but is not effective in comminuted fractures and osteoporotic bones. It often leads to loosening of wires, dislocation of fracture, hardware problem and failure of osteosynthesis, resulting in knee stiffness and post-traumatic osteoarthritis. The aim of the study is to evaluate clinical outcome in patients with acute patella fractures (<3 week) treated with unidirectional angle fixed low-profile titanium patella locking plate.

Materials and methods  Twenty patients who presented with displaced patella fractures, aged between 18–70 years were included in the study. All fractures were reduced and fixed with unidirectional angle fixed stable low-profile titanium patella locking plate. Knee Range of motion and Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL) was used to evaluate the outcome.

Results  We were able to achieve union in 19 out of 20 patients. One patient with comminuted patella fracture had failure of fixation, which was revised. Mean flexion at final follow-up was 124° (110°–130°) and none of the patients had extensor lag. The final radiograph revealed complete union in all patients.

Conclusion  This technique offers an option of fixation in comminuted patella fracture and in osteoporotic individuals. It provides mechanical stability for fracture fixation resulting in anatomical reduction, good functional outcome, lower incidence of symptomatic implant or failure of osteosynthesis.

Keywords  Patella fracture · Comminuted · Osteoporotic · Locking plate · Osteosynthesis

Introduction

Patella fracture accounts for about 1% of total skeletal fractures [1]. Patella plays a pivotal role during knee flexion, squatting and kneeling, by increasing the effectiveness of quadriceps. Absolute articular reduction of patella fracture is necessary, since incongruency of as low as 2 mm results in osteoarthritis of the knee joint, and hence osteosynthesis in comminuted patella fracture becomes challenging [2]. Tension band wiring has been a gold standard for treatment of transverse patella fracture for long, but over time it has been realized that there are some biomechanical limitations in this procedure, such as (a) tension band wiring works only during flexion and tends to fail under cyclic loading in extension, since fragmentary compression is neutralized [3]; (b) tension band wiring also demands an intact cortical buttress so that the tensile force of the quadriceps and patella tendon can be converted into compression at the articular surface, and this may be a reason for its failure in osteoporotic patella fracture [4]; (c) during fracture healing of patella, a three-dimensional complex force, i.e. bending, compression and tension, acts on the surface which necessitates accurate reduction and rigid fixation with restoration of articular surface and extensor mechanism for the fracture to heal with the best possible outcome; (d) the principle of tension band wiring does not...
apply in cases of comminuted and oblique fractures. These limitations necessitate the development of various other techniques for patella fracture fixation. Several studies and methods have been developed over years for better fixation and multiple plates have been developed such as mesh plate, hook plate, and mini plate. In our study, we used a unidirectional angle fixed stable low-profile titanium plate with multiple holes and undercut margins. These undercut margins and suture holes help in preserving small bony fragments for maximum anatomical reconstruction. The pre-contoured angle fixed plate (Fig. 1) properly recesses into the soft tissue, so that though the patella is subcutaneous, there is minimum wound problem and hardware complication. To our best knowledge, only one study has been published so far with such locking plate, in a German population between 2011 and 2015, and our study in an Indian population has given comparable results [5].

Materials and methods

This prospective observational study was conducted from 2018 to 2020, at a tertiary care centre in North India. Twenty patients fulfilling the inclusion criteria and giving consent were enrolled for the study, in a span of 6 months. The aim of the study was to analyse the outcome of patella fracture fixation with locking plate. Inclusion criteria for the study were: (1) age 18 years to 70 year, (2) acute fracture <3 weeks old, (3) displaced transverse patella fracture, (4) comminuted patella fracture with articular incongruity or osteoporotic patella fracture.

Exclusion criteria were: (1) ipsilateral lower limb fracture around the knee, (2) open wound, (3) active local infection, (4) anterior knee soft tissue defects, (5) patella fracture post total knee replacement.

Technique

Standard patella fixation approach was used, keeping in mind to raise a thick flap to make sure the plate is covered with adequate soft tissue. In case of absence of any defect in the retinaculum due to injury, a 2 cm lateral arthrotomy was done to clinically palpate the articular reduction. Reduction was then secured with the help of k-wire and reduction clamp, following which the appropriate size star-shaped suture plate was chosen according to the fracture pattern and size of patella (Fig. 2a). The unidirectional angle fixed stable low-profile titanium patella locking plate by Arthrex (Germany) was used in all patients. It had undercut holes which were used in cases of comminuted fracture where small fragments could be held in reduction with the help of non-absorbable braided suture (Fig. 2b). After fixation of plate with locking screws, a finger is passed through lateral arthrotomy to check for any intra-articular penetration of the screws. Lateral view fluoroscopy is not so reliable owing to the triangular shape of the patella with the apex down, though skyline view may also be used alternatively. Stability of fixation is checked by knee flexion before closure (Fig. 2c).

Results

Over the course of 6 months, 53 patients presented with patella fracture at our trauma center, out of which 13 had undisplaced fracture pattern, 9 had associated ipsilateral lower limb fracture, 6 had open wound over patella and 1 had patella fracture post-total knee replacement. Out of the remaining 24 patients, 20 patients gave consent and were included in the prospective study.

Out of 20 patients, 3 were females and 17 were males. Average age was found to be 42 years. Thirteen patients

![Fig. 1  a–c Fixed angle anatomically precontoured patella locking plate. Larger holes are for locking screws, while the smaller holes have undercut margins to help in fixation of smaller fragments using suture](image-url)
had comminuted fracture and 7 had osteoporotic fracture. Average time of follow-up was 13 months (10 months to 21 months). Out of 20 patients, 19 achieved union (Fig. 3) except 1 (5%), with comminuted patella fracture had implant failure for which a revision surgery was done. Four out of 20 had their plates removed after union, Two of 20 (10%) had anterior knee pain and difficulty in kneeling due to implant impingement and the other two did not want to retain any hardware in their body, though the implant had no soft tissue irritation.

During follow-up, all the patients had full recovery of extensor mechanism (Fig. 4a). The Mean flexion achieved was 124°, 13 patients achieved flexion of minimum 130° (Fig. 4b) and the patient with implant failure on union achieved flexion of 110°. Most patients had no trouble in cross leg sitting (Fig. 4c). The influence of symptoms on daily activity is shown in Table 1 and the functional outcome of the patient was also well acceptable (Table 2). Eighteen out of 20 (90%) patients were pain free or slightly affected by pain in daily activity. Nineteen out of 20 (95%) did not have knee stiffness. Seventeen out of 20 (85%) did not have problem in walking. Four out of 20 (20%) patients had difficulty in kneeling on the front. None had difficulty in standing. One patient who underwent second surgery due to implant failure had some restrictions in daily activity and also complained of symptomatic pain. The average ADL score was 86%, which means the function of the patient’s knee in daily life returned to an average of 86% to their function before trauma.

**Discussion**

In this study we have done a prospective outcome analysis of patella fracture using unidirectional angle fixed stable low-profile titanium patella locking plate fixation and compared it with the available relevant data of tension band wiring.
Tension band wiring has prerequisites like transverse fracture pattern and intact cortical buttress to facilitate union [6]. The poor outcome of tension band wiring in comminuted displaced patella fracture led to development of various other methods for treatment of patella fracture such as basket plate, hook plate, and mini plate [7]. In our study, we used an anatomically pre-bend plate in all 20 patients, out of which only 1 patient underwent complication of implant failure (Fig. 5), i.e. 5% as compared to 20–30% failure rate in tension band wiring. Smith et al. reported that a significant displacement was seen during the perioperative period in as much as 22% patients treated with tension band wiring. This problem was overcome by the use of a more rigid construct like locking plate [8]. Dy et al. in his meta-analysis have reported that 34% patients underwent re-operation after tension band wiring as compared to 5% (1 in 20) by using locking plate, as seen in our study [9].

The Superiority of locking plate to tension band wiring has been proven in a biomechanical test by Wurm et al. [10] and a cadaveric study by Thelen et al. [11, 12]. This superiority has enabled us to engage patients with early rehabilitation protocol, thus avoiding problems of knee stiffness,

Table 1 Influence of symptoms on daily activity (KOS-ADL)

<table>
<thead>
<tr>
<th></th>
<th>I do not have the symptom</th>
<th>I have the symptom, but it does not affect my activity</th>
<th>The symptom affects my activity slightly</th>
<th>The symptom affects my activity moderately</th>
<th>The symptom affects my activity severely</th>
<th>The symptom prevents me from all daily activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>10</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stiffness</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Swelling</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Slipping</td>
<td>11</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Buckling</td>
<td>14</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weakness</td>
<td>18</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 4  a–c Functional outcome of locking plate post-union. a Presence of complete extension which was a consistent finding in all patients. b Most patients were able to achieve full flexion and do squat. c Most patients had no problem in cross leg sitting.
which is a well-documented complication in tension band wiring. We recommended our patients to start immediate weight bearing, passive flexion of up to 90° with brace support in the initial 2 weeks and then 120° degree passive knee flexion over the next 4 weeks.

Even after use of advanced techniques and early wound healing methods of tension band wiring, the subcutaneous nature of patella makes symptomatic implant as one of the most commonly encountered problems. Symptomatic implant is recorded in up to 60% patients with tension band wiring as compared to only 10% (considering patients' subjective symptom, but could be even less if it was because of cicatrix) in our method of fixation [13]. Other dreaded complications of tension band wiring like osteoarthritis, marginal fractures [14], and wire breakage [15] have also been well documented and can be easily avoidable using a locking plate. It provides excellent compression and a rigid construct along with the undercut surface of plate, which aids in fixing larger fragments with non-absorbable braided suture. Our method of fixation also permits direct clinical visualization of the articular surface which helps in a possible better outcome and avoids development of patella–femoral joint arthritis. An additional surgery was done in four patients for implant removal, only after at least 9 months of fixation, out of which only 2 had impingement while kneeling in the front and the other 2 desired not to retain any metal implant in their body. Similar tendencies have also been reported in other implants which maybe acknowledged to the social and psychological factor as opposed to irritation by implant [16].

In our study, a good functional recovery of range of motion was noted, with 124° as an average and 13 patients achieving at least 130°. Only one patient had flexion of 110°; this patient had undergone a revision operation due to implant failure and was revised with addition wire circlage and repositioning of the plate. Most of the patients were symptom free, and only two of them (10%) had moderate to severe pain as compared to 30–40% patients who have residual pain when fixation was done by tension band wiring or screw fixation [1]. Even in activities of daily life, most of the patients were asymptomatic. Three patients had severe problem in kneeling to the front, and two of them had their implant removed but did not show much benefit post-implant removal. Kneeling remained a problem for them even in further follow-ups, concluding that pain in kneeling was not because of the implant but because of the scar of the healed wound.

Wurm et al. [5] had done a study in a German population, using a similar plate. The average age in their study was 56 years as compared to 42 years in our study. The male: female ratio in their study was 0.67 as compared to 5.67 in our study, mainly because of the larger number of road traffic accidents in our country. They also included patients with periprosthetic patella fracture and failed tension band wiring. They achieved a range of motion of 127° and complication rate of 6%. The average ADL score in their study was

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity is not difficult</th>
<th>Activity is minimally difficult</th>
<th>Activity is somewhat difficult</th>
<th>Activity is fairly difficult</th>
<th>Activity is very difficult</th>
<th>I am unable to do the activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk</td>
<td>13</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Go upstairs</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Go downstairs</td>
<td>10</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Stand</td>
<td>15</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kneel on the front</td>
<td>8</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Squat</td>
<td>11</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Sit with your knee bent</td>
<td>12</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rise from a chair</td>
<td>13</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 2** Functional limitations with activities of daily living (KOS-ADL)

Scoring: each row has a maximum of 5 points and the lowest of 0 points, 5 being given to the best outcome and 0 to the worst. The first column is scored 5 points, followed in successive columns by scores of 4, 3, 2, 1, and 0 for the last column. The total points for all patients was calculated which came out to be 1205, and then divided by 70 (maximum points for individual patient)*20 (total no. Of patients in study). The average ADLs score calculated was 1205/1400 × 100 = 86%

![Fig. 5 Radiology of the patient presenting 2 months post-fixation with anterior knee pain and extensor lag, showing failure of implant](image-url)
77% as compared to 86% in our study. The results are almost reproducible in the Indian population, except for a better functional outcome in our study which may be because of inclusion of acute fractures only. They had a comparatively larger portion of patient having problem kneeling and squatting, which can be accountable to multiple operations a few patients underwent in the study and thus a larger anterior knee scar.

The advantages of plating over tension band wiring are that plating can be used in comminuted, oblique and osteoporotic patella fractures. It helps in preserving maximum bone, aiding in anatomical reduction which is important for normal quadriceps excursion. It has minimum wound problems, lesser hardware complication, reduced incidence of knee stiffness due to early rehabilitation protocol, and better visualized articular congruency especially helpful in comminuted and osteoporotic patella fracture.

The disadvantages of using locking plate are mainly the hardware cost, rigid fixation in compression might cause overtensioning of the patellar tendon, and the screws might penetrate intra-articularly if proper precautions are not taken.

Conclusions

Based on our results, we conclude that angle fixed low-profile patella locking plate is a more bone-preserving and better implant for treatment of patella fractures. This technique offers an option of fixation in comminuted patella fracture and fractured patella in osteoporotic individuals. It provides mechanical stability for fracture fixation, resulting in anatomical reduction, good functional outcome and decreased incidence of symptomatic implant or failure of osteosynthesis. The proven better biomechanical strength of the same has helped in early rehabilitation and return of patients back to their normal daily lifestyle.

Limitations

This was a prospective cross-sectional analytical study and direct comparison of the patella plate fixation with other modalities of treatment was not done. The results of the present study were compared with already existing data in the literature, which might have caused some bias to finding inferior outcomes of tension band wiring. The inclusion criteria of the current study included only acute fractures (<3 weeks) and primary fixation, and the use of a similar method in chronic or failed osteosynthesis by other methods may not give similar results. This study had a small sample size; further studies with bigger sample size and comparison with other modalities will aid in providing better comparative results.

Author contributions SS: conceptualization. RS: writing—original draft; writing—review and editing. AR: writing—original draft; writing—review and editing. DS: writing—original draft; writing—review and editing.

Funding None.

Compliance with Ethical Standards

Conflict of interest The author(s) have no conflicts of interest to declare.

Ethical standard statement All procedures performed in this study involving human participants were in accordance with the ethical standards of the Institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was taken from all patients.

References


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Identification of Tibial Malrotation After Nailing Using Unique CT Scan Reference Line, and Influence of Position of Leg for Distal Locking on Rotation

D. R. Ramprasath¹ · S. Vetrivel Chezian² · V. Surendar³

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Abstract

Introduction Tibial torsion can be measured by various clinical and radiological methods. Computed tomography (CT) scan measurement is currently the investigation of choice. The purpose of our study was to compare the clinical and CT scan methods to reveal malrotation after nailing of tibia and also to find out if leg position for distal locking has any influence on incidence of malrotation.

Materials and methods We have included 106 patients (21–68 years) of tibia nailing, and categorised them as category A (figure of four position \(n=54\)) and category B (knee straight position \(n=52\)) based on limb position for distal locking. The plumb line measurement, Thigh Foot Axis (TFA) and CT scan measurement (using new reference line) were documented and compared with the uninjured limb.

Results We observed plumb line measurement to be the most inaccurate method followed by TFA method. CT scan measurement was the most accurate method showing external rotations (> 10º) in 32 cases (30.1%) and internal rotation (> − 10º) in five cases (4.71%). The TFA method had a sensitivity of 44% and specificity of 86% in identifying malrotations. The interobserver reliability for CT scan measurement was 0.96. Even though statistically not significant (\(P\) value), figure of four position for distal locking leads to larger number of malrotations (both external and internal rotation).

Conclusion CT scan is the most accurate method of measuring malrotation. The new reference line used in our study provides accurate measurement of malrotation. The two different positions of leg for distal locking do not have a statistically significant influence on incidence of malrotation.

Keywords CT scan · Leg position · Malrotation · Tibia nailing · Tibial torsion · Rotation · Thigh · Tibia · Tibial fractures · Tomography

Introduction

Tibial torsion has been defined variously as torsion of tibia along its longitudinal axis [1]; relationship between the axis of rotation of the knee and transmalleolar axis [2]; the anatomical twist of the proximal versus distal articular axis of the tibial bone in the transverse plane around the longitudinal axis [3, 4]. Tibial torsion is neutral at birth, i.e., the malleoli are about level. The medial malleolus rotates forwards during growth, causing tibial torsion in the adult of approximately 20º (Le Damany 1909) [5].

Numerous authors have described various anthropometric, clinical and radiographic methods to determine tibial torsion, including direct measurement of cadaver bones [6], clinical assessment of patient’s limbs, and several imaging techniques using plain films [7], fluroscopy [8], CT [5], MRI.
The most accurate technique for measuring tibial torsion is anthropometric measurement on necropsy specimens. Although this approach is useful for establishing normative data, it cannot be used clinically [11]. The clinical methods for measurement of tibial torsion include thigh foot angle, bimalleolar angle [12–14], foot progression angle and thigh transmalleolar angle [15]. However, the accuracy of physical examination has not been proven [16].

In cases of tibial fractures fixed with intramedullary nail, distal locking is done with limb either in figure of four position, or with knee in straight position. This may create disparity in the rotational alignment of tibia.

The aim of our study was to determine the incidence and severity of tibial malrotation based on

1. Alignment of plumb line to second toe.
3. CT scan measurement (using posterior transcondylar axis as proximal reference line and anterior transmalleolar axis as distal reference line).

and categorising the findings for patients whose distal locking was done with limb in

1. Figure of four position
2. Straight position.

Materials and methods

This was a prospective study done over a period of 13 months (from October 2017 to November 2018). The patients were divided into two categories, with category A patients in whom distal locking was done with leg in figure of four position, and category B patients in whom distal locking was done in straight position. In category B patients the proximal jig was dismantled so that the knee could be extended for straight position.

All consecutive cases of closed fracture both bone leg in adults who consented for postoperative CT scan were included in the study. Compliance with ethical requirements was fulfilled. Paediatric patients, open fractures grade II and III, previous ipsilateral tibial trauma, ipsilateral proximal or distal tibial fractures, fractures extending into knee or ankle joint, multiple trauma, patients with pre-existing limb deformity and pregnancy were excluded from the study.

The patients were categorised as category A and category B and alternate case was operated positioning the limb either in figure of four position (category A) or straight position (category B) (Fig. 1). Fracture reduction was assessed by indirect methods like (a) shin in proximal fragment falling in line with shin in distal fragment which was revealed by palpation, (b) fluoroscopic guided correction of angulation and matching cortical thickness at fracture site.

Once the patient was able to bend the knee to 90°, the patient was made to sit on a table with both the legs suspended from the edge of the table. A plumb line was created by using a device having a thread with one end touching the tibial tuberosity and the other end hanging just anterior to and below toes (Fig. 2). The toe through which the plumb line passed was noted. The same was repeated on the opposite normal side.

Fig. 1 Distal locking in (a) figure of four position (b) straight position

Next the patient was made to lie prone with knee in 90° of flexion. With the help of a goniometer, the angle subtended between the thigh axis and foot axis (line passing from the centre of the heel to the second toe) was measured and documented (Fig. 3). The same was repeated on the opposite normal side.

A CT scan of both the legs was done with 3 mm axial cuts. A line drawn along the posterior condyles of tibia in the section just proximal to the fibular head section was considered as “proximal reference line”. Another line drawn along the anterior surface of medial and lateral malleoli in the section just distal to the articular surface section (of ankle) was considered as “distal reference line”.

The proximal and distal sections which were selected according to the previous description were aligned in the computer. The proximal and distal reference lines were drawn as described. The angle subtended between the
perpendicular lines drawn to the proximal and distal reference lines was documented (Fig. 4). Similar procedure was performed for the opposite side. The findings were documented as tabular column and statistical analysis was done. The difference in angle was recorded as “positive”, if the operated limb was found to be more externally rotated (ER) when compared to the normal limb. The difference in angle was recorded as “negative”, if the operated limb was found to be internally rotated (IR) when compared to the normal limb. Patients with difference of > 10° between operated and non-operated limbs were considered as malrotation cases. Another observer was assigned the measurement of torsion angles using the same axial cuts. The torsion angle of the contralateral normal tibia was tabulated separately.

**Statistical analysis**

The SPSS software version 20.0 was used for statistical analysis and the statistical significance ($P < 0.05$) for different methods of assessing external and internal rotation was done by Chi square test (Epi info version 7). The mean and standard deviation for the torsion of normal limbs were also calculated. The inter observer reliability was calculated using Pearson correlation coefficient method.

**Results**

There were a total of 106 patients in the age group of 21–68 years [mean – 38.3 years] with male, female distribution of 81:25. Out of 106 patients, 54 underwent distal locking in the figure of four position (category A), and the remaining 52 cases underwent distal locking in straight position (category B).

The plumb line was found to be away from second toe in 66 cases. Of these, the line passed medial to the second toe (i.e., denoting external rotation, ER) in 47 cases, and lateral
to the second toe (i.e., denoting internal rotation, IR) in 19 cases (Table 1).

The thigh foot axis measurement (compared to normal side) was same in 11 cases, internally rotated (> − 10°) in 3 cases, externally rotated (> 10°) in 21 cases. According to TFA method, the range of difference of external rotation observed was + 2° to + 30°. Similarly, the range of difference of internal rotation observed was − 2° to − 20°.

According to CT scan measurement, the range of difference of external rotation observed was + 2° to + 20°. Similarly, the range of difference of internal rotation observed was − 2° to − 20°. The number of cases with ER > 10° and IR > − 10° were tabulated (Table 2).

The statistical significance between plumb line measurement and CT measurement was calculated (P = 0.03 for ER > 10°, P = 0.04 for IR > − 10°). The statistical significance between TFA and CT measurement was calculated (P = 0.08 for ER > 10°, P = 0.47 for IR > − 10°). The number of cases of malrotation based on the position of the leg for distal locking (i.e., figure of four or straight knee position) was analysed separately and tabulated (Table 3). The statistical significance between figure of four position and straight position was calculated (P = 0.25 for ER > 10°, P = 0.65 for IR > − 10°).

The number of true positive cases and true negative cases were tabulated (Table 4) and sensitivity and specificity of TFA measurement was calculated. TFA measurement has a sensitivity of 44% and specificity of 86% when compared to CT measurement.

The tibial torsion angle in the operated tibia measured by two different observer was statistically analysed to calculate the correlation coefficient (inter observer reliability). The correlation coefficient between the two observers was 0.96.

The measurement of torsion angle in contra-lateral normal tibia demonstrated a torsion of 22° to 44° (29.25 ± 5.41) on the right side and a torsion of 20° to 40° (29.80 ± 5.49) on the left side (Table 5).

**Table 1** Distribution of cases according to plumb line measurement

<table>
<thead>
<tr>
<th>Plumb line</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Figure of 4 (Cat A)</td>
</tr>
<tr>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>1. Second toe</td>
<td>18 (16.98%)</td>
</tr>
<tr>
<td>2. Medial to the second toe (ER)</td>
<td>26 (24.5%)</td>
</tr>
<tr>
<td>3. Lateral to the second toe (IR)</td>
<td>10 (9.43%)</td>
</tr>
</tbody>
</table>

**Table 2** Distribution of cases according to TFA measurement and CT scan measurement

<table>
<thead>
<tr>
<th>Malrotation</th>
<th>Thigh foot axis n (%)</th>
<th>CT measurement n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External rotation &gt; 10°</td>
<td>21 (19.8%)</td>
<td>32 (30.1%)</td>
</tr>
<tr>
<td>Internal rotation &gt; − 10°</td>
<td>3 (2.83%)</td>
<td>5 (4.71%)</td>
</tr>
</tbody>
</table>

**Table 3** Distribution of cases based on position of limb for distal locking

<table>
<thead>
<tr>
<th>Malrotation</th>
<th>Figure of 4 (Cat A) n (%)</th>
<th>Straight (Cat B) n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thigh foot axis CT</td>
<td>Thigh foot axis CT</td>
</tr>
<tr>
<td>External rotation &gt; 10°</td>
<td>12 (11.3%)</td>
<td>19 (17.9%)</td>
</tr>
<tr>
<td>Internal rotation &gt; − 10°</td>
<td>2 (1.88%)</td>
<td>3 (2.83%)</td>
</tr>
</tbody>
</table>

**Table 4** Diagnosis of malrotation by thigh foot axis

<table>
<thead>
<tr>
<th>Method</th>
<th>CT &gt; 10° (ER + IR)</th>
<th>CT &lt; 10° (ER + IR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFA &gt; 10° (ER + IR) n = 24</td>
<td>16 (True positive)</td>
<td>8 (False positive)</td>
</tr>
<tr>
<td>TFA &lt; 10° (ER + IR) n = 82</td>
<td>24 (False negative)</td>
<td>58 (True Negative)</td>
</tr>
</tbody>
</table>

**Table 5** Tibial torsion in uninjured normal side

<table>
<thead>
<tr>
<th>Malrotation axis</th>
<th>No of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees</td>
<td>Right n (%)</td>
</tr>
<tr>
<td>20° to 30°</td>
<td>35 (33.01%)</td>
</tr>
<tr>
<td>&gt; 30°</td>
<td>22 (20.7%)</td>
</tr>
<tr>
<td>Total</td>
<td>57 (53.7%)</td>
</tr>
</tbody>
</table>
Discussion

Since tibia is one of the most common fractured long bones managed with intramedullary nailing, the number of patients with malrotations following intramedullary nailing is also high. This may range from subtle malrotations to gross malrotations causing gait alterations. Though clinical methods can be used as an easy measure to calculate the malrotation, most of them are inaccurate. Our study compares the clinical methods with the CT scan methods. Moreover, our study analyses the differences between rotational alignment after distal locking in two different positions of knee (figure of four and straight position).

There is no consensus in the literature regarding proximal and distal reference point in the measurement of torsion [17]. The proximal reference line quoted in the literature is either a line passing through the posterior condylar axis just proximal to the fibula head, or a line passing through the middle of the tibial condyles. The line joining the centre of both malleoli is most used as the distal reference axis [17]. The distal reference axis connecting the centre of the both malleoli may be skewed, since the two points are chosen arbitrarily and may, therefore, decrease the intra and inter-observer reliability. So, we have chosen a line connecting the anterior surface of both malleoli just distal to the articular surface in our study, and it rectifies this limitation of reliability, since we have used fixed landmarks. The measurement of torsion angle according to our method using fixed landmarks demonstrated an inter observer reliability of 0.96 (strong correlation). The difference in measuring methods and in definitions, explain why previous reports on tibial torsion in adult vary, on the average, from 14 to 24 degree [5].

Rotational deformities may lead to early onset osteoarthritis [22]. Tibial torsion plays an important role in patellofemoral arthritis [23], genu valgum and varum [24]. However, Bonnevialle et al. demonstrated that there was no correlation between tibial malrotation and arthrosis [25].

Court-Brown et al., and Puno et al. reported 3 and 1 cases of clinically detected malrotation after tibia nailing in groups of 125 and 51 patients, respectively [26, 27]. Detecting malrotation clinically was very difficult and may lead to underestimation of the extent of the problem.

In 1949, Hutter and Scott [7] used X rays to measure the torsion. In 1980, Jakob et al. [12] used CT scan to quantify the torsion. Among the radiological methods, CT measurement is the investigation of choice with good inter- and intra-observer reliability and repeatability [28]. In our study there was over estimation by plumb line method (47 patients) (P value-0.03) and underestimation by TFA method (21 patients) (P value – 0.08) by comparing with CT scan method (32 patients). So the plumb line method seems to be grossly inaccurate followed by TFA method. Moreover, according to our study, sensitivity of TFA measurement was 44% and specificity of TFA was 86%.

According to Trafton’s criteria, rotation deformities of more than 10° is considered as malrotation [29]. In our study, we have considered a difference of > 10° as malrotation. There are few studies which measured tibial malrotation following IMIL nailing. In a study of 22 patients Prasad et al. found a difference of 8° or greater in 36% of patients [30]. In a study of 89 patients Bonnevialle et al. found a difference of 6.84° in 27% of patients [25]. In a study of 25 patients Poluski et al. found malrotation of > 10° in 20% of patients [28]. In a study of 60 patients, Adel Ebrahimpour et al. found a malrotation of > 10° in 30% of patients [31]. In our study we observed tibial malrotation of > 10° in 30.1% (32) of patients.

Assuming that the position of leg for distal locking may have influence on malrotations, we analysed and categorised the malrotations based on leg position for distal locking. To our knowledge, there is no study that compares the malrotations based on leg position for distal locking. We observed external malrotation (> 10°) in 19 patients (17.9%) belonging to category A and 13 patients (12.2%) belonging to category B. Moreover, we have observed internal rotation of > − 10° in 5 cases (4.71%). Of these 5 cases, 3 were category A, and 2 were category B. Even though statistically not significant (P = 0.25 for ER > 10° and P = 0.65 for IR > − 10°), more number of malrotation in category A patients indicates that the figure of four position may lead to more malrotations (both ER and IR). The increased number of malrotations, especially external malrotations in category A may be attributed to difficulty in assessing rotational alignment in figure of four position. Future studies with larger sample size may be helpful to decide upon the impact of limb position for distal locking on the quantum of malrotation.

The tibial torsion in normal tibia was measured by CT scan in few studies. In a study of 50 normal subjects, Olav Reikeras et al. [5] reported a torsion of 32.3 ± 8.5° and 30.7 ± 10.4° for right and left side, respectively. In females. In the males, the values were 35.3 ± 7° and 32 ± 10.3°, respectively [5]. In a study of 100 legs, Arun B Mulla et al. [1] reported a torsion of 22.6 ± 7.8° and 20.6 ± 7.4° for right and left side, respectively, with a significant P value [1]. In the same study the mean left and right difference was 2° [1]. In our study, tibial torsion in uninjured tibia was found to be 29.25 ± 5.41° on right side and 29.80 ± 5.49° on left side. The difference between right and left legs, and hence the statistical significance could not be assessed in our study, because only one tibia was normal in each individual patient and the other tibia was injured.
Limitations of our study

The functional implications of malrotation were not included in the study.

Conclusion

The clinical methods commonly observed for analysing malrotation may underestimate/overestimate the real extent of the problem. CT scan provides the most accurate measurement of tibial malrotation. Anterior transmalleolar reference line uses fixed landmarks (conventional intersmalleolar reference line uses arbitrary landmarks), and, therefore, has a better interobserver reliability. In our study, the two different positions of limb for distal locking did not have a statistically significant influence on the incidence of malrotation. Further studies are needed to establish the impact of positioning of the limb for distal locking on malrotation.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical standard statement This study involved patients with fracture both bones of leg, who were managed in a tertiary care centre with multidisciplinary approach. We have performed only established and time tested procedures on these patients. We have not employed any new experimental methods (including surgical, pharmacological and radiological methods) on these patients. Every procedure was explained in detail to the patient, including the post operative CT scan for measurement of malrotation. We have exercised utmost care to follow the international principles of medical ethics in all our patients. We have also obtained informed consent for surgical aspects as well as for using their clinical and radiological images for scientific study purpose. As a corresponding author, I hold the full responsibility for any ethical related issues in this study.

Informed consent The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

References


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Long-Term Patient-Reported Knee Outcomes After Suprapatellar Intramedullary Tibial Nailing

Terrence S. Daley-Lindo1 · Matt Kerr1 · George J. Haidukewych1 · Kenneth J. Koval2 · Joshua A. Parry3 · Joshua R. Langford1

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Abstract
Background Suprapatellar nailing of tibial fractures has not been shown to affect short-term knee outcomes, however long-term outcomes are unknown. The purpose of this study was to report long-term patient-reported knee outcomes after suprapatellar nailing.

Methods Thirty-five adult patients with 37 tibial shaft fractures treated with suprapatellar nailing completed the Tegner-Lysholm Knee Score (TLKS) at an average of 5 years (range, 4–9 years) follow-up.

Results The median TLKS was 98 (interquartile range, 85–100): Scores were considered excellent in 24 (68%), good in 3 (9%), fair in 3 (9%), and poor in 5 (14%). Based on patient responses, 28 (80%) patients did not have a limp, 32 (91%) ambulated without assistance, 22 (63%) were pain free, 29 (83%) had no knee instability, 30 (86%) endorsed no catching or locking, 27 (77%) could climb stairs with no issue, and 24 (69%) had no problems with squatting. Patients with poor/fair outcomes on the TLKS were more likely to have had a complication [3 (38%) vs. 1 (4%), difference 34%, 95% confidence interval 1–65%] and had no detectable difference in age, gender, open fracture, fracture classification, or worker’s compensation.

Conclusion At long-term follow-up a majority of patients undergoing suprapatellar nailing had good/excellent knee outcomes. Poor/fair knee outcomes were associated with the development of complications.

Level of Evidence III, Retrospective cohort study.

Keywords Suprapatellar tibia intramedullary nail · Infrapatellar · Knee pain · Tegner-Lysholm Knee Score · Patient-reported outcomes

Introduction

Suprapatellar nailing has been widely adopted for the fixation of tibial shaft fractures as it allows for easier fracture reduction, better fracture alignment, and less fluoroscopy time [1–3]. Since the introduction of suprapatellar nailing there have been persistent concerns regarding articular damage to the patellofemoral joint secondary to the insertion of the nail, however clinical results have yet to demonstrate this [1, 3–7].

Outcome data extending beyond 12 months after suprapatellar nailing is limited and do not show increased rates of knee pain or arthritic changes compared to infrapatellar nailing [2, 3]. If this approach does result in cartilage damage longer-term follow-up may be necessary to detect increased rates of knee pain. The purpose of this study was to report long-term knee outcomes after suprapatellar nailing of tibial shaft fractures.

Materials and Methods

After institutional review board approval a chart review was performed to identify all patients who sustained a tibial shaft fracture treated with suprapatellar intramedullary...
nail at a level one trauma center between 2009 and 2013. We identified 148 tibial shaft fractures.

In brief, suprapatellar nailing was performed through a midline suprapatellar incision. A starting wire was then passed through the patellofemoral joint to achieve a starting point just medial to the lateral tibial eminence on the anteroposterior radiograph and just anterior to the articular surface on the lateral radiograph, with the wire parallel to the slope of the anterior tibia [8]. A protected cannula was then placed over the starting wire. A starting reamer was used, followed by sequential shaft reamers until reaching 1.5 mm over the desired nail diameter. The nail was then inserted and fixed proximally and distally with interlocking screws. After confirmation of reduction and hardware placement the insertion handle and cannula were removed from the knee. The knee was then irrigated with saline and closed in a layered fashion. Postoperatively patients were made weight bearing as tolerated with no restrictions in knee range of motion. Suprapatellar nails utilized included the Expert Tibial Nail (Depuy Synthes, Warsaw, IN) and the T2 Tibial Nail (Stryker, Kalamazoo, MI).

Patients who were non-English speakers or who had concurrent ipsilateral knee injuries were excluded. We successfully contacted and consented 35 patients with 37 tibial shaft fractures via telephone. The median patient age was 32 years (interquartile range, 26–53 years), 25 (69%) were male, and the average follow-up time was 5 years (range, 4–9 years). Open fractures were present in 10 (28%). Worker compensation was involved in 4 (11%) patients.

The Tegner-Lysholm Knee Score (TLKS), a knee-specific patient reported outcome measure used in multiple studies to evaluate knee outcomes after tibia nailing, was administered over the phone [2, 7, 9, 10]. In this scoring system, a score of > 90 is excellent, 85–90 is good, 65–84 is fair, and < 65 is poor. Patients were asked if they had undergone any subsequent surgeries to the knee, excluding proximal interlock screw removal, since the initial surgery. The medical record was reviewed for complications and reoperations.

Nonparametric statistical tests were used based on the presence of non-normally distributed data as determined by the Shapiro-Wilks test. Continuous data is as the median and interquartile range (IQR). The Wilcoxon rank sum test and the Fisher Exact test was used to compare continuous and categorical variables between groups, respectively. The difference in medians along with the 95% confidence interval (CI) between non-parametric continuous variables was calculated with the Hodges-Lehmann estimator. A \( p \)-value less than 0.05 was considered statistically significant. All analyses were carried out using JMP Pro version 14 statistical software (SAS; Cary, NC).

**Results**

The median TLKS was 98 (interquartile range, 85–100): Scores were considered excellent in 24 (68%), good in 3 (9%), fair in 3 (9%), and poor in 5 (14%). Based on patient responses, 28 (80%) patients did not have a limp, 32 (91%) ambulated without assistance, 22 (63%) were pain free, 29 (83%) had no knee instability, 30 (86%) endorsed no catching or locking, 27 (77%) could climb stairs with no issue, and 24 (69%) had no problems with squatting.

Patients with poor/fair outcomes on the TLKS, compared to those with good/excellent outcomes, were more likely to have had a complication, but had no detectable difference in age, gender, open fracture AO/OTA fracture classification, or worker’s compensation (Table 1). The confidence intervals were wide for all observed differences between these groups, therefore clinically significant differences cannot be excluded.

There were 4 (11%) complications, all secondary to osteomyelitis after open fracture. None of the infections involved the knee joint. All patients required operative debridement.

<table>
<thead>
<tr>
<th>Continuous variables</th>
<th>Excellent/good TLKS (( \geq 85 )) (n = 27)</th>
<th>Poor/fair TLKS ((&lt; 85 )) (n = 8)</th>
<th>Difference, 95% CI</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>31 (26–53)</td>
<td>45 (27–53)</td>
<td>3, −13 to 22</td>
<td>0.6</td>
</tr>
<tr>
<td>Female gender</td>
<td>9 (33%)</td>
<td>2 (25%)</td>
<td>−8%, −38 to 29%</td>
<td>1.0</td>
</tr>
<tr>
<td>Open fracture</td>
<td>7 (26%)</td>
<td>3 (38%)</td>
<td>12%, −22 to 47%</td>
<td>0.6</td>
</tr>
<tr>
<td>AO/OTA classification</td>
<td>A: 19 (70%)</td>
<td>A: 5 (63%)</td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>B: 3 (11%)</td>
<td>B: 1 (13%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C: 5 (19%)</td>
<td>C: 2 (25%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complication</td>
<td>1 (4%)</td>
<td>3 (38%)</td>
<td>34%, 1 to 65%</td>
<td>0.03*</td>
</tr>
<tr>
<td>Worker’s compensation</td>
<td>3 (11%)</td>
<td>1 (12%)</td>
<td>1%, −22 to 34%</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Continuous variables are presented as median (interquartile range) and nominal variables are presented as \( n \) (%)

**TLKS** Tegner Lysholm Knee Score, **CI** confidence interval

*\( A \) \( p \)-value less than 0.05 was considered statistically significant
Three patients underwent nail removal through an infrapatellar approach. Two of these patients required antibiotic spacer placement and had a poor TLKS (60 and 38, respectively). The third patient requiring nail removal had an excellent TLKS of 100. The fourth patient, who did not require nail removal, had a fair TLKS of 80.

There were five patients who had symptomatic interlock screw removal, all of which reported no knee pain and a TLKS of 100.

**Discussion**

Suprapatellar nailing of tibial shaft fractures has been increasingly adopted over the last decade with limited long-term follow-up. Insertion of a nail through the patellofemoral joint has raised concerns over damage to the articular surface [4–6]. This study found that at an average of 5 years after suprapatellar nailing 77% of patients had excellent/good knee outcomes. Poor/fair knee outcomes in this cohort were associated with the development of a complication, which included four patients with osteomyelitis that required debridement and removal of the nail in three patients.

The median TLKS of 95 observed in our study compares favorably with other studies looking at the short-term knee outcomes after suprapatellar nailing. Serbest et al. [10] performed a prospective study of suprapatellar nailing in 21 patients with a minimum of 12 months of follow-up and reported an average TLKS of 95. Arthroscopy performed after the procedure did not identify articular damage in any of the patients. Additionally, none of the patients endorsed anterior knee pain or functional limitations. Similarly, Chan et al. [2] reported an average TLKS of 98 in patients undergoing SP nailing at 12 months with no patients endorsing anterior knee pain.

Although long-term knee outcomes after suprapatellar nailing is unavailable, it is known for infrapatellar nailing: The incidence of knee pain after this procedure has been reported to be high, ranging from 30 to 69% with functional limitations being prevalent across studies [11–13]. Lefaivre et al. [7] collected outcome scores on 56 patients a median of 14 years after infrapatellar nailing and found 73% of patients had at least moderate knee pain. A prospective randomized control trial comparing transtendinous vs. paratendinous infrapatellar nailing at 3 years found that 67% vs. 71% of patients complained of anterior knee pain and had an average TLKS of 90 and 92, respectively.

Direct comparisons of long-term patient-reported knee outcomes after suprapatellar vs. infrapatellar nailing are currently not available. Chan et al. [2] did compare knee pain and TLKS between the two approaches at 12 months in a prospective randomized control pilot study of 41 patients and reported no difference in knee pain or TLKS, with scores of 86 and 98 in the infrapatellar and suprapatellar groups, respectively. This study that was not sufficiently powered to detect a minimal clinical significant difference (MCID) in TLKS between these groups. Based on the average (± standard deviation) TLKS observed in our study (87 ± 21) we estimate that the MCID in TLKS would be 10 points [14]. We estimate that 138 patients would be needed to detect a 10-point MCID in the TLKS between suprapatellar and infrapatellar nailing for a two-sided 0.05-level test with a power of 80%.

The findings of this study are limited by the lack of a control group and its reliance on phone survey information. As such, we are unable to comment on clinical or radiographic outcomes like range of motion or arthritic changes, and how this compares to infrapatellar nailing. We were only able to successfully contact and survey 35 patients due the inherent difficulties of contacting a trauma population several years after injury, which could also bias our results. Another limitation includes the lack of preoperative knee outcomes, however this is currently a limitation of all studies on this subject as pre-injury outcomes cannot be obtained secondary to the nature of trauma. Other factors that could result in knee pain, such a limb alignment, were also not evaluated, however the goal of this study was to obtain baseline TLKS scores in this patient population for comparison with data from the infrapatellar nail population. If suprapatellar nailing does result in increased knee pain, this group would expect to have higher rates of knee pain regardless of other factors. Finally, this study was underpowered to detect differences in variables that could affect knee outcomes scores as evidenced by the wide confidence intervals.

Despite this study’s limitations, it is the first study to report patient-reported knee-specific outcomes at long-term follow-up after suprapatellar nailing. This data is valuable because it can be compared against long-term outcomes after infrapatellar nailing, which is available in the literature. In addition, we were able to use this data to perform a sample size calculation that can be use for the development of future prospective studies comparing long-term knee outcomes after suprapatellar and infrapatellar nailing.

**Conclusion**

At long-term follow-up a majority of patients undergoing suprapatellar nailing had good/excellent knee outcomes. Poor/fair knee outcomes were associated with the development of complications that required revision surgery. The findings of this study allowed for the sample size calculation necessary for future studies to compare the long-term knee outcomes between suprapatellar and infrapatellar nailing.
Funding  None.

Compliance with ethical standards

Conflict of interest  The authors declare that they have no conflict of interest.

Ethical standard  This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent  For this type of study informed consent is not required.

References


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Management of Neglected Upper Cervical Spine Injuries

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Abstract
Background Injuries involving upper cervical spine are serious and fatal injuries which are associated with alteration of normal occipital–cervical anatomy. These injuries may result in permanent neurologic deficits or neck deformity if not treated in a timely and appropriate manner.

Objective To evaluate the outcomes of neglected upper cervical spine injuries treated by various methods.

Study design Retrospective study.

Materials and methods Twelve patients attending ER or OPD with a history of neck trauma and who were diagnosed with fractures and fracture dislocations C1 and C2 were included in the study. Fresh injuries sustained within a week were excluded from study. The outcomes were measured in terms of improvement in VAS, ODI Scores and correction of the neck deformity. Surgical parameters like duration of surgery and blood loss were also observed.

Results Eleven males and one female. The mean age was 40.9 ± 16.9 (07–67 years). Eleven patients underwent posterior instrumentation, while one patient was treated anteriorly. The mean delay in presentation was 28 ± 8.67 days (15–42 days). The mean duration of surgery was 188.3 ± 34.35 min (120–240 min), average blood loss was 350 ± 111.8 ml (150–600 ml). The mean VAS improved from 8.45 ± 0.89 to 3.9 ± 0.51 (p < 0.05). The mean ODI Pre-operatively was 88.45 ± 5.89 which improved to 31.9 ± 4.01 (p < 0.05). The neck deformity/torticollis was corrected in all the patients.

Conclusions Neglected upper cervical spine injuries are difficult to treat and a posterior approach is helpful in reducing the subluxations indirectly and to obtain a posterior fusion.

Keywords Upper cervical spine · C1–C2 fractures and fracture dislocation · Neglected fractures · Cervical deformity

Introduction
Injuries involving upper cervical spine are serious and fatal injuries which are associated with alteration of normal occipital–cervical anatomy [1]. The relation of odontoid to the ring of atlas is unique. The major factors providing stability to atlas and axis are the transverse ligament and the C1–C2 joints. If the injury leads to disruption of these stabilizing factors, atlanto-axial dislocation ensues which may manifest clinically as cervical deformity [2, 3].

Upper cervical spine injuries consists of fractures of atlas and axis with or without atlanto-axial dislocations [2]. Neglected spinal injuries are defined as injuries not treated in a timely fashion and found late when options are limited [3]. Overlooked diagnosis is the most common cause of delayed presentation. These injuries may be overlooked when associated serious and distracting peripheral injuries co-exist. Altered consciousness and poly trauma patients...
having C1–C2 injuries are also often missed [3]. The single most common error made in not diagnosing these injuries is the failure to obtain an adequate series of cervical spine radiographs [4, 5].

Anderson and D’Alonzo type II fractures are the commonest type of fractures of Odontoid [6]. These may be part of high-energy injuries in young adult population, but may be associated with even low-energy trauma in children and older population [7]. Progressive neural deficit is the most serious concern of overlooked spinal injuries. They result in progressive deformity and persistent pain which could be avoided with early diagnosis and timely surgical intervention [3, 8]. The treatment becomes more challenging when the injuries present late to the emergency. Literature is sparse in guiding the management of neglected upper cervical spine injuries. We carried out this study to find out the challenges in the treatment of neglected upper cervical spine injuries with deformity.

**Materials and methods**

This retrospective study was conducted in a tertiary health care teaching hospital. Records of 12 Patients were analyzed after obtaining Ethical clearance. Patients attending ER (Emergency Room) or OPD (Out Patient Department) with a history of neck trauma, who were diagnosed with fractures of C1, C2, were included in the study. Fresh injuries sustained within a week and fracture below C3 vertebra were excluded from the study. The patients underwent AP and Lateral X-rays, CT angiography and MRI of Cervical spine along with detailed clinical work-up. The main mode of fixation was C1 lateral mass and C2 pedicle/pars screws with extension to C3 or C4 as required. The patient was placed prone on Mayfield/skull traction with cervical spine in flexion. In neglected injuries, often the reduction of subluxation is difficult due to contracted soft tissues and capsule of the joint. To reduce the subluxation, sufficient soft tissue release in the vicinity of C1–C2 joints may be required. After taking hold in C1 lateral mass on either side, placement of C2 pedicle screw or C2 pars screw was carried out. The overhanging part of superior facet of C2 was burred when required [9]. An axial traction was given in the direction of the deformity after placement of all the screws. Once the locked facets were disengaged, extension was carried out to gain congruous joint which was then confirmed radiographically before placing rods. Depending on the morphology of fracture, instrumentation was either stopped at C2 or extended to C3, residual subluxation reduced once the rods were tightened to the screws. The procedure was carried out under intra-operative neuro-monitoring. Posterior and posterolateral fusion was done using autologous graft harvested from posterior iliac crest. One patient who had Type 1 Hangman fracture had concomitant fracture dislocation involving C3–C4, underwent corpectomy C4 and anterior instrumentation from C2 to C5. The outcomes were measured in terms of improvement in VAS (Visual Analogue Scale), ODI (Oswestry Disability Index) Scores and correction of the neck deformity. Surgical parameters like duration of surgery and blood loss were also observed.

**Results**

Twelve patients were included in this study; eleven males and one female. The mean age was 40.9 ± 16.9 years (07–67 years). The most common mechanism of injury in our patients was fall from height: 08 out of 12 patients, three suffered injuries as a result of road traffic accident. One elderly patient had a hit on the forehead during sudden deceleration. The mean delay in presentation to hospital after injury was 28 days ± 8.67 days (15–42 days). Six patients had type 2 odontoid fractures with atlanto-axial subluxations; four Hangmans fractures; two were fractures subluxation C2–C3. Out of twelve, six patients had signs of myelopathy like increase in tone, exaggerated reflexes and plantar extensor, among six, four were Nurick grade 1 and two were Nurick grade 0 [10]. Two patient with Nurick grade 1 had motor weakness in both upper and lower limbs (ASIA D) (Table 1). Eleven patients underwent posterior instrumentation with an attempt at indirect reduction of the subluxation (Fig. 1), one patient underwent anterior instrumentation. Complete recovery of weakness was seen in all with some residual spasticity and weakness of hand grip in two patients. The mean duration of surgery was 188.3 ± 34.35 min (120–240 min) and average blood loss was 350 ± 111.8 ml (150–600 ml). The mean VAS Score pre-operatively was 8.45 ± 0.89. There was significant improvement in the mean post-operative VAS score to 3.9 ± 0.51 (p < 0.05). The mean ODI pre-operatively was 88.45 ± 5.8 (78–98) which improved to 31.9 ± 4.01 (26–46) post-operatively (p < 0.05). The neck deformity/torticollis was improved in all the patients (Fig. 2). All the patients had improved functional outcomes at the end of 1 year. One patient had lateral breach of C1 lateral mass screw (right side); however, she was asymptomatic in the post-operative period. Increased bleeding during dissection and release was seen in two patients intra-operatively which was promptly reduced and controlled by routine methods.

**Discussion**

Neglected spinal injuries are frequently encountered in the developing world. Overlooked diagnoses, poor accessibility to healthcare and socio-economic factors are the major
<table>
<thead>
<tr>
<th>S. no</th>
<th>Age</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>Mechanism of injury</th>
<th>Duration between injury and surgery (days)</th>
<th>Pre-op myelopathy score (Nurick, mJOA)</th>
<th>Pre-op neurology</th>
<th>Surgical procedure</th>
<th>Duration (minutes)</th>
<th>Estimated blood loss (ml)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>M</td>
<td>Type 2 displaced odontoid fracture with Right C2 lateral mass fracture with C1–C2 subluxation</td>
<td>Fall from height (Roof of house)</td>
<td>30</td>
<td>Nurick-0, mJOA-18</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C3</td>
<td>210</td>
<td>400</td>
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<tr>
<td>2</td>
<td>32</td>
<td>M</td>
<td>Type 2 displaced odontoid fracture with B1 fracture Anterior arch atlas</td>
<td>Fall from height during work</td>
<td>37</td>
<td>Nurick-Nil, mJOA-18</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C2</td>
<td>120</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>61</td>
<td>M</td>
<td>Type 2 displaced odontoid with atlanto-axial subluxation</td>
<td>Motor vehicle accident (Deceleration injury)</td>
<td>42</td>
<td>Nurick-0, mJOA-17</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C2</td>
<td>150</td>
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<tr>
<td>4</td>
<td>27</td>
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<td>Type 2 displaced odontoid with atlanto-axial dislocation (Locked facets)</td>
<td>Fall from height (Roof of house)</td>
<td>38</td>
<td>Nurick-1, mJOA-16</td>
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<td>5</td>
<td>54</td>
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<td>Type 3 Hangmans fracture C2</td>
<td>Motor vehicle accident</td>
<td>15</td>
<td>Nurick-Nil, mJOA-18</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C3</td>
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<td>6</td>
<td>7</td>
<td>M</td>
<td>Type 1 Hangmans fracture C2 with C3–C4 fracture dislocation</td>
<td>Fall from height (Roof of house)</td>
<td>24</td>
<td>Nurick-1, mJOA-15</td>
<td>ASIA D</td>
<td>Anterior cervical plating C2–C5</td>
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<td>7</td>
<td>35</td>
<td>M</td>
<td>Type 2 displaced odontoid with atlanto-axial subluxation</td>
<td>Fall from Height (during repair)</td>
<td>34</td>
<td>Nurick-Nil, mJOA-18</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C2</td>
<td>220</td>
<td>400</td>
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<td>8</td>
<td>58</td>
<td>F</td>
<td>Type 3 Hangmans fracture C2</td>
<td>Fall from height (tree)</td>
<td>28</td>
<td>Nurick-Nil, mJOA-18</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C3</td>
<td>240</td>
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<td>9</td>
<td>67</td>
<td>M</td>
<td>C2–C3 Subluxation with fracture spinous process C3, C4 and fracture lateral mass C2</td>
<td>Motor vehicle accident</td>
<td>19</td>
<td>Nurick-Nil, mJOA-18</td>
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<td>10</td>
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<td>C2–C3 Subluxation with fracture C3 lateral mass</td>
<td>Motor vehicle accident</td>
<td>22</td>
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<td>ASIA E</td>
<td>Posterior instrumentation C2–C4</td>
<td>160</td>
<td>150</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>M</td>
<td>Type 2 displaced odontoid with atlanto-axial subluxation</td>
<td>Fall from height (Roof of house)</td>
<td>15</td>
<td>Nurick-1, mJOA-17</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C2</td>
<td>180</td>
<td>300</td>
</tr>
<tr>
<td>12</td>
<td>35</td>
<td>M</td>
<td>Type 2 Hangmans fracture C2 with fracture lateral mass C3</td>
<td>Fall from height (electric pole)</td>
<td>32</td>
<td>Nurick-1, mJOA-16</td>
<td>ASIA E</td>
<td>Posterior instrumentation C1–C3</td>
<td>240</td>
<td>450</td>
</tr>
</tbody>
</table>

Odontoid fracture: Anderson and D’ Alonso classification, Hangman fracture: Levine and Edwards Classification
reasons for such occurrences [3]. Overlooked spinal injuries are far more common in the cervical spine compared with the thoracolumbar spine and sacrum. The overall incidence of overlooked spinal column injuries with or without neurologic deficit varies between 4 and 30% [11, 12]. The initial diagnosis of cervical spine injury relies on proper patient selection on a clinical basis, obtaining appropriate radiographs, and properly interpreting them. Injuries to the cervical spine occur in approximately 3% of patients with major trauma and in 10% of patients with serious head injuries [9, 13].

It is a well-known fact that type 2 odontoid fractures frequently go into nonunion. The reported rate in literature varies between 26 and 76% [6]. If left untreated, patients may develop irreducible atlantoaxial dislocation (AAD). The most serious consequence of overlooked spinal injuries is progressive neural deficit. Certain fractures are known to commonly escape detection on plain radiographs. Clark et al. reported delayed radiologic diagnosis in 23% of odontoid, 16% of teardrop, 14% of facet, and 10% of hangman’s fractures. In a multicenter study, the Spinal Surgery Study Group of the Italian Society of Neurosurgery reviewed 172 patients with cervical spine injury who had surgical stabilization more than 20 days after the initial trauma [14]. Webb et al. described seven cases of late vertebral deformity after flexion injuries of the cervical spine. In four of these, the clinical and radiologic features were subtle and because the patients walked into the emergency department the severity of the injury was not initially appreciated [15]. Majority of the patients in our study were males (11 out of 12). Chowdhury et al. and Yadav et al. in different studies also showed that these injuries are more common among men. The mean age of the patients in our study was 40.9 years (range 07–67 years). This morphology of fracture was more prevalent in elderly age group where mostly, the trauma was due to fall from height and did not have any associated injuries. In a similar study of 33 patients done by Wang et al. the mean age of the patients with supra-axial cervical spine

Fig. 1 A 61-year-old male presented to us with neck pain and cervical myelopathy following sudden de-acceleration injury a Pre-operative X-ray of cervical spine lateral view in flexion b Pre-operative X-ray of cervical spine lateral view in extension c MRI of cervical spine (sagittal) showing compression of cord and subluxation d MRI of cervical spine (axial) showing compression of cord e CT Scan sagittal view showing fracture of dens (D’ Alonzo type II) with C1–C2 subluxation f Immediate post-operative X-ray cervical spine lateral view g Final follow-up X-ray cervical spine lateral view h Final follow-up CT scan showing maintenance of good reduction and fracture union
injuries was 32 years [16]. In a study done by Frangen et al. among 27 patients, the mean age was 85.5 years [17]. The majority of the population was old age. This indicates that the main population affected by supra-axial cervical spine injuries is elderly population. Due to decreased care and neglect of such elderly population, the fractures of the cervical spine can easily be missed after a fall. It is only when the neck deformity persists, or neck movements become painful, the patients come back for further treatment.

The mean delay in presentation to hospital after injury was 28 ± 8.67 days (15–42 days). This delay occurs due to lag period from the time of injury to the diagnosis in the local hospital and also the time taken for travel to the tertiary hospital. The mean duration of surgery was 188.3 ± 34.3 min (120–240 min). Neglected atlanto-axial dislocations can be treated by posterior technique by facet joint manipulation and remodeling. Joint manipulation involves distraction of C1–C2 joints while remodeling involves drilling or osteotomizing the overhang of C2 and if required C1 facet [18, 19]. In a situation where the subluxation does not reduce with adequate posterior release, an anterior approach for the direct release and decompression may be required. In a study by Hao DJ et al. ten patients of irreducible atlanto-axial subluxations were treated by one-stage anterior release and reduction with posterior fusion with satisfactory outcome [20]. Wang et al. in his study of 33 patients, described Trans oral release of irreducible atlanto-axial joint dislocation where all the patients went in for fusion with good outcomes [16], Yadav et al. described single-stage anterior release and anterior fusion for irreducible atlanto-axial dislocations with good functional outcomes in 15 patients [20]. The duration of surgery increased as the time duration from injury to presentation increased. Similar studies done by Yadav et al. and Fragen et al. had mean operative time duration of 145 min and 139 min, respectively [17, 20]. The average blood loss was 350 ± 111.8 ml in our study. The studies where anterior procedures were done like Wu et al. Frangen et al. Yadav et al. had average blood loss of 150, 120 and 70 ml, respectively [17, 21, 22].
Six patients in our study had some neurologic compromise on presentation where four were Nurick grade 1 and two were Nurick grade 0 [10]. No patient had complete quadriplegia. At the end of the treatment, all the patients had complete recovery of the weakness with mild residual spasticity in two patients. In studies done exclusively on supraaxial injuries like Wang et al. Chowdhary et al. Wu et al. majority of the patients have shown improvement in neurological compromise at the end of the treatment [22–24]. The VAS and ODI scores significantly improved at the end of one year in our study indicated by p values < 0.05. Similarly, a study was done by Aebi et al. which had significant improvement in VAS and ODI scores. There was significant improvement in the neck deformity in all the patients which indicated reduction of the dislocation/subluxation. The main challenges in treating neglected supra-axial dislocations are the difficulty in reduction and the release around the capsule of C1C2 joint. Most of the times, the “all-posterior technique” works as shown by our study but if the dislocation is irreducible even after release, anterior approach should be used. A number of new instruments like such as T-type and L-type reducers have been used by various authors to facilitate joint reduction in cases of subluxed atlanto-axial joints, but these instruments are less beneficial in long-standing complete dislocations [25]. Another challenge is the bleeding during release that happens while clearing the fibrosis. A proper preparedness to counter increased bleeding with materials like gel foam, cellulose polymer or hemostatic matrix is very necessary before starting the procedure.

### Conclusion

Neglected supra-axial cervical spine injuries are always difficult to treat as direct reduction of associated odontoid fractures with routine anterior approaches becomes difficult due to contracted soft tissues. In such conditions, a posterior approach would be helpful in reducing the subluxations indirectly and also to obtain a posterior fusion. These neglected fractures can be treated by posterior approach with a good clinical outcome as described in our study. The outcomes of an adequately treated supra-axial cervical spine injuries are more than satisfactory and should always be treated irrespective of the time passed by after injury.

### Funding

None.

### Compliance with Ethical Standards

#### Conflict of interest

None.

#### Ethical standard statement

All procedures performed in the study were in accordance with the ethical standard of the Institutional Ethics Committee (IEC) and with the 1964 Helsinki declaration and its later amendments or comparable standards.

### Informed consent

We have obtained all appropriate patient consent forms. The patients have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity.

### References


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Analysis of Factors Affecting Return to Work After Surgical Treatment in Patients with AO Type C Distal Humerus Fractures

Mert Kumbaraci1 · Can Doruk Basa1 · Ali Turgut1

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Abstract
Background The purpose of this study is to evaluate the functional results of distal humerus fractures which were treated by open reduction and fixation with pre-contoured angular stable plates in young patients, and investigate whether the patients could return to their pre-injury work and patients’ financial conditions while they were not working.

Materials and Methods The data of 48 patients, ages between 18 and 55 years, working in a job and having AO/OTA type C distal humerus fracture were retrospectively evaluated. Mayo Elbow Performance Score (MEPS) was used to determine functional results. Postoperative radiographs were evaluated to determine the rate of union, degenerative changes, malunion and heterotopic ossification. Financial outcome form was constituted by the authors and the patients asked whether she/he could return to their pre-injury works after treatment finished and the financial status of the patients during the treatment and after the treatment.

Results The mean flexion–extension arc was \(114° \pm 12°\) (range 85°–135°) and the mean MEPS score was \(85 \pm 11\) (range 65–100). The average time to return to work was \(6.5 \pm 2.4\) months (3–12 months). AO type C2 and C3 fractures and heterotopic ossification negatively affected the functional results and also adversely affected the patients’ return to their pre-injury works. 38 (79%) patients returned to pre-injury work and 29 (76%) of them started to work at the same position before the fracture occurred. Nine of 38 patients (24%) had to change their positions. Among the 48 patients, 10 patients (21%) could not return to the same work, 7 of them found light duty and 3 of them had not been to work.

Conclusion Although the functional results of surgical treatment of intra-articular distal humerus fractures are good, at the end of the treatment, especially heavy workers may have difficulties in returning to their former works.

Keywords Distal humerus fracture · Angular stable fixation · Functional results · Return to pre-injury work

Introduction

Intra-articular distal humerus fractures (DHF) are relatively rare injuries and constitute approximately 2% of all fractures [1]. Like all other intra-articular fractures, an anatomic reduction of the articular surface and rigid fixation of the fracture which can tolerate early range of motion are mandatory for success of the treatment. The aim of the treatment of these fractures is to achieve an elbow which is painless, stable, and mobile. The rehabilitation process is very important both for the patient to be functionally independent and to return to pre-injury work. However, the complexity of the anatomy, possible soft tissue contractures and heterotopic ossifications can all affect the success of the treatment adversely [2–5].

Distal humerus fractures often occur with low-energy trauma in elderly and osteoporotic patients and resulting in higher-energy trauma in young, active and working adults [1, 3]. Especially, working accidents and traffic accidents cause distal humeral fractures and these fractures cause the patients to return to their jobs late or to have to change their jobs or positions. Although scoring systems such as Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire and general health status measured with the Short Form-36...
(SF-36) survey, mental component summary (MCS) and physical component summary (PCS) were used in determination of returning to work after upper extremity injuries, we could not find any information about type C distal humerus fractures [6].

There are many studies about the results of distal humeral fracture treatment [7–13]. However, none of these studies evaluates return of the patients to their pre-injury works and the possible financial effects of this injury on the patients. Returning to pre-injury work is a necessity for most of the fractured patients because of financial issues. The purpose of this study is to evaluate the functional results of DHF, which were treated by open reduction and fixation with pre-contoured angular stable plates in young patients, and investigate whether the patients could return to their pre-injury occupation level and patients' financial conditions while they were not working.

Our hypothesis is that the patients who had intra-articular DHF treated with open reduction and internal fixation may have difficulty returning to their pre-injury works, even though their functional results are good.

Materials and Methods

The patients who had intra-articular DHF treated with open reduction and pre-contoured angular stable plate fixation between January 2010 and January 2017 were evaluated retrospectively. The patients between 18 and 55 years of age, working in a job and having type C distal humerus fracture according to AO/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association) classification system were included in the study. Exclusion criteria were: extra-articular and partial articular distal humerus fractures (AO type A and B), previous operative treatment because of the upper extremity fracture, history of primary or metastatic tumors with pathologic fractures, other additive upper and/or lower extremity injuries and unemployed patients.

When the patient records were examined in the light of these criteria, 56 active, employee patients of ages between 18 and 55 years who had type C distal humerus fractures and treated with open reduction and plate osteosynthesis were found. Six patients could not be reached due to address and phone change and two patients refused to participate in the study. Totally, 48 patients were included in the study. The medical records were reviewed retrospectively, and the patients were invited to return for a comprehensive follow-up evaluation under a protocol approved by the Local Ethical Committee. The protocol for collecting the data of human subjects was approved by the hospital ethics committee, and the study was conducted in accordance with the standards of the Declaration of Helsinki (Finland).

Preoperative anteroposterior (AP) and lateral views were obtained to analyze the fracture. After evaluating the preoperative X rays and CT scans, fractures were classified according to AO/OTA classification system. There were 29 (60.4%) type C1, 13 (27.1%) type C2 and 6 (12.5%) type C3 fractures (Table 1). There were four (8%) type I open fractures according to Gustilo–Anderson classification system [14].

Olecranon osteotomy or paratricipital approach was used in 40 (83.4%) and 8 (16.6%) elbows, respectively. The medial and lateral column fixation was performed in all fractures with pre-contoured anatomic locking anatomic plates which were positioned perpendicular to each other. If the medial plate irritated the ulnar nerve after osteosynthesis, the nerve was transported to the anterior, subcutaneously. The olecranon osteotomies were fixed with tension band wiring technique in 37 (93%) patients and by 6.5 mm partially threaded cancellous screw in 3 (7%) patients. The arm was put on a splint until edema resolved.

If the osteosynthesis was considered as stable under visual control intraoperatively, active-assisted range of motion exercises of the elbow were initiated 2–3 days after the operation under the supervision of a physiotherapist. During outpatient clinic controls, the patients who did not have sufficient improvement in the flexion arc were included in the rehabilitation program with a physiotherapist. Patients were followed up on the 15th day, 6th week, and 3, 6 and 12th months with regular clinical and radiographic review. At the last visit, the range of motion of the elbow was measured with a goniometer. Mayo Elbow Performance Score (MEPS) was used to determine functional results [15].

Table 1 Demographic data of the patients

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Patients (n=48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) Mean+ SD</td>
<td>38.1 (range 19–55)</td>
</tr>
<tr>
<td>Gender, n (%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>36 (75%)</td>
</tr>
<tr>
<td>Female</td>
<td>12 (25%)</td>
</tr>
<tr>
<td>Cause of injury, n (%)</td>
<td></td>
</tr>
<tr>
<td>Working accident</td>
<td>20 (42%)</td>
</tr>
<tr>
<td>Simple fall</td>
<td>15 (31%)</td>
</tr>
<tr>
<td>Fall from height</td>
<td>7 (14%)</td>
</tr>
<tr>
<td>Traffic accident</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>Fracture type (AO/OTA), n (%)</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>29 (60.4%)</td>
</tr>
<tr>
<td>C2</td>
<td>13 (27.1%)</td>
</tr>
<tr>
<td>C3</td>
<td>6 (12.5%)</td>
</tr>
<tr>
<td>Open fracture, n (%)</td>
<td>4 (8%)</td>
</tr>
<tr>
<td>Mean follow-up (months)</td>
<td>39 (range 12–84)</td>
</tr>
</tbody>
</table>

AO/OTA Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association
Postoperative anteroposterior and lateral radiographs were evaluated to determine the rate of union, possible changes in hardware position, articular step-off, varus–valgus angulation and heterotopic ossification. The development of degenerative changes was graded according to the method of Broberg and Morrey classification system [16]. Heterotopic ossification was classified by using the Brooker’s system [17].

In addition, the effects of gender, fracture type, heterotopic ossification, ulnar neuropathy and olecranon osteotomy on the elbow joint range of motion, functional results and time to return to work were investigated.

The financial outcome form was constituted by the authors and the patients asked to complete the form (Table 2). In this form, the patient was asked if he or she was able to return to the same job and position after completing the treatment. After starting to work, being able to continue the former job until the last visit was accepted as a criteria for ‘returning to pre-injury work’. In case of returning to the same work, the capacity to do the same work at the same time was asked. In addition, the financial status of the patient during the treatment and after the treatment was questioned.

All statistical analyses were performed using SPSS 13.0 Windows (SPSS Inc. Chicago, IL, USA). Normality of the data was assessed with Shapiro–Wilk test. If continuous data were found to be non-normally distributed, Mann–Whitney U or Kruskal Wallis tests were used according to the group number. Chi-squared or Fisher EXACT tests were used for categorical data comparison. p value below 0.05 was accepted as statistically significant.

**Results**

The average age of patients at the time of admission was 38.1 ± 5.4 years (range 19–55) and 36 (75%) patients were male. The mean follow-up time was 39 months (range 12–84 months). The dominant upper extremity was involved in 40 (83.3%) patients. Fifteen (31%) fractures were the result of a working accident, 20 (42%) fractures resulted after falling from a standing height, 7 (15%) fractures resulted after falling from a height (more than 2 m) and 6 (12%) fractures resulted from a motor vehicle accident (Table 1). The mean time from the date of injury to operation was 4 days (range 0–9 days).

The mean elbow flexion was 128° ± 9° (range 100°–145°). Mean flexion–extension motion arc was 114° ± 12° (range 85°–135°) and mean flexion contracture was 14° ± 5° (range 5°–25°). The mean MEPS score was 85 ± 11 (range 65–100); according to MEPS score, the results were graded as excellent for 26 (54%) elbows, good for 15 (31%) elbows and fair for 7 (15%) elbows (Table 3). The flexion arc was more limited in C3 fractures (p = 0.05) (Table 4) and MEPS was lower in these fractures (p = 0.12). It was observed that patients with high MEPS could return to their pre-injury work more than the patients with low MEPS (p = 0.04). The average of MEPS of patients who returned to their pre-injury work was higher than those who could not (89.2 ± 11.2 and 77.5 ± 9.7, respectively) (p = 0.01) (Table 5).

Heterotopic ossification was seen in 15 (31%) patients (11 elbows type 1, two elbows type 2 and two elbows type 3) (Table 6). Elbow flexion and flexion arc were more limited in patients with heterotopic ossification (p = 0.02 and p = 0.04 respectively) (Table 7). Heterotopic ossification

---

**Table 2** Questionnaire form

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was it an industrial accident?</td>
<td>Yes</td>
</tr>
<tr>
<td>If it is not an industrial accident, what type was it?</td>
<td></td>
</tr>
<tr>
<td>Were you working before the accident?</td>
<td>Yes</td>
</tr>
<tr>
<td>Were you working before the accident?</td>
<td></td>
</tr>
<tr>
<td>Return time to work?</td>
<td></td>
</tr>
<tr>
<td>Have you returned back in the same position?</td>
<td></td>
</tr>
<tr>
<td>Do you lift load or transport heavy objects at work?</td>
<td></td>
</tr>
<tr>
<td>Do you use tool or equipment at work?</td>
<td></td>
</tr>
<tr>
<td>Can you do the same or similar work?</td>
<td></td>
</tr>
<tr>
<td>Did you do your work at the same time?</td>
<td></td>
</tr>
<tr>
<td>Did the ratio of mistake increase at work?</td>
<td></td>
</tr>
<tr>
<td>Was it your own job/salaried employment/hourly employment?</td>
<td></td>
</tr>
<tr>
<td>How many months did you have medical report?</td>
<td></td>
</tr>
<tr>
<td>Annual family income per year?</td>
<td></td>
</tr>
<tr>
<td>Who supports the economy of your family?</td>
<td></td>
</tr>
<tr>
<td>Did you need government support during your medical report timeline?</td>
<td></td>
</tr>
<tr>
<td>Could you receive your salary when you had the medical report?</td>
<td></td>
</tr>
<tr>
<td>If you received, did you need extra money?</td>
<td></td>
</tr>
<tr>
<td>If you had not received or the money you received were not enough, what was the source?</td>
<td></td>
</tr>
<tr>
<td>Did your financial problems affect your psychiatric status?</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3** Functional results of patients

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Patients (n:48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean elbow flexion (degree)</td>
<td>128° ± 9° (range 100°–145°)</td>
</tr>
<tr>
<td>Mean elbow flexion contracture (degree)</td>
<td>14° ± 5° (range 5°–25°)</td>
</tr>
<tr>
<td>Mean elbow flexion–extension arc (degree)</td>
<td>114° ± 12° (range 85°–135°)</td>
</tr>
<tr>
<td>MEPS</td>
<td>85 ± 11 (range 65–100)</td>
</tr>
<tr>
<td>Excellent</td>
<td>26 (54%)</td>
</tr>
<tr>
<td>Good</td>
<td>15 (31%)</td>
</tr>
<tr>
<td>Fair</td>
<td>7 (15%)</td>
</tr>
</tbody>
</table>

**MEPS** Mayo Elbow Performance Score
occurrence was observed more commonly in less complex fractures interestingly \((p = 0.02)\) (Table 4). The rate of return to pre-injury work was lower in patients with heterotopic ossification \((p = 0.05)\) (Table 5). However, it was observed that the development of heterotopic ossification did not affect the returning time to work \((6.1 \pm 2.7 \text{ months, } 6.7 \pm 2.2 \text{ months, respectively})\) \((p = 0.53)\).

Degenerative arthrosis was seen in 13 (27%) patients and among these 8 were grade 1, 4 were grade 2 and 1 was grade 3, according to Broberg–Morrey classification (Table 6). Elbow flexion and flexion arc were more limited in patients who developed degenerative changes \((p = 0.09 \text{ and } p = 0.04, \text{ respectively})\) (Table 7). However, it was found that the development of osteoarthritis did not significantly affect MEPS \((p = 0.49)\).

Nonunion was observed in two patients, one (2%) at humeral metaphysis and one (2%) at the olecranon osteotomy side. The patient who had nonunion at the metaphyseal area of the distal humerus was re-operated 4 months after the trauma. The nonunion area was grafted with autologous bone graft, stabilization was achieved with longer plates and the bone union was achieved after 6 months postoperatively. Nonunion in the olecranon osteotomy line was seen in the patient who underwent osteosynthesis with a 6.5 mm cancellous screw. In this patient, the screw was removed, the osteotomy line was cleaned, osteosynthesis was performed using the tension band technique and union was achieved after 6 months postoperatively. Both patients were able to return to their pre-injury work.

Five patients (10%) had early postoperative superficial wound infection managed non-operatively with oral antibiotics and wound care (Table 6).

During the operation, in ten patients the ulnar nerve was transposed anterior due to implant irritation and at the last control none of them had ulnar neuritis signs. At the last control, four of the patients without ulnar nerve transposition had mild ulnar neuritis (Mcgowan grade 1) [18]. Ulnar sensory neuropathy symptoms did not improve in two patients. In these patients, after completion of the union, the medial plate was removed and the ulnar nerve was released. During the follow-up, patients’ complaints improved. The symptoms of the other two patients recovered spontaneously and completely within 3 months after operation. No statistically significant relationship was found between ulnar nerve transposition and flexion arc width and MEPS \((p = 0.71, p = 0.67 \text{ respectively})\) (Table 7). All of the patients who had ulnar neuritis signs could return to their pre-injury works.

Olecranon osteotomy was applied to 40 of 48 patients. There was no difference between the patients performed olecranon osteotomy and those did not in terms of flexion arc and MEPS \((p = 0.90 \text{ and } p = 0.65, \text{ respectively})\). It was also found that olecranon osteotomy did not negatively

### Table 4 Comparison of heterotopic ossification and flexion motion arc among fracture subtypes

<table>
<thead>
<tr>
<th>Fracture Type (AO/OTA)</th>
<th>Heterotopic ossification (patients)</th>
<th>Flexion arc (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
</tr>
</tbody>
</table>

### Table 5 Factors that affect the return to work

<table>
<thead>
<tr>
<th>Return to work</th>
<th>Yes</th>
<th>No</th>
<th>(p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, (n) (%)</td>
<td>38</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Fracture type (AO/OTA), (n) (%)</td>
<td>24</td>
<td>2</td>
<td>0.03</td>
</tr>
<tr>
<td>C1</td>
<td>11</td>
<td>5</td>
<td>0.05</td>
</tr>
<tr>
<td>C2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>yes</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>No</td>
<td>28</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Olecranon osteotomy, (n) (%)</td>
<td>32</td>
<td>8</td>
<td>0.53</td>
</tr>
<tr>
<td>Yes</td>
<td>6</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>34</td>
<td>10</td>
<td>0.77</td>
</tr>
<tr>
<td>Manual labor, (n) (%)</td>
<td>4</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>126 ± 8.5</td>
<td>120 ± 4.7</td>
<td>0.02</td>
</tr>
<tr>
<td>No</td>
<td>113.6 ± 10.6</td>
<td>108 ± 4.8</td>
<td>0.02</td>
</tr>
<tr>
<td>Flexion arc (degree)</td>
<td>89.2 ± 11.2</td>
<td>77.5 ± 9.8</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MEPS</th>
<th>Mayo Elbow Performance Score, AO/OTA Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bold values denote statistical significance at the (p \leq 0.05) level</td>
</tr>
</tbody>
</table>

**Table 6 Complications**

<table>
<thead>
<tr>
<th>Complication type</th>
<th>Patients ((n:48))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial infection (n) (%)</td>
<td>4 (8%)</td>
</tr>
<tr>
<td>Nonunion (n) (%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Ulnar neuropathy (n) (%)</td>
<td>4 (8%)</td>
</tr>
<tr>
<td>Heterotopic ossification (Brooker’s system) (n) (%)</td>
<td>11 (23%)</td>
</tr>
<tr>
<td>Type 1</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Type 3</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Degenerative arthritis (Broberg–Morrey classification) (n) (%)</td>
<td>8 (17%)</td>
</tr>
<tr>
<td>Grade 1</td>
<td>4 (8%)</td>
</tr>
<tr>
<td>Grade 3</td>
<td>1 (2%)</td>
</tr>
</tbody>
</table>
affect the return to work or the time of return \( (p = 0.53\) and \( p = 0.83\), respectively) \( (\text{Table } 5)\).

In our study, all of the patients were considered to be blue collar workers. Blue collar was considered as jobs in entry- or low-level position, manual labor, or requiring no specialized training. The average time to return to work was 6.5 ± 2.4 months (3–12 months). The rate of return to pre-injury work after treatment was higher in women \( (p = 0.517)\).

Thirty-eight (79%) patients returned to the same work and 29 (76%) of them started to work at the same position before the fracture occurred. Nine of 38 patients (24%) had to change their positions. Among the 48 patients, 10 patients (21%) could not return to the same job, 7 of them began to work in a lighter job and 3 of them had to be retired. If the injury was the result of a working accident, the average time to return to work was longer \( (p = 0.08)\). The rate of return to the same job was lower for heavy workers \( (p = 0.38)\). All the patients who changed their works and changed their positions were manual laborers. Twenty-nine patients who went back to the same position were manual laborers using instruments. Five of them declared that they had difficulties while working.

Among the 48 patients, 34 (70%) were breadwinners. All of the patients had taken grant in aids during the healing periods from a social security institution (approximately 2/3 of their earnings). Thirty-five (73%) patients needed additional money and 25 of them had taken money.

### Discussion

The main goal of the treatment of intra-articular DHF is anatomical reduction of the joint surface and a stable fixation that allows early rehabilitation without failure of fixation. Although good functional results have been reported in the literature for the treatment of DHF with anatomical plates, many complications can be seen in the treatment of these fractures [19–24]. The most important finding of this present study was that 79% patients with a type C distal humerus fracture who were treated with double plating were able to return to pre-injury work in a mean 6.5 ± 2.4 months (range 3–12).

In this study, the functional results according to MEPS were excellent or good in 85% of the patients. In the studies evaluating the functional results of DHF treated with angular-stable plates, good and excellent results were reported as 92% by Schmidt-Horlohe et al., 86% by Kaiser et al. and 85% by Reising et al. [4, 9, 10]. Wound complications, heterotopic ossification, obesity and ulnar neuropathy are risk factors that may affect functional results negatively [20–23]. One of the most important factors affecting the functional results is elbow range of motion. Morrey reported that gaining between 30 and 130 degrees of joint motion arc is enough to achieve 90% of the daily activities [26]. In their study, Tunalı et al. evaluated all of the possible risk factors for stiffness such as fracture type (complexity, open–closed), presence of olecranon osteotomy–postoperative neuropraxia and delayed time from injury to surgery. They concluded that patients had complex fractures and patients who were operated 7 days or more after the injury show more limitation in elbow movements [2]. In our study, the range of motion was more restricted in more complex fractures and MEPS was lower in these fractures similarly. However, it was observed that ulnar neuropathy and presence of olecranon osteotomy did not adversely affect the flexion arc and functional results.

In our study, it was also observed that most of the patients with high MEPS score could return to their pre-traumatic work.

Heterotopic ossification is one of the most important causes of elbow stiffness and decreased range of motion [20]. Sanchez-Sotelo et al. stated that the differences in flexion, extension and the total arc of motion between the
patients with and those without heterotopic ossification were all significantly different (p < 0.001) [12]. In our study, the elbow flexion arc was found to be more limited in patients with heterotopic ossification. The ulnar neuropathy has been reported to be 0–15% in the treatment of DHF [9, 12, 24, 28–30]. In the present study, ulnar neuropathy resulting in transient hypoesthesia occurred in four (8%) patients. This rate is consistent with the other reported results [9, 12, 24, 28–30]. In our study, ulnar nerve was routinely identified and protected. The anterior transposition of the ulnar nerve is still a matter of debate. Wang et al. suggested the routine anterior transposition of the ulnar nerve [28]. Shin et al. recommended in their review that the decision to transpose the ulnar nerve may be based in part on the injury type and can be performed when the implants irritated the ulnar nerve [29]. In our operations, after we applied the medial plate, we evaluated whether the medial plate irritated the ulnar nerve during flexion and in the presence of irritation the nerve was transported to the anterior, subcutaneously.

The effects of surgical approach on functional outcomes in the treatment of distal humerus fractures have always been a matter of curiosity [18, 31, 32]. Azboy et al. evaluated the functional outcomes of patients with intra-articular DHF treated with triceps-reflecting anconeus pedicle (TRAP) and olecranon osteotomy and they found that TRAP provides better arc of elbow motion with low complication and reoperation rates [31]. Chen et al. compared the triceps-sparing approach with olecranon osteotomy regarding their effects on the functional outcomes of intercondylar fracture and concluded that there was no difference between the functional outcomes obtained by both methods [32]. In our study, paratricipital approach was used in eight patients who had AO type C1 fractures. Olecranon osteotomy was preferred in the remaining 40 patients and the majority of these patients were AO type C2 and C3 fractures. The effects of olecranon osteotomy on the elbow range of motion and functional results were examined and no statistically significant differences were found.

There are many studies that investigate the outcomes of DHF [4, 5, 7–13]. However, very little attention has been focused on what seems to be a major concern of patients after trauma [6, 33–35]. Still, we have not obtained certain responses for ‘‘When can I return back to work? Will my arm be functional as before the injury? Can I do my work as before?’’. Patients expect that they will return to premorbid activities as soon as possible, but only few patients have made adequate provisions for prolonged time off work. Trauma causes serious financial problems for patients, especially blue collar workers [33]. In our country, employees receive social security benefits at the rate of 2/3 of their earnings during recovery. These patients do not have the financial reserves to withstand not having an income for several months. Distal humerus fractures prevent the patients from returning to work for several months. Because of this issue, most patients try to solve the financial problems with alternative methods. In our study population, 35 (73%) patients were breadwinners. For this group, loss of the 1/3 monthly earning is a big financial problem. This financial impact is important not only to the patients, but also to those close to them. The relied-upon source for fulfilling financial obligations post-injury was reported as family and friends, with 71% of patients using them as a source.

In our study, ten (21%) patients could not return to the same job and nine (19%) of the patients who returned back to work had to change their positions. The return of patients to their work may not always be an appropriate parameter in measuring the outcomes of a treatment or evaluating its effectiveness. This process can be affected by many factors such as the patient’s health status, psychological problems, his/her job and medico-legal issues. Many studies in the literature have shown that psychosocial factors are the most important factors that affect returning back to work, especially in patients with chronic musculoskeletal pain [30–32]. In addition, patients may experience physical, emotional and mental exhaustion throughout their working life. This exhaustion can affect both patients’ recovery process and motivation to return to work. People who are happy at work, who are more satisfied with their work and have good relationships with their coworkers may return to work earlier. The work accidents and traffic accidents also cause expectation of compensation in patients, which can increase the patient’s returning to working period. In our patients group, both psychosocial factors and expectation of compensation may have affected patients’ returning time to their works. However, the fact that the judicial processes in our country are very long and that many of the patients in the study group are the only people who make money at home have taken us away from this idea. At the final controls, the patients who could not return to their works stated that they wanted to start working, but the work they did was heavy and the condition of their elbows was not sufficient to do this work.

Our study has several limitations. First of all, it is a retrospective study. A second limitation is the small number of patients which makes it difficult to draw clear conclusions. The results should be verified in a larger population. Another important limitation was absence of the control group consisting of white collars. This group would allow us to compare the level of education of the patient and the effects of light work on returning to work. The range of supination and pronation motions was not evaluated as osteotomy of the olecranon might affect it. In the literature, this is the first study which investigated whether patients with DHF can return to their pre-injury work after the treatment.

As a conclusion, AO-type C2 and C3 fractures and heterotopic ossification had negative effects on elbow flexion arc.
and functional results. These factors also adversely affected the patients’ returning to their pre-injury works. It was also determined that olecranon osteotomy, ulnar nerve transposition or neuropathy and degenerative arthritis are not risk factors for functional outcomes. When the results were evaluated, it was observed that the study hypothesis was confirmed. Although the functional results of surgical treatment of intra-articular distal humerus fractures seem to be good, at the end of the treatment, especially heavy workers may have difficulties in returning to their pre-injury works.

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**Compliance with Ethical Standards**

**Conflict of Interest** All authors declare that they have no conflict of interest.

**Ethical Standard Statement** This article does not contain any studies with human or animal subjects performed by any of the authors.

**Informed Consent** For this type of study informed consent is not required.

**References**


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Surgery or Conservative Treatment of Forearm in Patients Diagnosed with Pediatric Floating Elbow? Retrospective Analysis of 60 Consecutive Cases

Burçin Karşılı · Kamil İnce · Nevzat Gönder · Bahri Bozgeyik · Volkan Kılınçoğlu

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Abstract
Background The coexistence of supracondylar humerus fracture and forearm fracture is a rare trauma (3–13%) and it is called floating elbow. The aim of this study is to clinically compare the treatment outcomes of the patients diagnosed with floating elbow who underwent surgical treatment and who were followed up forearm with immobilization with splint.

Materials and Methods When scanned retrospectively, 60 patients who were treated with the diagnosis of floating elbow due to traumatic causes and followed up for at least 1 year were included in our study. Surgical treatment was performed on 42 patients for forearm fracture. Eighteen patients followed up with immobilization with a long arm splint. The results were evaluated according to the criteria modified by Templeton and Graham, in comparison with the patient’s intact side.

Results In the patients whose forearms were followed up conservatively, the mean age was 5.67 ± 2.25 years, and the mean follow-up period was 62.17 ± 45.91 months. In the patients who underwent surgery for the forearm, the mean age was 8.79 ± 2.01 years, and the mean follow-up was 47.14 ± 34.25 months. Eighteen patients whose forearms followed up conservatively, 12 had excellent and good clinical results and 6 had poor and moderate clinical results. Excellent and good clinical results in 27 patients who underwent surgical treatment for their forearms, moderate and poor clinical results obtained in 15 of them. There was no significant difference between the two groups ($p = 0.357$).

Conclusions In conclusion, satisfactory clinical and radiological outcomes can be obtained with immobilization of the forearm fracture with splint, if acceptable reduction can be provided for the forearm following fixation of the supracondylar humerus fracture with the K-wire for treatment of floating elbow injury.

Keywords Floating elbow · Supracondylar humerus fracture · Forearm fracture

Introduction

Isolated supracondylar humerus and forearm fractures are the common fractures in children. However, the coexistence of supracondylar humerus fracture and forearm fracture is a rare trauma (3–13%) [1–3]. The coexistence of these two fractures is called floating elbow [1]. There are different views in the literature regarding the treatment of this severe injury, which generally occurs after high-energy traumas, such as falls from height. The treatment options include closed reduction and long arm casting for both fractures, casting after soft tissue swelling resolves following traction of olecranon with the pin, percutaneous pinning of the humerus, short arm casting of the forearm or closed reduction and percutaneous pinning for both fractures.

The best treatment option remains controversial, as there are few studies in the literature on pediatric floating elbow, and it is a rare combination of fractures. The aim of the study is to clinically and radiologically compare the treatment outcomes of the patients diagnosed with floating elbow who underwent surgical treatment and who were followed up with immobilization with splint in our clinic.
Materials and Methods

The study protocol was approved by the Scientific Research Ethics Committee of Gaziantep University, Faculty of Medicine (Gaziantep University Noninterventional Clinical Studies Intuitional Review Board, 01.07.2020, 2020/201). The study included 60 patients who were admitted to Gaziantep University, Medical Faculty, Orthopedics, and Traumatology Clinic between August 2009 and October 2019, and who were treated with the diagnosis of floating elbow due to traumatic reasons and followed up for at least one year. Supracondylar humerus fractures were classified according to the Gartland classification. Only the patients with Gartland type 3 supracondylar humerus fracture were included in the study. In our patients data archive, there were only 15 fractures of supracondylar humerus fractures that were classified as types I and II. We excluded Gartland type I and type II fractures because of low patient numbers and we wanted to create homogenous groups. All patients had an extension-type supracondylar humerus fracture. All patients underwent surgery for supracondylar humeral fracture.

In addition to supracondylar humerus fracture, 30 patients also had both bone forearm fracture and 30 patients had radial distal fracture. Fifteen patients had distal forearm, 11 patients forearm shaft and 4 were proximal forearm fractures. Surgical treatment was performed on 42 patients for forearm fracture. Forearm fractures were fixed firstly. Conservative treatment was performed for forearm fractures according to acceptable criteria. In our study, fracture level did not affect our choice of treatment. The factor determining our treatment was the stability of the forearm fracture after reduction in acceptable criteria. Acceptable criteria in pediatric forearm fractures; angulation of less than 15° is accepted in midshaft fractures, less than 10 degrees is accepted in distal shaft fractures, while angulation is not accepted in proximal shaft fractures. Less than 30° of malrotation and %100 displacement are acceptable [4]. The splint was removed at 4 weeks and joint range of motion exercises were initiated for elbow, for humerus, wrist, and forearm for surgically treated patients. K-wire was removed at 6th week. For the other group of patients, splint was removed after 6 weeks K-wires were removed at 6th week. The data of the patients included in the study are given in Table 1.

The follow-up results of the 42 patients, who underwent surgery for the forearm and the 18 patients who were followed up conservatively, were evaluated in comparison with the patient’s intact side according to the criteria defined by Flynn and modified by Templeton and Graham [5, 6]. (Table 2).

In addition, it was statistically evaluated whether there was any difference between the two groups in terms of wrist and forearm range of motion (ROM), reduction loss and requirement for re-reduction, postoperative neurological deficit and development of compartment syndrome.

---

### Table 1 Demographic characteristic data of two groups

<table>
<thead>
<tr>
<th></th>
<th>Surgical treatment group</th>
<th>Conservative treatment group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year) (mean ± SD)</td>
<td>8.79 ± 2.01</td>
<td>5.67 ± 2.25</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>39</td>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Trauma mechanism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall from height (1–6 m)</td>
<td></td>
<td>Fall from height (1–3 m)</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>18</td>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
<td>24</td>
<td>Left</td>
</tr>
<tr>
<td>Follow-up time (months)</td>
<td>47.14 ± 34.25</td>
<td>62.17 ± 45.91</td>
</tr>
<tr>
<td>(mean ± SD)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SD standard deviation

### Table 2 Criteria defined by Flynn and modified by Templeton and Graham

<table>
<thead>
<tr>
<th>Classification</th>
<th>Wrist Flexion</th>
<th>Wrist Extension</th>
<th>Forearm rotation Supination</th>
<th>Forearm rotation Pronation</th>
<th>Elbow function Flexion/extension loss</th>
<th>Elbow cosmetics carrying angle change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>70–&gt;80</td>
<td>70–&gt;80</td>
<td>75–&gt;90</td>
<td>70–&gt;85</td>
<td>0–5</td>
<td>0–5</td>
</tr>
<tr>
<td>Good</td>
<td>60–69</td>
<td>60–69</td>
<td>60–74</td>
<td>55–69</td>
<td>6–10</td>
<td>6–10</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;45</td>
<td>&lt;40</td>
<td>&gt;15</td>
<td>&gt;15</td>
</tr>
</tbody>
</table>

Evaluated by comparing with the intact extremity on the opposite side
Statistical Analysis

Analyses for the demographic characteristics of the data obtained from the study were carried out using descriptive statistical analysis methods (frequency and percentage analysis, mean and standard deviation values). The chi-square test was used to analyze the correlation between the variables of treatment type, elbow, wrist, and forearm functions, and postoperative complication. The analyses were carried out using the SPSS 22.0 software. A $p$ value of $< 0.05$ was considered statistically significant.

Results

In the patients whose forearms were followed up conservatively, the mean age was 5.67 (2–8) years, and the mean follow-up period was 62.17 (12–121) months. In the patients who underwent surgery for the forearm, the mean age was 8.79 (7–12) years, and the mean follow-up was 47.14 (12–113) months. Three patients had Gustilo Anderson type 1 open fracture. In the surgery of supracondylar humerus fractures; open reduction and fixation with Kirschner (K) wire were performed on 54 patients because of closed reduction cannot be achieved, closed reduction and fixation with K-wire (CRIF) were performed on 6 patients. CRIF was applied for the distal radius fracture in patients who underwent surgery on the forearm, while close reduction and fixation with titanium elastic nail (TEN) were applied for forearm fractures. Eighteen patients who had acceptable reduction for the forearm were followed up conservatively with a long arm splint. The most common etiological cause is fall from height [2, 3]. The most common mechanism is fall on an outstretched hand when the wrist is in dorsiflexion, the forearm is in pronation and the elbow is in extension. The injury mechanism in all patients in our study was fall on an outstretched hand from different heights.

Twelve of 18 patients whose forearms were followed up conservatively were classified as excellent and good, and 6 patients were classified as poor (Fig. 1). Of the 42 patients who underwent forearm surgery, 27 were classified as excellent and good, and 15 were classified as moderate and poor (Fig. 2). Although the carrying angle was altered in 27 of 42 patients who underwent forearm surgery, 9 of the 18 patients in the conservative treatment group had change. There was no significant difference between the two groups according

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**Fig. 1** a Pre-op, post-op, and 9-year follow-up X-rays of a 15-year-old patient whose forearm were followed up conservatively

**Fig. 2** b Pre-op, post-op, and 8-year follow-up X-rays of a 14-year-old patient who underwent forearm surgery
to these criteria (Table 3). The clinical image of the change in elbow carrying angle of the patients in Figs. 1 and 2 is shown in Fig. 3.

In the group whose forearms were followed up conservatively, the forearm ROM was restricted in three patients, and the wrist and forearm ROM was full in other 15 patients. Of the patients who underwent surgery, 9 had restricted forearm ROM and 3 had restricted ROM in both the wrist and forearm. The other 27 patients had full ROM in the wrist and forearm. Patients who underwent surgical treatment of forearm fractures had higher incidence of forearm and wrist ROM restriction but there was no significant difference between the two groups in terms of forearm and wrist ROM (Table 4).

None of the patients had reduction loss and required for re-reduction. None of the patients had pin site infection or pin-related complications. The time to reach final range of motion was the same in both groups. Preoperatively, one patient had radial nerve symptom, one patient had posterior interosseous nerve symptom. Postoperatively, one patient who underwent elbow and forearm surgery developed iatrogenic ulnar nerve symptom and the nerve healed completely during follow-up. No patient developed compartment syndrome. Preoperative circulatory disorder was not observed in any patient.

Table 3  Comparison of clinical outcomes between two groups

<table>
<thead>
<tr>
<th>Indices</th>
<th>Surgical treatment group</th>
<th>Conservative treatment group</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified criteria of Templeton and Graham</td>
<td>Excellent + good 27</td>
<td>Excellent + good 12</td>
<td>0.357</td>
</tr>
<tr>
<td></td>
<td>Fair + poor 15</td>
<td>Fair + poor 6</td>
<td></td>
</tr>
<tr>
<td>Carrying angle change</td>
<td>Yes 27</td>
<td>Yes 9</td>
<td>0.550</td>
</tr>
<tr>
<td></td>
<td>No 15</td>
<td>No 9</td>
<td></td>
</tr>
<tr>
<td>Cubitus varus</td>
<td>Yes 9</td>
<td>Yes 6</td>
<td>0.573</td>
</tr>
<tr>
<td></td>
<td>No 33</td>
<td>No 12</td>
<td></td>
</tr>
<tr>
<td>Neurological deficit</td>
<td>Yes 3</td>
<td>Yes None</td>
<td>0.502</td>
</tr>
<tr>
<td></td>
<td>No 39</td>
<td>No 18</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3  a 15-year-old patient whose forearm was followed conservatively had an elbow carrying angle of +4°. b 14-year-old patient who underwent forearm surgery had an elbow carrying angle of −11°
Discussion

The optimal treatment of patients with pediatric floating elbow remains controversial. Reed and Apple suggested conservative follow-up for supracondylar humerus and forearm fractures in their study. However, the results showed that cubitus varus developed, and compartment syndrome could develop with swelling in the elbow as a result of casting performed while the elbow was in flexion [6].

Our study includes long-term results. The literature showed that cubitus varus still remains a common complication in pediatric supracondylar humerus fractures in the long term [7]. Because it is a more complicated high energy and challenging treatment process as compared to isolated supracondylar humerus or forearm fractures, the increased cubitus varus and carrying angle changes seem to be a possible cause. Other possible mechanism of cubitus varus includes initial traumatic insult, which may cause vascular damage and changes in the growth plate [8]. Eren et al. observed that in Gartland type III fractures had higher incidence of cubitus varus [9]. However, review in the literature, pediatric floating injuries are related with generally good and do not reflect

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>Forearm ROM</th>
<th>Wrist ROM</th>
<th>Elbow ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full</td>
<td>Restricted</td>
<td>Total</td>
</tr>
<tr>
<td>Conservative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>15</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>83.3%</td>
<td>16.7%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Surgery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>30</td>
<td>12</td>
<td>42</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>71.4%</td>
<td>28.6%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>45</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>75.0%</td>
<td>25.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

No statistically significant correlation was found between the treatment method and forearm, wrist and elbow ROM.
the poor prognosis that adult floating elbows represent [10]. In our study, there was no significant difference between the patients who underwent surgery for the forearm and those who were not operated in terms of development of cubitus varus, and none of the patients developed compartment syndrome. Williamson, Papavasiliou, and Stanitski suggested fixation of supracondylar humerus fracture with K-wire and treatment of forearm with cast [11, 12].

In the studies conducted by Tabak et al. and Ring et al., it was suggested that surgery should be performed for both supracondylar humerus and forearm fractures, because there was no need for stabilization with cast in excessive flexion, there was no increase in elbow swelling and there was no reduction loss and need for re-reduction. They also suggested that early mobilization could be initiated, and better outcomes were obtained in terms of elbow ROM, as the forearm fracture was fixed with the K-wire [3]. In our study, fixation with K-wire was performed to prevent development of varus and post-cast swelling-related compartment syndrome, because the humeral component of the fracture was Gartland type 3 supracondylar humerus fracture in all patients. There was no difference between the group who underwent surgery for forearm fracture and the group who received immobilization with a splint in terms of Templeton's modified criteria, forearm and wrist ROM.

In the study by Ring et al., it was stated that patients who underwent surgery for supracondylar humerus fracture and were followed up with forearm cast had loss of reduction and needed re-reduction [13]. In different studies, it has been stated that re-reduction may be required with a rate of 7–15% as a result of conservative follow-up of the forearm [14, 15]. In our study, there was no loss of reduction and requirement for re-reduction in patients who were conservatively followed up with a splint.

One of the most commonly discussed topics in patients with floating elbow is whether there is an increased risk of developing compartment syndrome compared to patients with isolated supracondylar fractures. In these patients, the compartment syndrome was reported at a rate of 7% by Wil-liamson and Cole, and at a rate of 33% by Blackmore et al. [11, 16]. In the study by Muchow et al. on 1228 patients who presented with isolated supracondylar humerus fracture, 150 patients had floating elbow; there was no increase in the risk of the compartment syndrome in the patients diagnosed with floating elbow compared to the patients with isolated supracondylar humerus fracture [17]. In a series, Robertson et al. mentioned the high incidence of compartment syndrome in patients with diagnosis of pediatric floating elbow [18]. In our study, the compartment syndrome was not observed in any patient. We think that the development of compartment syndrome is probably related to secondary factors, such as circular cast, elbow flexion degree and elevation, similar to some previous studies [19].

In different studies, it was thought that patients presenting with floating elbow had increased neurovascular injuries [3, 17]. In a study conducted by Muchow et al., it was stated that the patients with floating elbow had a twofold higher rate of neurological injury at the first presentation compared to the patients with isolated supracondylar fracture [17]. In our study, two patients had preoperative neurological deficit. Neurological deficits of the two patients returned to normal in a period of 4 weeks on average. None of the patients included in our study developed vascular injury.

The limitation of the study was the retrospective design of the study. In our study we performed open reduction for most cases of supracondylar fractures due to not achieve closed reduction. This situation can affect the clinical results. We combined all forearm shaft and distal radius fractures. The groups could be separated according to fracture types of forearm fractures but to perform this analysis more patients needed to reach ideal results. Also, we did not use any classification system to classify the patients. For other floating injuries there are some classifications to classify the injuries [20]. This situation could be another study subject.

In conclusion, floating elbow is a rare childhood trauma, and there are different views in the literature regarding its treatment. Satisfactory clinical and radiological outcomes can be obtained with immobilization of the forearm fracture with a splint, if acceptable reduction for the forearm can be provided following fixation of the supracondylar humerus fracture with the K-wire for the treatment of floating elbow injury.

Compliance with Ethical Standards

Conflict of interest All authors approved the manuscript and all authors declare that are no conflicts of interest regarding the publication.

Ethical standard statement The study was approved by the local ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed consent Informed consent was obtained from all participants.

References


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Dual Locking Plate Osteosynthesis for 3- or 4-Part Proximal Humeral Fractures Combined with Multiple Fractures of the Greater Tuberosity

Yongchuan Li¹ · Nan Lu¹ · Fan Zhang¹ · Zhibin Zhou¹ · Liangyu Zhao¹ · Aimin Chen¹

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Abstract

Background This retrospective study was conducted to evaluate the efficacy of dual locking plate osteosynthesis for treating 3- or 4-part proximal humeral fractures combined with multiple fractures of the greater tuberosity.

Methods From January 2012 to December 2018, 19 skeletally mature patients, who suffered 3- or 4-part proximal humeral fractures combined with multiple fractures of the greater tuberosity, were treated with open reduction and internal fixation using a dual locking plate technique through a delto-pectoral approach. Indexes for evaluation included fracture healing, quality of reduction, and incidence of complications (infections, screw perforation into the glenohumeral joint, subacromial impingement, hardware failure, avascular necrosis, and loss of reduction). Shoulder function was evaluated using Constant–Murley scoring.

Results The patients were assessed at a mean time of 25.3 months after surgery. Union of fractures was radiographically confirmed for all 19 patients. The mean Constant–Murley patient score was 85.2 points, and complications were identified in two patients during follow-up evaluations.

Conclusions The method of using dual locking plate osteosynthesis through a delto-pectoral approach resulted in a satisfactory union rate, excellent fracture reduction, low complication rate and good shoulder function for patients with complex proximal humeral fractures. The method is effective for treating 3- or 4-part proximal humeral fractures combined with multiple fractures of the greater tuberosity.

Keywords Proximal humeral fracture · Internal fixation · Plating · Greater tuberosity

Abbreviations

S3 Spatial Subchondral Support
PHILOS Proximal humerus-locking compression plate
VA-LCP Variable Angle LCP

Background

Proximal humeral fracture is one of the most common types of fracture, especially in elderly people with osteoporosis. They account for approximately 6% of all fractures seen in accident and emergency departments [1–3]. It is the third most common fracture overall following hip and distal radial fracture [4–6]. Most proximal humeral fractures are undisplaced or minimally displaced [7], and can be successfully treated using conservative methods [8]. However, displaced fractures require surgical treatment.

The most frequently used classification for proximal humeral fractures is Neer classification [9–11]. Neer classification is based on the four anatomical segments of the proximal humerus (the humeral head, shaft, and greater and lesser tuberosities) and whether these segments are fractured and/or displaced. According to Neer, 3- and 4-part proximal humeral fractures are classified as comminuted displaced fractures. These account for 13–16% of all proximal humeral fractures, and always require surgical treatment [2].
Single-plate osteosynthesis is usually recommended as the method of fixation for this type of fracture [12–15]. However, the use of a single plate is not always successful in 3- or 4-part proximal humeral fractures, especially when fractures are combined with multiple fractures of the greater tuberosity. Although surgeons may have used tension banding, screws or transosseous sutures for treating the greater tuberosity fractures, some cases need an additional plate or screw treatment if original treatments resulted in poor fixation and/or if the fracture was not reduced. In recent years, dual locking plate osteosynthesis has been used to treat these complex proximal humeral fractures, based on radiographic understanding of the fractures.

The authors applied Spatial Subchondral Support (S3) Proximal Humerus Plating Systems as the main plates to fix the proximal humeral fractures and F3 Fragment Plating Systems as secondary plates to fix the fractured greater tuberosities. This retrospective study was conducted to evaluate the radiographic and clinical outcomes. We hypothesized that satisfactory clinical and radiographic results could be achieved using this technique.

Patients and Methods

The study was approved by our institution’s Committee for Research Ethics. Informed consent was obtained from all individual participants included in the study. The criteria for inclusion in the study were being aged at least 18 years and having a closed 3- or 4-part proximal humeral fracture with multiple fractures of the greater tuberosity. Exclusion criteria were other fracture patterns (non-displaced, 2-part); open fractures; old fractures; multiple injuries; fractures associated with vascular or nerve damage requiring repair; suspected pathologic fractures; and patients with failed conservative treatment. Radiographs were used to determine the locations and Neer classifications of the fractures.

From January 2012 to December 2018, 24 skeletally mature patients with 3- or 4-part proximal humeral fractures combined with multiple fractures of the greater tuberosity were treated with dual locking plate osteosynthesis (S3 and F3). Open reduction and internal fixation were conducted through a delto-pectoral approach by fellowship-trained traumatologists at the department of Orthopaedics in Shanghai Changzheng Hospital. Fractures were classified using Neer’s classification system. Surgery was performed within 6 days (mean 3.8 days) of the traumatic event in all the cases.

On admission, each patient was subjected to a standard radiologic protocol including X-rays and CT scans with 3-dimensional reconstruction. These images provided detailed information for making specific surgical decisions. Cases were assessed by different team leaders (we have five trauma teams). If the case was considered to be fit for the ‘‘dual locking plate’’ technique, the patient was transferred to our team in Shanghai Changzheng Hospital. All 19 cases were operated on by our research team (Yongchuan Li, Nan Lu, Fan Zhang, Zhibin Zhou, Liangyu Zhao, and Aimin Chen).

Surgeries were performed in the beach-chair position on a radiolucent table, with side placement of an image intensifier to allow viewing of the humeral head in two planes. Surgeries were performed through a delto-pectoral approach while patients were under general anesthesia. A 12–14 cm incision was started midway between the coracoid and clavicle, and extended distally up to the deltoid insertion. The cephalic vein was identified and retracted laterally. Blunt dissection was performed through the delto-pectoral groove and the deltoid muscle was retracted to the lateral direction. This allowed access to the greater tuberosity, lesser tuberosity, the long head of the biceps muscle, and the fracture site of the proximal humerus. The long head of the biceps is an important landmark, as it indicates the location of the rotator interval space. Fractures were reduced through traction and manipulation and then provisionally stabilized with Kirschner wires. After the reduction had been confirmed by imaging, an S3 locking plate was placed approximately 3 cm distal to the tip of the greater tuberosity and just lateral to the sulcus bicipitalis. A detailed description of the fixation technique can be found in our previous study [16]. The second locking plate (F3) was positioned on the greater tuberosity fragment. After drilling and determining the correct screw length, we inserted the locking screws to fix the fragment in place. The intra-operative motion of the shoulder must be checked for impingement in all directions, especially in abduction and external rotation, to exclude subacromial impingement and to confirm reliable fixation of the proximal humerus. Intra-operative use of the C-arm image intensifier helped surgeons to accomplish reduction and verify correct screw placement to prevent intra-articular penetration. If a tear of the rotator cuff was found intra-operatively, a 2.5-mm nonabsorbable suture was used to repair it (Figs. 1, 2).

Intravenous antibiotics consisting of a first-generation cephalosporin or alternative were administered pre-operatively and for 24 h post-operatively. All patients were treated with a similar post-operative rehabilitation protocol that emphasized early passive and active motion exercises. Each patient wore a sling for the first 2 weeks following surgery. We encouraged patients to do isometric deltoid, biceps, and triceps strengthening exercises, starting on the first post-operative day. In general, passive range of motion exercises was initiated after changing the surgical dressing (on the second or third day after surgery). Active and active-assisted activities began within the second week after surgery (once sutures were removed). Pendulum exercises, anteflexion and external rotation with the arm were encouraged as tolerated. Patients continued with these actions for the first 6 weeks.
Fig. 1  
(a) A 63-year-old male sustained a 3-part proximal humeral fracture due to a fall from standing height. 
(b, c) Post-operative radiographic anteroposterior and lateral views showed an anatomic fracture reduction with the use of the Spatial Subchondral Support Proximal Humerus Plating System and F3 Fragment Plating System.

Fig. 2  
(a) A 65-year-old male sustained a 3-part proximal humeral fracture due to a fall from height. 
(b, c) Post-operative radiographic anteroposterior and lateral views showed loss of fracture reduction with the use of the single Spatial Subchondral Support Proximal Humerus Plating System. 
(d, e) An additional F3 locking plate was used to fix the greater tuberosity fracture in the second operation. 
(f, g) Post-operative radiographic anteroposterior and lateral views showed anatomic fracture reduction with the use of dual locking plate osteosynthesis.
post-operatively. Then, weight training and supervised physical therapy were allowed. When their fractures were healed completely (about 3 months after surgery), patients were permitted to do further stretching and strengthening.

Data related to fracture healing, quality of reduction, and complications (infections, screw perforation into the glenohumeral joint, avascular necrosis, and loss of reduction) were recorded during post-operative clinical examinations and standardized X-rays (anteroposterior, lateral and axillary views) at 2, 6, 12, 26 and 52 weeks after surgery. Shoulder function was evaluated using the Constant–Murley score [17], which allocates 20 points for daily life, 15 for pain, 40 for range of motion, and 25 for strength. The highest total score is 100, indicating a healthy, asymptomatic joint, and the lowest is 0.

Results

From January 2012 to December 2018, 91 patients with 3- or 4-part proximal humeral fractures were treated in our department. Among the patients, there were 24 cases combined with multiple fractures of the greater tuberosity. These cases required the dual locking plate osteosynthesis procedure. For five of these patients, follow-up data were absent due to migration, death or other reasons. The remaining 19 cases were included in the final analysis of fracture healing, quality of reduction, complications and functional outcomes. Table 1 shows the patients’ demographic information. Seven of the patients were men and 12 were women, and the mean age was 58 years (range 32–77). The dominant hand for all patients was their right, and 13 of them sustained the injury on the dominant side. Thirteen patients were in the age group of > 65 years and six patients were in the age group of < 65 years.

Mean data related to the patients’ (treated with dual locking plates) hospital stays, surgery and long-term recovery are presented in Table 2. Patients stayed in the hospital for an average of 12.5 days (range 7–19). Operative management took a mean total operation time (including anesthesia) of 157.0 min (range 110–190). Union of fractures was radiographically confirmed for all 19 patients. Patients also were re-assessed during follow-up visits at a mean time of 25.3 months after surgery (range 14–26).

Follow-up visits revealed one case of varus malunion (head-shaft angle of less than 120°), one case of intra-articular screw penetration, and one case of subacromial impingement. The patient in whom the fracture had malunited did not require any treatment, as the range of movements was acceptable. There was no evidence of superficial infection, avascular necrosis, loss of reduction, hardware failure, loosening of locking screws, or delayed union for any of the patients. Table 3 shows complications noted during the follow-up visits. The patients had an overall mean Constant–Murley score of 85.2 points. At final follow-up evaluations, seven patients had excellent functional outcomes, eight patients had good scores, four patients had moderate scores, and no patient had a poor result, according to their individual Constant–Murley scores.

### Table 1 Patients’ and fractures’ demographics

<table>
<thead>
<tr>
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<td>Patients</td>
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<td>Mean age (range)</td>
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<tr>
<td>Female</td>
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<tr>
<td>Injury mechanism</td>
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<tr>
<td>Work accident</td>
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<tr>
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<td>Arthritis</td>
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<td>Diabetes mellitus</td>
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### Table 2 Operation and follow-up data

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<tr>
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<td>157.0</td>
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<tr>
<td>Blood loss in surgery, ml</td>
<td>210</td>
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<tr>
<td>Hospital stay, days</td>
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<td>Follow-up, months</td>
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<td>Union rate, n (%)</td>
<td>19 (100%)</td>
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</table>

### Table 3 Complications during the follow-up

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<th>Complications</th>
<th>Number</th>
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<tr>
<td>Superficial infection</td>
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<tr>
<td>Screw perforation</td>
<td>1</td>
</tr>
<tr>
<td>Subacromial impingement</td>
<td>1</td>
</tr>
<tr>
<td>Hardware failure</td>
<td>0</td>
</tr>
<tr>
<td>Avascular necrosis</td>
<td>0</td>
</tr>
<tr>
<td>Loss of reduction</td>
<td>0</td>
</tr>
</tbody>
</table>
Discussion

Most complex proximal humeral fractures are caused by high-impact injury, and fully understanding these fractures is the basis for successful treatment. In the past, less attention was paid to greater tuberosity fractures, and conservative treatment was applied in most isolated greater tuberosity fractures, which often resulted in shoulder dysfunction [18, 19]. By more frequent use of CT scans and careful review of CT images, some researchers have realized the importance of the greater tuberosity for proper shoulder function. However, their studies have focused mainly on isolated greater tuberosity fractures [20–23]. The current study focuses on 3- or 4-part proximal humeral fractures with multiple fractures of the greater tuberosity. The greater tuberosity fragment is often displaced by traction of the supraspinatus and infraspinatus, which serve as attachment points of the rotator cuff. In most cases, fragments were pulled into the anterior direction by the supraspinatus and into the posterior direction by the infraspinatus and teres minor, when 3- or 4-part proximal humeral fracture occurred. A single-plate osteosynthesis or plate osteosynthesis combined with greater tuberosity fixation using implements such as tension banding, screws or transosseous sutures is usually recommended as the definitive fixation technique for this kind of fracture. However, some cases require an additional plate or screw treatment to resolve poor fixation or loss of reduction. The previous technique may be unsuitable to fix large areas of the greater tuberosity [16] (Fig. 2a–c). In recent years, we have used a novel dual locking plate osteosynthesis technique to treat these complex proximal humeral fractures through a delto-pectoral approach. Our method strengthens the fixation and prevents further displacement of the greater tuberosity. No cases of lost reduction were noted during follow-up visits with the 19 patients. This is the first report in English literature of using this fixation method for complex proximal humeral fractures with multiple fractures of the greater tuberosity.

Common techniques used for open reduction and internal fixation of greater tuberosity fractures are tension banding, screws, and transosseous sutures. However, none of these techniques have been established as a gold standard, and moreover, these techniques may lead to several problems [19, 23]. It is difficult to replace and retain the fragile parts at their origin, when the tuberosity is displaced and multiple fractures occur. Simple screwing may lead to further damage to the fragments and screws with washers can lead to secondary subacromial impingement [24, 25]. Moreover, isolated screw fixation of these fractures has been described as infeasible if the fragment is comminuted and should, therefore, be used with caution due to the risk of further fracture or subsequent displacement [19]. The tension-banding technique may be inappropriate for patients with osteoporosis, given the risk of iatrogenic fracture of the surgical neck [24]. In contrast, transosseous sutures are widely used to treat proximal humeral fractures because they fix the fragment at the tendon–bone interface, minimize the risk of metal allergy, and need no removal of implant. A long-term follow-up study by Dimakopoulos et al. [25] showed satisfactory clinical results with transosseous sutures. However, when the greater tuberosity fragment is comminuted, suture fixation may further decrease stability when sutures tear out of the tissue around the loop [19]. A few recent studies have used plates to treat greater tuberosity fractures [20, 26]. Chen et al. [20] treated displaced isolated greater tuberosity fractures with open reduction and internal fixation using an AO x-shaped midfoot locking plate in 19 patients. The mean Constant–Murley score was 90.6 points and all fractures healed without any complications of wound infection, numbness, subacromial impingement syndrome, nonunion, secondary displacement, or implant loosening. Schöffl et al. [26] used a small Bamberg plate cut from a calcaneus plate to perform an osteosynthesis procedure on patients with multiple greater tuberosity fractures. Excellent postoperative outcomes were achieved, with no complications and no secondary losses of reduction. The Constant–Murley scores more than 6 months post-operatively reflected the excellent functional results in all cases. Choi et al. [27] described a new dual-plate fixation technique to treat comminuted proximal humeral fractures that were similar to the cases presented in our study. However, there were several significant differences between our studies. The first difference was that we used a Spatial Subchondral Support Proximal Humerus Plating System and F3 Fragment Plating System for comminuted proximal humeral fractures, while a proximal humerus-locating compression plate (PHILOS) and a Variable Angle LCP (VA-LCP) Distal Radius System were applied in the study by Choi et al. Second, the VA-LCP distal radius plate used by Choi et al. was to prevent nonunion, varus collapse of the neck-shaft portion and anterior–posterior angulation of the humeral head. In comparison, the F3 locking plate used in our study had the added functionality of providing fixation for multiple fractures of the greater tuberosity. Thirdly, the VA-LCP distal radius plate was harder to be shaped and more extensive soft tissue stripping was needed to fix the pale. In addition, we have treated a series of patients and obtained satisfactory clinical outcomes, whereas their study only provides a technical introduction.

The F3 fragment plating system is a collection of titanium alloy locking plates, which allows in situ contouring, and it is, therefore, suited to smaller bones in the distal extremities, particularly the foot and ankle. We applied this implant
to greater tuberosities with multiple fractures in conjunction with S3 Proximal Humerus Plating Systems for treating complex proximal humeral fractures. This small locking plate (F3) covers a larger fracture area and may potentially provide more reliable stability than screws, tension banding, or transosseous sutures, especially in cases of comminuted or osteoporotic fractures. Although previous studies have reported good results from using locking plates for 3- or 4-part proximal humeral fractures [12–15] or isolated greater tuberosity fractures [20, 26], ours is the first report on using two locking plates to treat 3- or 4-part proximal humeral fractures combined with multiple fractures of the greater tuberosity. Based on Constant–Murley scores and incidence of post-operative complications, our method provided better clinical results compared to other reported methods for treating complex proximal humeral fractures. The limitations of the present study are that: (1) the sample size was small because of the rarity of the injury; (2) a control group was not included to demonstrate the advantages of this procedure over other fixation techniques; and (3) the average follow-up time was after only 25.3 months, which is a relatively short evaluation period and most cases of post-traumatic arthritis would not have developed yet. A larger sample size with a control group and extended follow-up evaluations are recommended for future studies to strengthen their validity.

Conclusion

A dual locking plate osteosynthesis technique was performed through a delto-pectoral approach to treat 19 cases of complex proximal humeral fractures, resulting in a satisfactory union rate, excellent fracture reduction, low complication rate and good shoulder function for patients. It was demonstrated to be an effective method for treating 3- or 4-part proximal humeral fractures with multiple fractures of the greater tuberosity.

Author contributions AC and LZ designed the study; YL, ZZ, FZ, LZ and AC did the operation; YL, NL, FZ, and ZZ collected the data; YL, NL, FZ, and ZZ analyzed the data; YL, NL, FZ, ZZ, LZ and AC wrote the paper; YL, NL, FZ, and AC revised the manuscript.

Funding This research has no funding source.

Compliance with Ethical Standards

Conflict of interest There are no conflicts of interests.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Ethical approval The research has been approved by The Ethics Committee of Shanghai Changzheng Hospital and consented by all participants.

Informed consent The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Factors Influencing the Varus Deformity of Humeral Head in Proximal Humerus Fractures and Its Relation to Functional Outcome

H. Kantharaju 1 · Sangeet K. Gawhale 2 · G. S. Prasanna Kumar 2 · Balu Sahare 2 · Nadir Shah 2

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Abstract
Background  Fractures of the proximal humerus represent approximately 4% of all fractures and 26% of humerus fractures. Proper reduction, stable internal fixation and early initiation of physiotherapy help to achieve a good functional outcome. Aim of this study was to evaluate varus fixation/malunion of proximal humerus fractures and its relation to functional outcome.

Materials and Methods  We retrospectively evaluated 32 patients with proximal humerus fractures who were surgically treated between 2015 and 2017 at tertiary care hospital. We divided the patients into three groups on the basis of the neck-shaft angle as valgus group, normal group and varus group to observe the influence of neck-shaft angle on efficacy. Patients were evaluated for functional outcome using the Constant–Murley score.

Results  Two-part fractures had better functional outcome (Constant score = 75.15) compared to three parts with the moderate functional outcome (Constant score = 68.81) and the four-part fracture had poor functional outcome (Constant score = 52.66). After 6 months of follow-up, 13 patients had a neck-shaft angle of less than 126°. The functional outcome is significantly better among patients with normal neck-shaft angle and had a mean Constant score of 76.63 as compared to patients with varus deformity had a mean Constant score 60 (p = 0.001). 10 patients did not have medial support, in which 08 patients had neck-shaft angle less than 126° and 2 had a normal neck-shaft angle.

Conclusion  High fracture comminution, improper restoration of medial continuity causes varus deformity of the humeral head and it leads to poor functional outcome. The small sample size is the limitation of our study.

Keywords  Proximal humerus fracture · Varus fixation · Functional outcome · Fracture comminution

Introduction

The humerus is the largest bone in the upper extremity. Fractures of the proximal humerus represent approximately 4% of all fractures and 26% of humerus fractures [1]. These fractures are most commonly low energy injuries occurring in elderly individuals and high energy complex fractures occur in younger patients less frequently. These fractures are more common in females, over the age of 60 having a history of osteoporosis [2]. Regardless of the age of the patient or mechanism of injury, restoration of pain-free functional range of motion remains the primary treatment goal of these injuries. Treatment of proximal humerus fracture has been the subject of much controversy and confusion, this is because of the complexity of these injuries. Most commonly used criteria to be considered as a displaced proximal humeral fracture is having at least 1 cm of displacement between the fracture fragments or more than 45° angulation [3].
Percutaneous fixation of proximal humeral fractures requires less dissection and therefore fewer chances of avascular necrosis of humeral head which does not give stable fixation to start early mobilisation. Contraindications include the presence of severe osteopenia or osteoporosis. Communion of the medial portion of the calcar or proximal part of the humeral shaft is also a relative contraindication. Treatment is difficult in elderly patients with osteoporosis. Improper intraoperative reduction of fracture increases the risk of a second fracture, and pull out strength of screw decreased in osteoporotic bone, making the fixation unstable when using a conventional plate. The use of a locking plate for proximal humeral fractures is fast gaining popularity because of its better pull-out strength and angle stability than conventional plates [4].

Frequent complications after proximal humerus fracture include stiffness, malunion, non-union, subacromial impingement, rotator cuff tear and traumatic arthritis. Several factors may affect the shoulder joint function after treatment such as fracture type, time of initiation of physiotherapy, plate position, varus of the neck-shaft angle, insufficient restoration of medial calcar support and humeral head ischemia. Knowledge of these key factors is beneficial for predicting the outcome of the operation and improving treatment [5].

So, the present study was conducted to know the relation between varus fixation of the humeral head in proximal humerus fractures and the factors which lead to varus deformity and its relation to functional outcome.

**Materials and Methods**

A Retrospective study of 32 patients was conducted at tertiary care hospital from July 2015 to November 2017 after approval of the institutional ethics committee. Closed proximal humerus fracture patients were classified under Neers classification. All the data was tabulated in excel spreadsheet and analysed by Chi-square test in epi info 7 software. The functional outcome was assessed by using Constant–Murley score.

Inclusion criteria were patients with closed proximal humerus fracture (two, three and four-part fractures), age 20 years and above. Exclusion criteria were patients with age less than 20 years, Patients with head and chest injury, Patients with Pathological fractures, Medically unfit patients for surgery and Compound fractures.

All the patients were evaluated with X-ray shoulder anteroposterior and lateral views, routine blood investigations and Computed tomography of the humeral head to know the fracture anatomy and articular congruity.

**Surgical technique** All the patients were operated by a single surgeon (professor by grade), using a deltopectoral approach for proximal humerus in the supine position. After reaching the fracture site, fracture fragments were reduced and temporarily held by multiple k wires and final fixation was done using Proximal humerus internal locking system (PHILOS) plate.

**Results**

In our study we treated 45 patients of proximal humerus fracture, 03 patients died due to other comorbidities (patients died after discharge from the hospital at home, not intraoperatively. 02 patients died of COPD and one patient because of stroke as per telephonic conversation with patient relatives), 10 patients did not come for follow-up (as this is a tertiary care hospital and patients are usually referred here from peripheral hospitals, some patients do not come for follow-up as they reside in remote places) and we got follow-up of 32 patients (Table 1). Patients were between the age of 20–73 years with a mean age of 47 years. Among 32 patients 21 (65.63%) were males and 11 (34.63%) were females. Out of 32 patients, 13 (40.63%) had a two-part fracture, 16 (50%) had a three-part fracture, and 3 (9.38%) patients had a four-part fracture. Age distribution and proximal humerus fractures according to Neer classification are described in Table 2.

The functional outcome represented by Constant–Murley score was significantly different among patients with different types of fractures (Figs. 1, 2) as per Neers classification ($p < 0.01$). The mean Constant–Murley score was better

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<td>31–40</td>
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<p>| Table 2 Distribution of patients with proximal humerus fractures according to Neer classification |</p>
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among two-part fracture (75.15) followed by three-part fracture (68.81) and four-part fracture have the lowest score (52.66). The functional outcome was excellent to good in patients with age 20–60 years, moderate to poor in patients with age more than 60 years as per Constant–Murley score (Table 3).

We divided the patients into three groups: valgus group (> 145°), normal group (126°–145°), and varus group (< 126°) to observe the influence of neck-shaft angle on efficacy. Out of 32, 3 (9.38%) patients had post-operative varus deformity with a neck-shaft angle less than 126° and 29 (90.63%) patients had normal neck-shaft angle 126°–145° and no patient had neck-shaft angle above 145°. After 6 months follow-up 13 (40.63%) patients had a neck-shaft angle less than 126° and 19 (59.38%) patients had a neck-shaft angle between 126° and 145°. 10 patients who had a normal neck-shaft angle, had gone to progressive varus deformity in which 06 patients were from 2 part fractures, 03 from three-part fractures and 01 from four-part fracture.

The functional outcome was significantly better among patients with normal neck-shaft angle and had mean Constant score of 76.63 as compared to patients with varus deformity had mean Constant score 60 with a p value of <0.001 which was statistically significant (Tables 4, 5).

In our study, 22 (68.75%) patients had medial support and 10 (31.25%) patients did not have medial support. Among these 10 patients, 8 (61.54%) patients had a neck-shaft angle less than 126° and 2 (10%) had a normal neck-shaft angle.

The neck-shaft angle of patients on follow-up differ significantly among the patients whose medial continuity was restored and in those in whom medial continuity was not restored (p value = 0.002). Varus deformity was significantly higher among patients in whom medial continuity was not restored (61.54%).

Among 32 patients, 4 (12%) had headed in anteversion, 20 (62.5%) in a neutral position, 8 (25%) in retroverted position. We did not find any significant relation (p = 0.32) between the version of head and neck-shaft angle. The patient had greater tuberosity below the level of the head (20 patients) had good functional outcome (Constant score = 75.2) compared to patients had greater tuberosity above the head level (9 patients), who had poor functional outcome (Constant score = 63). position of greater tuberosity is directly related to functional outcome (p < 0.001).

The mean follow-up of the patients was 1.5 years. The follow-up was done at 6 months, 1 year, 1.5 years and at 2 years. In each follow-up, the functional outcome was measured using Constant–Murley score. The functional outcome was improved with time/follow-up and was not statistically significant (p > 0.05).

Limitations of our study were the small sample size and No uniformity or consensus regarding the normal neck-shaft angle of the proximal humerus.

Fig. 1 a Pre operative X-ray. b Postoperative X-ray after 1-year follow-up. c Functional outcome
Discussion

Fractures of the proximal humerus represent approximately 4% of all fractures and 26% of humerus fractures [1]. The functional outcome represented by Constant–Murley score was significantly different among patients with different types of fractures as per Neers classification ($p < 0.01$). In our study, we found that fracture containing more fragments had a poor outcome. Similarly, Mayank et al. [6] in Indian population and Bjorkenheim et al. [7] in Finnish
population obtained better outcome in patients with 2-part fractures compared to 3 and 4-part fractures based on Constant scores using PHILOS plate. As per Anthony Christiano [8], Increased fracture displacement and varus deformity are factors influencing the functional outcome. Similarly, Zhu [9] divided the patients into three groups: valgus group (> 145°), normal group (126°–145°), and varus group (< 126°) to observe the influence of neck-shaft angle on efficacy. The constant–Murley score was 78.67% (59/75) in the normal group, and it was significantly higher than that in the valgus group (60.00%, 6/10) and varus group (42.86%, 9/21) (p < 0.05). The complication rate was 28.57% (6/21) in varus group, 10.67% (8/75) in the normal group. Agudelo et al. [10] considered primary varus reduction to be an important risk factor which may cause poor results, which is similar to our study. Yewlett and King [11] also concluded that restoration of an adequate neck-shaft angle was the most important determinant in fixation. If this was not achieved, despite adequate infero-medial support, screw perforation or plate failure occurred. Rohra et al. [12] also concluded that varus mal-union is one of the potential complications following fixation of proximal humeral fractures. Hessmann et al. [13] reported secondary varus deformity and retroversion of the humeral head leads to poor outcome because of the lack of rotational and angular stability of the plate.

Lee et al. [14] concluded that decreased neck-shaft angle was induced by lack of medial support. Gardner et al. [15] and Osterhoff [16] concluded that the presence of medial support had a significant effect on the magnitude of subsequent reduction loss (p < 0.001). According to Jung SW [17] varus displacement (p = 0.001), medial comminution (p = 0.001), insufficient medial support (p = 0.001) are independent risk factors for reduction loss. Krappinger [18] and Jung [19] concluded that intra-operative anatomic reduction and restoration of the medial cortical support are the essentials for successful surgical fixation of proximal humerus fractures.

Malunion of the greater tuberosity may be due to improper fixation which can lead to a poor functional outcome which is to Similar Aaron et al [20] reported that displacement of the humeral tuberosity above the head leads to poor functional outcome. Verdano et al [21] suggested that posterosuperior displacement of greater tuberosity leads to poorer outcomes. Charles Court-Brown and Margaret McQueen [22] concluded that varus deformity may predispose to an increased incidence of impingement syndrome, it is also possible that impingement of the greater tuberosity on the acromion process might lead to restriction of movement.

**Conclusion**

Varus fixation/malunion of proximal humerus fractures leads to poor functional outcome and the factors causing varus malformation are high fracture comminution and improper restoration of medial continuity of the humeral head. Higher malpositioning of greater tuberosity leads to poor functional outcome. The small sample size is the limitation of our study.

**Funding** None.

**Compliance with Ethical Standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical standard statement** This article does not contain any studies with human or animal subjects performed by any of the authors.

**Informed consent** Taken.

**Ethical committee approval** Taken.
References


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Abstract

Background  Scapular fractures are uncommon injuries of upper extremity resulting mostly from high-energy trauma. Extra-articular fractures form the majority of them. Un-displaced fractures can be managed conservatively with good results. But displaced fracture does not yield satisfactory results and needs surgical fixation. In this case series, we report our experience about such fractures.

Methods  This was a retrospective study of 12 patients with displaced scapular body and neck fractures treated between 2015 and 2018. Scapular fractures were exposed by modified Judet approach and fixed with either 3.5 mm T buttress or recon locking plate and screws. One case had associated clavicle fracture which was fixed along with scapula. Patients were put on structured rehabilitation and followed up regularly. Functional outcome and range of motion were analyzed.

Results  The patients included 10 males and two females. Mean age was 42 years. Average follow-up was 33 months. Average constant and Murley score was 80. Excellent results were seen in four patients, good results in seven patients and one patient has got fair result. The mean post-operative range of motion of the shoulder at the time of final follow-up was 140° of forward flexion, 136° of abduction, and 34° of external rotation.

Conclusion  Displaced extra-articular scapula fractures managed by internal fixation using T buttress locking plates and reconstruction plates give good functional outcome.

Keywords  Scapula fracture · Extra-articular fracture · Floating shoulder · Plating

Introduction

Scapula forms an important link between the upper limb and trunk. It has an important role to play in coordinating the complex shoulder movements. Scapular fractures usually result from high-energy trauma. Scapular fractures per se are relatively uncommon. They constitute 0.4–1% of all fractures and 3–5% of shoulder injuries [1, 2]. Extra-articular fractures of the body and neck account for 62–98% of all scapular fractures sub-types [3, 4]. Most of the scapular fractures are treated conservatively. But displaced fractures have to be fixed surgically. Conservative management in displaced fracture can lead to shoulder joint dysfunction, chronic pain, and other complications [5, 6]. Internal fixation of scapular fracture is not an easy solution, because it posts unique challenges, with regard to approach and fixation technique. Obtaining proper reduction and a proper intraoperative radiographic image will be challenging, particularly with comminuted fracture. Moreover, there is a risk of injury to neurovascular structures around the scapula. Clinical observations have shown that most unstable fractures of the scapula are comminuted extra-articular fractures of the scapular body or glenoid neck. A variety of implants are available for fixation of these complex fractures. Some of the implants used for scapula fracture fixation reported in literature include locking compression plate, reconstruction plate, distal radius plate, distal humerus Y-type locking plate, T-plate, calcaneous deformed plate, and microplate [3, 4, 7–11]. Aim of our study was to evaluate the functional outcome of extra-articular scapula fractures treated by open reduction and internal fixation using recon plates and T buttress plates.
Materials and Methods

This was a retrospective study done at our institution, after obtaining approval from the institutional review board. Inclusion criteria were (1) Extra-articular Scapula fractures which were surgically managed with plate osteosynthesis. (2) Completed a minimum follow-up of 18 months. Exclusion criteria were (1) Conservatively treated scapula fracture (2) Open fracture. (3) Type 3 fractures of Ada and Miller’s classification (Intra-articular glenoid fracture) [5]. Twelve patients met with the criteria who were operated between 2015 and 2018 at our institute. All the patients who presented after the injury were examined according to ATLS protocol. Physical examination was done and other associated injuries were looked into. Plain radiograph was used to diagnose the fracture. These 12 patients were chosen for internal fixation based on the indication elucidated by Cole et al. [12].

1. Medial/lateral displacement > 20 mm,
2. Angular deformity > 45°,
3. Glenopolar angle (GPA) < 22° (defined as the angle between the line connecting the uppermost with the lowermost point of the glenoid cavity and the line connecting the uppermost point of the glenoid cavity with the lowermost point of the body of the scapula)
4. Medial/lateral displacement > 15 mm and angulation > 30°, and
5. Double disruption of the superior shoulder suspensory complex with displacement > 10 mm.

Surgical Technique

The procedure was performed under general anesthesia. The patients were placed in the lateral decubitus position with the affected side facing up. All the bony prominences were adequately padded. The affected shoulder and arm were disinfected and the entire upper limb was wrapped in an aseptic drape, since manipulation of the limb will be needed to facilitate reduction. The modified Judet approach was used to expose the scapular fracture. A boomerang shaped incision was made from the distal tip of the acromion, extending parallel to the scapular spine and then along the lateral border of the scapula till the inferior scapular angle. The skin, subcutaneous tissue, and fascia were incised to expose the posterior part of the deltoid muscle. Deltoid was dissected off its origin from scapular spine and base of acromion. An interval between infraspinatus and teres minor was made, by retracting teres minor inferiorly, to avoid injury to posterior branch of axillary nerve and infraspinatus superiorly, to avoid injury to suprascapular nerve and artery. Scapular spine, glenoid neck and the lateral aspect of the body will be exposed. The fracture was reduced and held temporarily using Kirschner wires. Fixation was done based on the ‘three point two line’ principle of internal fixation [13]. Distal radiusT buttress locking plate or 3.5 mm locking reconstruction plate was used to fix the fracture along the lateral column of the scapula. Additional fixation of the medial column and the spine was done in cases where it was needed. In those cases, infraspinatus was erased of its origin for additional exposure which was repaired at the end of the procedure. The shoulder joint was repeatedly moved and intraoperative image intensifier was used to see if the screws penetrated into the joint cavity. Deltoid repaired back to its origin from the scapular spine and base of acromion. Suction drain was placed and the incision was closed in a layered fashion. Apart from scapular fracture, one patient had associated clavicle fracture. This fracture was also fixed internally using anatomical pre-contoured clavicle locking plate. For fixation of clavicle, the patient was turned from lateral to supine position.

Post-operatively, the shoulder was immobilized for 2 weeks in an arm sling. Active mobilization of the elbow, wrist, and fingers was encouraged. Passive shoulder-lift and pendulum exercises were performed after 1 week. After 2 weeks, active-assisted forward flexion and abduction of the shoulder joint were started. Gradually active movements were encouraged. After 6 weeks, shoulder muscle strength training was gradually started. Further follow-up was done at 3, 6 and 12 months after
surgery. Fracture union was assessed using plain radiographs (Figs. 1, 2, 3, 4). Further, yearly follow-up was undertaken. Functional outcome was measured using the Constant Murley scores [14] and range of motion in the shoulder joint was recorded.

**Results**

Twelve patients were included as per the inclusion and exclusion criteria. There were 10 males and two females (Table 1). Mean age was 42 years ranging from 26 to 64 years. Eight patients had a left side scapula fracture and the rest had a right side involvement. The cause of injury was road traffic accident in eight patients and fall from height in the remaining four patients. There were five associated injuries in addition to scapula fracture. Four patients had associated rib fractures and one patient had ipsilateral clavicle fracture. One patient had hemothorax which compromised respiration. An intercostal drainage tube was inserted to drain the hemothorax for that patient which was removed later. The average duration from injury to surgery was 3 days with a range of 1–10 days. Average follow-up was 33 months ranging from 18 months to 5 years. Average constant and Murley score was 80 (range of 68–87). Excellent results were seen in four patients, good results in seven patients and one patient has got fair result due to delayed infection and restriction of shoulder movement in our series. The patient with a fair result was diabetic and developed a delayed infection after 8 weeks. He was treated with intravenous antibiotics and infection got settled with the same. The mean post-operative range of motion of the shoulder at the time of final follow-up was 140° (range of 130–160°) of forward flexion, 136° (range of 130–150°) of abduction, and 34° (range of 30–40°) of external rotation. All the patients went back to their original profession and were able to do their routine activities without any difficulty.
Discussion

Scapula forms an important part of shoulder girdle linking the upper extremity and the axial skeleton. It has three articulations: glenohumeral joint, acromioclavicular joint, and the scapulothoracic joint. Full range of motion at the shoulder needs movement at all three articulations. This complex movement is brought about by eighteen different muscles that originate from or insert on the scapula. These muscles coordinate six basic movements of the scapula: elevation, depression, upward rotation, downward rotation, protraction, and retraction. In earlier days, scapular fracture was managed by benign neglect. Poor functional outcome from conservative management led to internal fixation of the fracture. First internal fixation of scapula was performed by Albin Lambotte in 1910 [15]. He fixed an unspecified transpinous fracture of the body, or neck with two screws. William Arbuthnot Lane was the first one to do a plate fixation for a displaced vertical fracture at 1914 [16]. Posterior approach for shoulder joint, with retraction of the spinal portion of the deltoid and the infraspinatus was first described by Rowe in 1944 [17]. Gradually techniques and implant got refined coping with the increasing needs for fixing these complex fractures.

A number of classification systems exist for scapula fractures. We followed the one elucidated by Ada and Miller [5] because of its simplicity. It is an anatomical classification and divides scapula fractures into 4 types: type 1a: fracture of acromian; type 1b: fracture of spine; type 1c: fracture of coracoid; type 2: fracture of neck; type 3: glenoid fracture (intra-articular); type 4: body fracture. Undisplaced extra-articular scapula fractures can be managed conservatively with good functional outcome. On the other hand, angular deformity and displacement will result in malunion, which in turn leads to muscle imbalance, rotator cuff dysfunction, scapulothoracic dyskinesis and impingement. In a biomechanical study done by Chadwick et al. [18], shortening of rotator cuff muscles and reduced forces were observed in cases of scapular malunion, which will compromise shoulder function. In a case series of 113 patients, Ada and Miller [5] observed that patients with displaced scapular neck fractures had weakness with overhead activities, subacromial pain, and decreased shoulder motion. A systematic review done by Zlowodzki et al. had 22 case series with 520 cases [6]. They observed that 20% of the conservatively treated extra-articular scapula fracture had poor functional outcome, 25% had radiographic scapula deformity and 12% had persistent pain. Another systematic review done by Kannan et al. also established the fact that displaced and comminuted fractures warrant operative fixation [1]. They found that displaced scapular neck fractures (> 10 mm) had a better functional outcome following operative management.

<table>
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<tr>
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Internal fixation of extra-articular scapula fractures has its own list of challenges. Surgical approach itself is a bit complicated. The modified Judet approach needs a meticulous dissection because of the proximity to suprascapular nerve and vessel superiorly and the axillary nerve inferiorly. Excessive dissection and traction can cause injury to these vital structures. The deltoid which was released off its origin from the scapular spine and acromion must be repaired back strongly, preferably by making osseous tunnels. Otherwise there will be loss of deltoid strength and chronic shoulder pain. All 12 patients in our study regained good deltoid strength postoperatively. Unlike the classical Judet approach where the infraspinatus muscle is erased off the infraspinous fossa, modified Judet approach spares the infraspinatus. In an observational study, Porcellini et al. found that an infraspinatus-sparing surgical approach for scapula fracture avoids infraspinatus hypotrophy and external-rotation weakness and suggested to restrict the classic Judet approach only to difficult fractures, not reducible with a narrow exposure. In our series, infraspinatus was erased of its origin and repaired back later, in cases where a medial column plating was required. But we did not encounter any weakness or hypotrophy postoperatively. Numerous plates are available to suit the surgeons’ need. But from our experience, a locking reconstruction plate or a distal radius T buttress locking plate is well and good. Placement of plate is extremely important to get adequate hold. A cadaveric study done by Burke et al. to measure the scapula osseous thickness for optimum implant placement found that the lateral border, the lateral aspect of the base of the scapula spine, and the scapula spine provide adequate screw purchase and improved strength of fixation. In our study, plating was also done along the medial column in four patients and all had adequate bony purchase and none had implant failure.

Majority of the scapular fractures occur as a result of high-energy trauma and there can be other associated injuries. Most of these associated injuries can be more dangerous than the scapular fracture itself. Therefore, all cases should be carefully evaluated for other associated injuries. Rib fractures and pulmonary injuries are the commonly associated injuries. Double disruption of the superior shoulder suspensory complex (SSSC) is one other commonly observed pattern with scapular fractures. The SSSC is a functional ring in the shoulder girdle consisting of the glenoid, coracoid, acromion, distal clavicle, coracoclavicular ligaments, and acromioclavicular ligaments. These structures secure the upper extremity to the axial skeleton. Single disruptions of the SSSC are generally stable, but a double disruption will be very unstable. Surgical fixation is indicated for double disruptions that are accompanied by significant displacement, as these may lead to malunion, or nonunion with poor long-term results. In our case series, we had one such case with associated clavicle fracture which was surgically fixed along with the scapular fracture. Last but not the least, injury to neurovascular structures should be carefully ruled out. Injury to brachial plexus and subclavian artery can be associated with scapular fracture.

Limitations

Sample size was small. But considering the rarity of this injury and a very small percentage of them needing internal fixation, getting a large sample size will be difficult. Second, a comparison with non-operative management was not done. A comparative study would have been more informative.

Conclusion

Extra-articular scapular fracture with significant displacement can be very well managed by internal fixation. T buttress locking plates and reconstruction plates are very good implants for these complex fracture fixation. With this modality of treatment, one can expect good functional outcome and return to pre-injury level of physical activities.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

Patient consent The authors certify that they have obtained all appropriate patient consent forms. In the form the patients have given their consent for their images and other clinical information to be reported in the journal. The patients understood that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

References


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High Velocity Gunshot Fractures of Humerus: Results of Primary Plate Osteosynthesis

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Abstract
Background High velocity gunshot fractures usually seen in conflict zones, often mandate external fixation due to delayed presentation and associated contamination. In the presented observational study, we managed high velocity gunshot fractures of humerus with adequate debridement and primary plate osteosynthesis under controlled conditions with gratifying results.

Material and Methods Eighteen consecutive cases of fracture of the humerus secondary to high velocity gunshot wounds with ages ranging from 28 to 45 years reporting within 6 h of the initial injury formed our study group. Immediate debridement, lavage and primary plate osteosynthesis was carried out following hemodynamic stabilisation and intravenous antibiotics. All the cases were followed up at 2, 4, 6 months, 1 year and then annual follow-up including telephonic follow-up for six patients.

Results Fifteen cases of Gustillo Anderson type III A, two of type III B and one of type III C were managed with primary plate osteosynthesis. Brachial artery injury was addressed immediately, however injured radial nerve ends were tagged. Five cases showed delayed/non-union and were managed with decortication and autologous bone grafting. Two cases of deep infection could be managed with implant retention till union. The implants were removed following fracture consolidation. All the fractures united and no patient was left with sequelae of chronic infection.

Conclusion Timely presentation of high velocity gunshot fractures of humerus teamed up with adequate debridement, soft tissue management and primary plate osteosynthesis can offer satisfactory outcomes. Associated vascular injury needs immediate attention. Nerve injuries can be addressed in a staged procedure. Our results have been satisfactory and add to the scant literature available on the subject, however further studies are warranted.

Keywords Gunshot · Humerus · Open fracture · Internal fixation

Introduction
High velocity gunshot wounds are generally seen in conflict zones common in military settings. The energy imparted to the bone and the surrounding soft tissue, compounded with gross contamination, in the setting of delayed presentation often mandates stabilization with external fixation. Traditionally, caution has been advocated during internal fixation of such fractures due to a higher risk of infection [1].

We present an observational study of high velocity gunshot fractures of humerus which were managed with adequate debridement and primary plate osteosynthesis. The objective of the study was to analyse and compare the results of such management in terms of fracture union and infection rates in the light of limited available literature. The study tried to establish the role of primary internal fixation in the management of the said injuries as this could circumvent the need for multiple subsequent surgeries and shorten the treatment duration.
Material and Methods

An observational study of open fractures of the humerus was conducted at an orthopaedic referral centre located in an armed conflict zone from Jan 2016 to May 2018. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Patients with high velocity gunshot injury of arm leading to fracture of the humerus who presented to our hospital within 6 h of sustaining the injury were included in the study. Patients with other limb injuries and/or systemic or visceral injuries which render them unsuitable for primary internal fixation were proposed to be excluded from the study. However, co-existing vascular or neurological injuries did not form an exclusion criterion.

Upon presentation to the emergency department, hemodynamic stability and neurovascular status of the limb was assessed. Fluid resuscitation, if indicated and intravenous antibiotics as per institutional protocol were administered. Orthogonal radiographs were obtained to assess and document the skeletal injuries. Informed written consent was obtained for immediate wound lavage, debridement, skeletal stabilization and soft tissue management. The decision to internally fix the fracture or restrict to external fixator stabilisation was made intraoperatively following adequate debridement.

Our antibiotic policy included injection cefoperazone (1000 mg) with sulbactum (1000 mg) 12 hourly, injection amikacin (750 mg) 24 hourly, and injection metronidazole (500 mg) intravenous 8 hourly. These antibiotics were administered for 72 h postoperatively to provide adequate coverage for gram positive, gram negative and anaerobic microorganisms.

Postoperative follow-up visits were scheduled at 2, 4, 6 and 12 months following surgery and annually thereafter. The outcome measures studied included fracture union and infection rates. Clinical and radiological evidence of fracture union and possibility of infection were noted at each visit. Fractures were considered to be united upon appearance of bridging callus in three cortices on two orthogonal views. Infections have been categorised as early superficial wound infection and chronic implant related infection or osteomyelitis. Six patients were not able to attend the clinic physically after 3 months and telephonic follow-up was maintained for them with clinical photos and photos of radiographs using Whatsapp™ messenger. All the data were extracted from case records and compiled in Microsoft excel sheet. Descriptive statistics were calculated to depict the results.

Results and Observations

Eighteen consecutive cases of fracture of the humerus secondary to high velocity gunshot wounds satisfying inclusion and exclusion criteria formed our study group. Majority of the bullets belonged to the Avtomat Kalashnikova (AK) family of automatic assault rifles which are high velocity weapons with muzzle velocity above 700 m/s. All the patients were male with a mean age of 36 years. Sixty six percent cases had gunshot injury to the dominant upper limb whereas 33% cases had injury to the non-dominant upper limb. Out of a total of 18 cases, 2 patients had hypovolemic shock at presentation. One of these had a severed brachial artery. Four cases had associated radial nerve injury. Combined vascular and neurological injury was not present in any of the cases. None of the cases had any associated systemic or visceral injury making them unfit for definitive management of fracture. One patient had bullet engaged in the chest wall without an associated visceral injury and the bullet was retrieved by general surgery team. No patient had sustained injuries to other limbs.

All the cases were taken up for immediate surgery. The mean injury to surgery interval was 3 h and 47 min. Vessel exploration and control of haemorrhage in the patient with brachial arterial injury was carried out by vascular surgeon and reconstruction with reversed great saphenous vein autograft was carried out following bony stabilisation with internal fixation (Fig. 1). Four patients with radial nerve injury underwent debridement and fixation, regardless of the nerve injury. Contused radial nerve was noted in one patient and partially transected and completely transected radial nerves were noted in two others—these were tagged.

Fig. 1 Gunshot fracture of humerus distal diaphysis injuring brachial artery. a Preoperative image, b preoperative radiograph, c postoperative radiograph
In the fourth case with radial nerve injury, the nerve was not visualised during surgery and no active attempt was made to seek it. Definitive nerve exploration and repair for the two transections were carried out by reconstructive surgeons at a higher centre 4 weeks following index surgery. The confused and the un-explored radial nerve injuries were managed expectantly.

Internal fixation was performed with a 4.5 mm narrow titanium locked compression plate in nine cases (50%), proximal humerus anatomical plate in five cases (27%) (Fig. 2), and distal humerus locking plates in four cases (22%). One of the cases had a non-reconstructable fracture of humeral head along with diaphyseal fracture of the humerus. The head fragments were excised piece-meal and diaphyseal fracture was fixed (Fig. 3). Surgical approaches used depended upon the open wound and fracture configuration. Deltoplectoral approach was used for proximal humerus fractures whereas diaphyseal fractures were fixed using either anterior or posterior approaches. All the distal humerus fractures were operated using the trans-olecranon approach. Ulnar nerve transposition was performed routinely in these cases. For all cases, range-of-motion exercises were encouraged from as early as the first post-operative day.

Primary closure of the wound could be done in 11 cases (61%). Shoe lace sutures were utilised for delayed primary closure of the wound in three cases (17%). Secondary closure was resorted to in four cases (22%). Of these, negative pressure wound therapy was applied in one patient for 5 days and three cases needed split skin grafting for wound coverage. Three cases (17%) with features of early wound infection were managed with repeat wound debridement and continuation of intravenous antibiotics for 2 weeks empirically. They responded well but were given oral Linezolid 600 mg po bd for another 4 weeks.

Follow-up period for our study group ranged from 25 to 36 months with a mean follow-up of 28.5 months including telephonic follow-up with radiographic images. Thirteen fractures were noted to have united at 4 months’ follow-up visit. Three cases (17%) showed evidence of delayed union with poor callus formation. These cases were managed with autologous bone grafting and were further reviewed at 3 months following the procedure. All the three cases displayed fracture consolidation. Two cases (11%) were found to be in “non-union” with no callus formation at the 4 months’ follow-up visit. Decortication and bone grafting was done for both at 17th and 18th week while retaining the implants. Both the fractures were consolidated at 3 months following repeat surgery. The patient with arterial repair went on to have an uneventful post-operative recovery (Fig. 4). The two cases with radial nerve injury who underwent radial nerve repair showed good results with grade four power at finger and wrist extensors at 6 months follow-up visit. Also, pin prick sensation in autonomous zone of radial nerve was recorded. Complete recovery was noted in the other two cases who were managed expectantly suggesting neuropraxia. Two cases (11%) presented with a discharging sinus over the surgical site at 5 and 6 months, respectively, following index surgery. The types of initial wound closure

Fig. 2  Gunshot fracture of proximal shaft of humerus. a Wound of entry in close vicinity to neurovascular bundle, b wound of exit, c preoperative radiograph, d postoperative radiograph
in these cases were primary and secondary closure with SSG, respectively. None of these patients had shown any sign of superficial infection earlier. In both the cases, fracture consolidation was noted and they were managed with implant removal alone. Further review at 3 months following implant removal showed no evidence of residual infection clinically or radiologically. None of the patients displayed any effects of retained bullet subsequently.

Patients with fractures involving the proximal humerus had poorer range of motion at their shoulder joints. The
patient who underwent excision of the humeral head and was unwilling for any further intervention showed 40° of active abduction at shoulder joint at 2 years follow-up. However, full range abduction was possible with assistance (Fig. 5). All the fractures united and no patient was left with residue of infection upon completion of this study. All the studied variables and outcomes obtained have been summarised in Table 1.

Discussion

Although we kept our options regarding internal or external fixation open prior to surgery and the decisions were taken intraoperatively, we did not need to resort to external fixation in any of our cases. The only patient with associated vascular injury was managed with joint intervention wherein the bony stabilization was performed before vascular repair. In most of the cases, wound closure could be achieved either primarily or in a delayed primary manner. However, split skin grafting and negative pressure wound therapy were also resorted to. We did not need full thickness flap cover for any of the cases.

We could achieve union in all the cases. However in our study, we utilised secondary procedures early to achieve union in five cases. Our cumulative rate of delayed union is 16.66% and that of the non-union is 11.11%. Our delayed infection rate has been 11% with 2 out of 18 cases developing it which could be managed with implant removal following fracture consolidation. Upon including early infections to this figure, our cumulative infection rate becomes 27%. All cases of early infections could be tackled with debridement and intravenous antibiotics for 2 weeks followed by oral antibiotic, with no long-term sequelae.

In the presented study, two cases of nerve injury did not require any intervention and showed complete recovery spontaneously. Also, the two cases with structural lesions of the nerve managed with nerve repair at 4 weeks showed satisfactory recovery at the 6 months’ follow-up visit.

Involvement of upper extremity has been witnessed more commonly in gunshot injuries. Research publications regarding management of gunshot fractures of the humerus had become available even before the First World War [2]. It

![Fig. 5 30 months follow-up of the case shown in Fig. 3 above. a Healed surgical scar, b radiograph showing consolidated diaphyseal fracture with absent humeral head, c active abduction of 40°, d assisted abduction full range, e passive flexion of 120°, f active extension of 30°, g active internal rotation near full range, h active external rotation 50°](image)
is noteworthy that most of the available literature till date deals with low velocity gunshot fractures of the humerus. No study is available regarding the management of such injuries using internal fixation exclusively [3]. Although the basic principles of management of such fractures remain the same, high velocity gunshot wounds are associated with greater soft tissue disruption along with larger area of contamination and comminution; as a minor increase in the velocity of the projectile increases its kinetic energy exponentially and consequently the damage.

Gunshot injuries should be treated as a separate clinical entity from open humerus fractures caused by other mechanisms [4]. The treatment options for various gunshot fractures range from non-operative to primary internal fixation [5]. Various studies [6] have recommended treatment based upon the grade of open humerus fractures. Conservative management with functional bracing has been recommended for grade I injuries whereas operative or non-operative treatment for grade II open humerus fracture has been recommended based upon the level of contamination. Operative management has been suggested for grade III open fractures. There are many proponents of conservative management of gunshot fractures of the humerus despite of being an open fracture [7]. Dougherty et al. suggested use of external fixation for contaminated open humerus fractures as a temporizing measure as well as definitive management [8]. Suzuki et al. studied the conversion of external fixation to internal fixation and reported union in 88% of cases in 11.1 weeks [9]. However, a prospective study conducted on the victims of gunshot wounds by Keller et al. in year 1991, showed higher rates of complications with external fixation as compared to bracing. The non-union rate with external fixation was 71.5% as compared to 14% with bracing. However, their results could have been affected by the delayed presentation (mean delay 9.5 days) and higher rates of local infection at the initial presentation (89%) of the patients. They obtained good results with functional bracing. Nonetheless, the authors also reported that patients treated with external fixation and traction had sustained more severe

<table>
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injuries. In other studies, with external fixation in upper limb injuries, the non-union rates have varied from 5 to 62% [7].

Primary internal fixation for gunshot fractures similar to our study were studied by Wild et al. and they obtained poor results [10]. Connolly et al. [6] studied primary internal fixation in open humerus fracture due to all causes in 46 patients and reported good results with mean union time of 18.4 weeks in 40 patients. They reported delayed union in six patients. Our results outstand all of the above mentioned studies with similar or better fracture union rates and infection rates with reduced number of interventions.

Gunshot wounds are not sterile in nature and auto sterilisation of bullets is a myth [11]. Oral cephalosporin has been recommended for low velocity gunshot injuries whereas intravenous cephalosporin with aminoglycoside have been recommended for high velocity gunshot injuries [12]. Additionally Penicillin has been recommended for use in cases of soil contamination. Our protocol included intravenous metronidazole for anaerobic cover apart from generation cephalosporin and aminoglycoside for 72 h postoperatively. Antibiotic with anti-psudomonal activity has been recommended for war injuries [4]. Oral Linezolid has been used in our study in cases of infection.

The extent of soft tissue injury is an important determinant of the recovery and useful functionality of the limb [13]. All gunshot fractures have been classified as Gustillo Anderson grade III fractures and aggressive surgical management has been suggested in the literature. With advancement in surgical techniques and early administration of antibiotics, primary closure of the wound has become safer. Early ‘Fix and Flap’ technique endorsed by various surgeons has obtained good results. It helps in avoiding multiple subsequent surgeries and hence lowers the cost of treatment. The chances of complications increase with increasing trauma to surgery interval [14]. Soft tissue management is the major determinant of the duration of hospital stay in such patients and aggressive wound management resulted in a shortened hospital stay. Neural injuries have been cited to be the most important factor in regaining useful function and the persistence of long-term disability. Kumar et al. [15] performed free flaps for open fractures sustained in battle fields following repeated debridement in 26 cases with a remarkable success rate of 96% with the infection rate of 8 percent. The mean delay for the recipient site to be ready for grafting was 31 days. Though we did not need full thickness flap but split skin grafting was needed for three cases. One case was treated with negative pressure wound therapy for 5 days.

The incidence of nerve injury ranges from 0–58% in the literature [3]. Neuropraxia or axonotmesis is the usual injury observed in low velocity gunshot wounds whereas complete transection is more likely in high velocity gunshot injuries [16]. Expectant management without nerve exploration has been indicated for isolated nerve injury. However, when associated with vascular injury, disruption of the nerve is more likely and immediate exploration is indicated [17]. Associated peripheral nerve injuries should not guide the treatment plan of operative vs. conservative therapy [18]. Exploration of affected nerve during operative management is also of questionable value as most nerves explored in various studies were found to be in continuity. The timing of repair of transected nerves in such injuries has been suggested as 2–3 weeks as this period allows adequate management of primary injury, debridement, control of infection and soft tissue cover [19]. In our study, two cases had neuropraxia and showed complete recovery spontaneously. Also, the other two recovered satisfactorily following intervention at 4 weeks with complete function at 6 months.

Incidence of vascular injuries in gunshot wounds of the upper limb ranges from 0–15% [20]. Coexisting vascular injury warrants immediate integrated intervention. The order of intervention—whether vascular repair first or fixation first remains a debate. Vascular repair before fixation gives the advantage of relieving the most crucial factor of limb ischemia and improves the chances of limb salvage. Bony stabilisation before vascular intervention ensures that the subsequent orthopaedic procedure does not jeopardize the repair [12]. McHenry et al. [21] demonstrated that vascular repair prior to an orthopaedic procedure was associated with lesser complications and a shorter hospital stay. In the presented study group, we had only one patient with associated vascular injury. Bony stabilisation was performed before vascular repair in this patient.

The limitation of the presented work is non-homogeneity of the study population. We have included all the fractures of the humerus in our study group irrespective of the part of the bone involved. Blood supply of the humerus varies in different parts of the bone, being most precarious in distal third of the shaft, the most common site of delayed and non-unions [22]. Having stated that, we should also keep in mind that though proximal, diaphyseal and distal humerus fractures are essentially different injuries and affect adjacent joint functions differently, the primary variables of interest in the presented study were union rates and infection rates. Irrespective of the location of the fracture, the mean time to union in our study was 19 weeks. Primary plate osteosynthesis makes our study unique as no other study discusses plating for open fractures exclusively [3]. We were able to achieve good results with reasonably few complications in the presented study. However due to a small sample size, definitive conclusions could not be drawn to support primary internal fixation in high energy gunshot wounds of the humerus. Nonetheless, we feel that in gunshot wounds presenting within 6 h of injury, primary plate osteosynthesis following thorough debridement is definitely a treatment.
option. Based upon our results, further studies are recommended to establish it as a standard of care.

**Conclusion**

High velocity gunshot fractures of the humerus are common in military conflict zones. They have been associated with remarkable morbidity irrespective of the interventions offered. In the presented study, timely presentation of the patient to emergency room, adequate debridement and soft tissue management along with primary internal fixation could offer satisfactory fracture union rates and infection rates. Primary osteosynthesis has also been helpful in reducing the morbidity and costs incurred in repeated surgeries for such injuries. Associated vascular impairment necessitates multi-speciality intervention on an emergent basis. Nerve injuries may be safely tackled in a staged procedure. We could obtain reasonable results for such injuries, but further studies are warranted to substantiate the practice.

**Patient Declaration**

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

**Compliance with Ethical Standards**

**Conflict of interest** Manoj Kumar, J. P. Khatri and C. M. Singh declare that they have no conflict of interest.

**Ethical standard statement** This article does not contain any studies with human or animal subjects performed by the any of the authors.

**Informed consent** For this type of study informed consent is not required.

**References**


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Open Classic Latarjet Procedure Performed Using Freehand Technique—Surgical Technique and Outcome

M. Karthik Selvaraj1 · Tapan Kumar Das2 · Nikhil Joseph Martin3 · M. Shyam Sundar2 · David V. Rajan2

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Abstract

Introduction Latarjet procedure is commonly performed for recurrent anterior shoulder instability with glenoid side bone loss. Classic Latarjet procedure can be performed using specially designed drill guides, jigs, or by freehand technique. Here we have described a technical note on classic Latarjet procedure performed with freehand technique utilizing simple rulers and caliper. The functional and radiological outcomes of our patients have also been analysed.

Material and Methods 149 open classic Latarjet procedures were performed using our technique between March 2015 and July 2018. The mean age of the patients was 32.95 years (Range 22–59 years). The functional outcome of the patients was measured using Western Ontario Shoulder Instability (WOSI) and Oxford Shoulder Instability Score (OSIS) at 2 years of follow-up. Screw and graft positioning were studied in 24 consecutive patients with a postoperative computed tomography (CT) scan.

Results There was no incidence of recurrent subluxation or dislocation post-surgery. Mean OSIS score increased from 15.63 ± 3.20 preoperatively to 42.44 ± 3.88 postoperatively (p value < 0.05). WOSI score decreased significantly from 62.54% ± 8.24 to 10.26 ± 6.33 postoperatively at 2-year follow-up (p value < 0.05). Postoperative CT scan also showed satisfactory screw placement in all patients.

Conclusion Open Latarjet procedure performed using freehand technique provides good functional and radiological outcomes in patients with recurrent anterior shoulder instability with glenoid side bone loss.

Keywords Classic Latarjet · Freehand technique · Anterior shoulder instability · Coracoid graft · Recurrent instability

Introduction

Latarjet procedure has evoked renewed interest around the world in recent years, especially in patients with recurrent anterior shoulder instability with glenoid bone loss. The surgery was shunned due to the high rates of complications reported in the literature. The French have to be credited for popularising the procedure again and describing the correct technique thus minimizing the complications and giving good results. The success of Latarjet surgery comes from its ‘triple blocking’ effect [1]. ‘Triple blocking’ is given by the bony effect, ligament effect, and muscular effect. The bony effect is given by the bone graft which enhances the glenoid width. The muscular effect is given by the conjoint tendon sling which reinforces the inferior subscapularis. The ligament effect is usually obtained by suturing the anterior capsule to the coracoacromial ligament (CAL). With increasing success reported in the literature, the Latarjet procedure is being preferred as a primary procedure for most cases of...
recurrent anterior shoulder instability. It is cost-effective, allows an easier return to play, and necessitates less strict postoperative immobilization.

The concept of “critical” bone loss has been highlighted in different studies as a predictive factor for failure of the arthroscopic bankart repair. 19–21% of glenoid side bone loss has been attributed to compromised arthroscopic Bankart repair outcomes [2]. Glenoid side bone loss leads to a reduction in glenoid track width which may subsequently lead to off-tract Hill-Sachs lesion [3]. Latarjet procedure is a preferred surgery for patients with bone loss.

Latarjet is a technically demanding procedure as the incidence of complications is directly related to the position of the screws. A lateral overhang of the graft of 1 mm can lead to osteoarthritis whereas medial placement by 2 mm can lead to failure and recurrence of instability. The invention of newer drilling guides for screw placement has shown to provide promising functional and biomechanical results [4, 5]. However the drill guide may not be of use in small glenoid and coracoid dimensions [6, 7].

In this article, we describe the classic Latarjet procedure performed with a simple freehand technique using caliper and rulers. We have also studied the accuracy of screw placement with this technique with computed tomography (CT) scans and analysed the functional outcome of our patients at 2 years of follow-up.

**Surgical Technique**

**Patient Positioning and Anaesthesia**

We perform the procedure under interscalene block. Patient is placed in beach-chair position with appropriate padding of bony prominences. The shoulder is prepared and draped in a sterile fashion. The arm should remain draped free to allow for intraoperative manipulation of the upper extremity.

**Surgical Approach**

A 6–7 cm axillary crease incision is given, medial to the traditional deltopectoral incision (Fig. 1). Subcutaneous tissue dissection is done and then the clavipectoral fascia is identified and incised. The cephalic vein is found in the medial part of the flap. The cephalic vein is retracted along with the deltoid laterally. Deltopectoral interval is developed and self-retaining Gelpi retractors are inserted in the interval. Hohmann retractor is placed at the base of the coracoid to help improve visualization. Often, the branches of the deltoid artery are found to cross anterior to the coracoid and can cause bleeding if injured during retraction. These vessels can be ligated or cauterized as needed.

Fig. 1 Skin incision marking from coracoid process to anterior axillary fold

**Coracoid Exposure**

A good exposure of the coracoid process is obtained with the Hohmann at the base of the coracoid. Coracoacromial ligament (CAL) is identified with the arm in abduction and external rotation and transected with 1 cm stump attached to the coracoid. This remnant CAL would be later sutured to the shoulder capsule. Pectoralis minor tendon is sharply released from the medial aspect of the coracoid process using diathermy. Routine identification of axillary or musculocutaneous nerve is not needed. But a thorough knowledge of their location is necessary to avoid inadvertent damage.

**Coracoid Graft Harvest**

We generally use a 1-inch curved osteotome for graft harvest. The osteotomy is done just at the base of the coracoid (Fig. 2). During the osteotomy, it is made sure that coracoacromial ligaments are not disturbed. An instrument is placed underneath the coracoid to avoid inadvertent neurovascular injury. A paper ruler is used to measure the appropriate graft length. After the osteotomy is completed, the coracoid graft is held with a Kochers or Sponge Holding forceps. Specific coracoid graspers are available. An oscillating saw and a nibbler are used to freshen and decorticate the undersurface of the coracoid graft. A burr can also be
used to perform decortication. Next, a caliper is used to measure the dimensions of the graft (Fig. 3). Pre-drilling is performed with a solid drill bit of size 2.5 mm for the inferior screw. Then, the distance between the drill hole and lateral margin of the coracoid is measured. The graft thickness helps us decide the length of the screw. The second drill hole is not made at this stage.

**Glenoid Exposure**

Adduction and external rotation of the shoulder help us visualise the subscapularis. The subscapularis muscle is then sharply split with a curved Metzenbaum scissors at the junction of the upper half and lower half. The division need not extend to the tendon. Once the muscle is split, the white shiny capsule comes into view. The plane between the subscapularis and the anterior glenohumeral capsule is developed. A Gelpi retractor can be inserted in the subscapularis split to help in retraction. A longitudinal skin incision is given over the shoulder capsule to expose the joint. The capsule is then tagged with Vicryl suture to facilitate identification during the subsequent capsular repair. A Fukuda humeral head retractor is now inserted to retract the humeral head. An anterior glenoid retractor is used to expose the glenoid. The anterior-inferior glenoid labrum is dissected using electrocautery and elevator. A burr is used to prepare the anterior neck of the glenoid.

**Coracoid Graft Transfer**

The Coracoid graft should be flush with the articular surface of the glenoid. The longitudinal axis of the coracoid graft is positioned in the superior-inferior direction along the anterior glenoid neck with the lateral aspect of the graft flush with the articular surface in the classic Latarjet procedure. Having pre drilled the inferior screw hole on the coracoid, the screw hole on the glenoid has to be drilled at the appropriate site. Place a ruler scale on the anterior aspect of the glenoid and make a mark at the same distance from the glenoid articular surface so that after placement of the graft, the graft will be flush with the glenoid without lateral overhang (Fig. 4). The distance is usually between 6 mm to 8 mm from the glenoid articular surface. Now drill the glenoid at the marked site parallel to the surface of the glenoid. Measure the depth of the glenoid hole using a depth gauge and this can be added to the previously measured coracoid thickness to get the appropriate screw length. A guidewire is inserted from the coracoid graft inferior drill hole into the glenoid drill hole and then fixation is done with a 4 mm cancellous screw (Fig. 5). Do not fully tighten the inferior screw now. The second drill hole is made at the mark on the coracoid graft. If needed, at this time minor adjustments in the graft placement can be done, by rotating the graft. At the end tighten both screws alternatively to get the coracoid graft flush with the glenoid (Fig. 6).
Capsular Closure

The previously tagged capsule remnant is now repaired to the CAL to make the graft partly intraarticular. The subscapularis split is not repaired and the conjoint tendon exiting through the split in the subscapularis provides the muscular effect as described by Patte. Now the wound is closed in a standard layered fashion.

Post-Operative Care

The arm is kept in a sling for 3 weeks. The sling can be taken off for having food from day 1. Active assisted movements usually start at 4 weeks and strengthening exercises start at 8 weeks. The Patient is fit to return to [8] sports usually by around 4–6 months.

Results

From March 2015 to July 2018, 149 open classic Latarjet procedures were performed by 2 surgeons of our institution. The mean age of the patients was 32.95 years in the age group of 22–59 years. All patients were followed at regular intervals for a minimum period of 24 months. Four patients were lost to follow up during the 2 years follow-up period. All patients had their dominant hand affected. None of the patients had subluxation or dislocation post-surgery. Functional outcomes of the patients were evaluated using the Western Ontario Shoulder Instability (WOSI) score and Oxford Shoulder Instability Score (OSIS) at 2 years post-surgery. The mean OSIS increased from 15.63 ± 3.20 preoperatively to 42.44 ± 3.88 postoperatively (p value < 0.05). WOSI score decreased significantly from 62.54% ± 8.24 to 10.26 ± 6.33 postoperatively at 2-year follow-up (p value < 0.05).

From the 144 patients, in a consecutive case series of 24 patients, we did a post-operative CT scan to evaluate the accuracy of coracoid graft screw placement. The coracoid graft is considered to be flush with the glenoid if in axial plane the lateral edge of the graft was within ≤ 1 mm lateral to ≤ 4 mm medial to the glenoid articular surface [4]. In our study, we found that in 83% of cases our graft placement was flush with the glenoid. All patients had 60% graft below the equator. From the 24 patients, 20 patients had the graft flush to glenoid in the axial plane and 2 had lateral overhang of 1 mm and 2 had medially placed graft of 1 mm.

Discussion

In both clinical and biomechanical studies, the open Latarjet procedure has demonstrated consistent results in providing glenohumeral stability. Recent literature has swayed towards better outcomes and lesser or equal long-term complications with the latarjet procedure compared to the Bankart repair. Hovelius et al. in a prospective study performed in 118 patients reported a 3.4% recurrence rate and 98% success rate after 15 years of follow up [8]. Mizuno et al. in a long-term retrospective analysis of 68 latarjet procedures reported a recurrence rate of 5.9% after a mean follow-up of 20 years [9]. In a systematic study involving ten clinical studies, Bhatia et al. reported recurrent instability in 0–8% of cases [10].

Gartsman et al. in their case series of 416 latarjet procedures reported a complication rate of only 5%. They reported 13 cases of neurologic complications, of which 11 cases recovered without any deficit at final follow-up [11]. Shah et al. in their study of 48 shoulders described a 10% incidence of neurologic injuries [12]. In a systematic review with a meta-analysis of eight comparative case series between bankart repair and Latarjet procedure, Vincent et al. concluded that the Latarjet procedure was associated with less chance of re-dislocation and recurrence [13]. They found that the Latarjet procedure was associated with higher Rowe scores and lower loss of external rotation compared to the Bankart repair procedure.
Precise placement of the coracoid graft over the glenoid is of utmost importance. Excessive lateralization of the coracoid graft has led to abnormal glenohumeral contact pressures and glenohumeral arthropathy in cadaveric biomechanical studies [14]. Barth et al. compared the accuracy of screw placement in patients who underwent the Latarjet procedure using the freehand technique with those who underwent the same procedure using drill guides [4]. Using drill guide, the coracoid graft was placed flush in 85.2% and 88.9% of cases in the inferior and middle quartiles of the glenoid. The study also reported in 85.2% of cases, 60% of the graft was inferior to the equator of the glenoid. These results are comparable to our results where 83% of patients had the graft flush with the glenoid and all 24 patients had 60% of their length below the equator.

The Freehand technique also provides several advantages. Screw diameter size can be changed according to the size of the graft in our technique which is not possible with a drill guide. We can readjust the position of the graft while drilling for the second screw. Drill orientation also can be manipulated in patients with severe glenoid side bone loss. The main disadvantage of the technique is that it could be cumbersome on part of the surgeon initially to measure with scale and rulers in each step from graft harvest to graft positioning. Nevertheless, the technique can be easily mastered.

**Conclusion**

Open Latarjet procedure performed using freehand technique provides good functional and radiological outcomes in patients with recurrent anterior shoulder instability. Precise measurement of the graft and accurate marking of screw entry points over the graft and glenoid as described in our technical note will help to prevent graft mal-positioning.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare no conflict of interest.

**Ethical standard** The study was approved by local ethic committee.

**Informed consent** The authors certify that they have obtained all appropriate consent forms.

**References**


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Eden-Hybinette Procedure for Revision Surgery in Recurrent Anterior Shoulder Instability in Epilepsy

Ravi Mittal · Siddarth Jain

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Abstract

Aims The purpose of this study was to analyze the clinical outcomes after Eden-Hybinette procedure for revision surgery in recurrent anterior shoulder instability in patients with epilepsy.

Materials and Methods We retrospectively evaluated eight such patients between 2015 and 2018. Four patients had failed Latarjet/Bristow procedure and two had failed arthroscopic Bankart procedure, while two had history of both the procedures. After medical control of epilepsy, Eden-Hybinette procedure was performed in all patients. WOSI score and Rowe shoulder score was recorded preoperatively and in subsequent post-operative follow-up. A paired t test was used to analyze and compare preoperative and postoperative outcomes and was considered significant if p value was < 0.05.

Results The average follow-up was 30 months (range 24–48 months). There was no recurrence of shoulder instability. The mean WOSI score before surgery was 77.3 (range 70–83), which improved to 24.2 (range 19–30) at 24-month follow-up. The mean Rowe score before surgery was 11.3 (range 5–15), which improved to 81.8 (range 65–90) at 24-month follow-up. The improvement in WOSI and Rowe score was found to be statistically significant [p value < 0.05]

Conclusions We conclude that Eden-Hybinette is a useful revision procedure to manage recurrent anterior shoulder dislocation in patients with epilepsy. Optimum medical control of seizure is also an important factor in preventing recurrent shoulder instability

Keywords Eden-Hybinette procedure · Epilepsy · Anterior shoulder instability · Hill Sachs lesion · Bipolar lesion

Introduction

The prevalence of epilepsy is 1% in Indian population and shoulder dislocation has an incidence of 0.6% in epileptic seizures [1–3]. Such dislocations occur mostly in males between 20 and 40 years [4]. It can occur without any direct trauma or due to a fall during the seizure [5, 6]. No single surgical procedure has been described as treatment of choice for the primary surgery or for the revision in anterior shoulder instability in this subset of population. The general guidelines for the management include adequate seizure control with anticonvulsant drugs, evaluation of glenoid and humeral bone loss, and pathology-specific surgical treatment. Soft tissue procedures and Latarjet procedure have not shown good results in epileptic population [1, 5, 7]. The recurrence rate is higher among these patients as compared to non-epileptics (69% vs. 10%) [7]. This may be due to concurrent seizure activity or selection of an inappropriate surgical procedure. Eden-Hybinette procedure is commonly used for revision in failures of Latarjet procedures with good outcome in the general population. However, there is no report describing the use of Eden-Hybinette procedure using autologous iliac bone graft in revision surgery in epileptic population. The purpose of this study was to analyze the clinical outcomes following revision surgery with Eden-Hybinette procedure using autologous iliac bone graft along with optimum medical anti-epileptic treatment in recurrent anterior shoulder instability in patients with epilepsy.

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Materials and Methods

We retrospectively evaluated eight patients who were treated for recurrent anterior shoulder dislocation with epilepsy between 2015 and 2018. Patient’s age was between 18 and 40 years. Four patients had failed Latarjet/Bristow procedure and two had failed arthroscopic Bankart procedure while two had history of both the procedures. We excluded the patients with posterior or multidirectional instability, rotator cuff tear, and glenohumeral or acromioclavicular joint arthritis. Clinical and radiological evaluation was done preoperatively and in subsequent post-operative follow-up. All patients had complaints of persistent apprehension, recurrent glenohumeral dislocations or subluxation. It was confirmed by clinical examination. WOSI score and Rowe shoulder score was recorded preoperatively and in subsequent post-operative follow-up at 3, 6, 12 and 24 months to assess the functional outcome. All the records and relevant investigations of previous surgery were analyzed. Besides the standard AP view radiographs, CT scan was done preoperatively to evaluate glenoid and humeral bone loss. Preoperative MRI was also done to evaluate rotator cuff. Post operatively CT scan was done at 6 months to confirm union of iliac crest autograft. Before the surgery, medical control of epilepsy was ensured in consultation with the neurologist. The medical treatment of epilepsy was continued after the surgery also.

Surgical Technique

All surgeries were performed in beach chair position under general anesthesia by the same surgical team. The shoulder and arm were prepared and draped in a sterile fashion and the arm was kept free. Deltopectoral approach was used for surgery with a skin incision from the tip of the coracoid process to the anterior axillary fold. The deltopectoral interval was opened, and the cephalic vein identified, freed and taken laterally with the deltoid. In some cases, it was not identifiable due to previous open surgery. Subscapularis muscle was identified and exposed. In cases with previous Latarjet/Bristow procedure, the subscapularis was elevated subperiosteally from lesser tuberosity leaving a small margin of the tendon tissue close to and along the bicipital groove for repair at the end of procedure. It was retracted medially to expose glenoid neck. Anterior capsule if found, was cut in T shaped with longitudinal arm of incision till glenoid neck. Margins of the capsule were tagged with Ethibond no. 5 sutures. Next, a Fukuda retractor was inserted between the glenoid and humeral head to expose the glenoid. At this point, the screws/anchors used in the previous surgery were removed (Figs. 1, 2).

Fig. 1 X-ray showing failure of Latarjet procedure with bent screw and broken graft

Fig. 2 CT scan showing failure of Latarjet procedure with broken graft

Remnants of coracoid graft were resected. Rough bleeding surface was prepared over anterior glenoid neck for the autologous tricortical iliac bone graft fixation. In cases
where Latarjet procedure was not previously performed, the subscapularis was not elevated from lesser tuberosity. The muscle was split longitudinally along the fibers to expose the capsule and the joint. A tricortical graft of 2.5 cm length and 1 cm height was harvested from the iliac crest. The graft size was checked by placing it on the glenoid in such a way that its inner smooth concave surface was aligned to the glenoid articular surface and the cortical surface of iliac crest was facing anteriorly. A 2.5-mm drill bit was used to drill three holes for 4 mm cancellous screw fixation. It was ensured that the holes were centered on the graft. Graft was placed in desired position and 2.5-mm drill bit was used to penetrate the glenoid through the predrilled holes in the graft. Partially threaded 4-mm screws were inserted after measuring the depth with depth gauge. One or two screws out of the three were put along with washers to obtain better compression between the glenoid and the graft. All the screws were tightened completely and the final positioned of the graft was checked again. Subscapularis was reattached to the remaining fibers on the lesser tuberosity in cases where it was detached. The repair was reinforced by two 5-mm suture anchors on the lesser tuberosity (Fig. 3). The wound was thoroughly irrigated and closed in a standard layered fashion.

**Postoperative Rehabilitation**

The arm was supported with an arm sling for 4 weeks. From the first operative day, pendulum exercises and shoulder shrugging were started. Active-assisted ranges of motion (ROM) exercises were started 4 weeks after surgery. When the patient was able to perform active forward elevation above the shoulder level, strengthening exercises were started. All the patients were advised to strictly adhere to the medical treatment of epilepsy after the surgery, as advised by the neurologists.

**Statistical Analysis**

An independent statistician performed statistical analysis. A paired t test was used to analyze and compare preoperative and postoperative outcomes and was considered significant if p value was <0.05. The Pearson correlation method and sample t test were used to assess correlation of functional outcomes with multiple variables.

**Results**

There were six males and two females. The age ranged from 20 to 40 years and the average age was 31.6 years. The average duration of surgery was 90 min and average hospital stay was 3 days. Bipolar lesion was found in 3D CT analysis in all the patients. Glenoid bone loss was measured as more than 25% in all the patients. All the Hill-Sach lesions were found off-track on 3D CT analysis. In subsequent postoperative radiological evaluation, humeral head found to be reduced with graft well placed. The average follow-up was 30 months (range 24–48 months). There was no seizure episode during the follow-up period and there was no recurrence of shoulder instability in any of the cases. The mean WOSI score before surgery was 77.3 (range 70–83), which improved to 24.2 (range 19–30) at 24-month follow-up (Table 1). The mean Rowe score before surgery was 11.3 (range 5–15), which improved to 81.8 (range 65–90) at 24-month follow-up (Table 1). Improvement in WOSI and Rowe score was found to be significant [p-value <0.05]. All grafts were united with the glenoid as confirmed with CT scan at 6 months (Figs. 4, 5). There were no postoperative complications of infection. Range of movement improved postoperatively, but it was not statistically significant. The range of external rotation was generally less (decreased by 10 degrees in six cases; no decrease in two cases) than that on opposite shoulder but there was no weakness of subscapularis.

**Discussion**

Recurrent anterior shoulder instability occurs more commonly in association with generalized tonic clonic seizures than with partial seizures [8]. Due to violent muscle contractions during the seizures, it is invariably associated with bipolar lesion, that is bone loss both on glenoid and humeral head. The severity of anterior shoulder instability is proportional to the amount of bone loss in glenoid and humeral head [9–11]. Arciero et al. reported that bipolar lesions had combined negative effect on shoulder stability [12].

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Fig. 3 Post-operative X-ray after Eden-Hybinette procedure
tissue repairs, like Bankart repair, have not produced adequate stability in such cases. Buhler and Gerber reported the outcome of 34 unstable shoulders in 26 epileptic patients [4]. They concluded that skeletal reconstruction was necessary to obtain clinical stability. Thangarajah and Lambert evaluated shoulder instabilities in epileptics and reported a recurrence rate of 71% after soft tissue repair alone and 28% after bone augmentation [7]. Hutchinson et al. also reported similar results in 14 patients with grand mal seizures and recurrent anterior instability [9].

Itoi suggested that in presence of an off-track Hill-Sach lesion with the glenoid bone loss of $\geq 25\%$, the glenoid defect needs to be reconstructed [13]. The two popular options for glenoid bone reconstruction are Latarjet procedure and Eden-Hybinette procedure. In a systematic review and meta-analysis, Gilat et al. found the two procedures to be equally good but noted a significant heterogeneity in the included studies [14]. Malahias et al. also did not find any difference in the outcome of these two procedures [15]. Goudie et al. described Latarjet procedure as the most commonly performed surgical procedure in presence of significant bone loss in glenoid [16]. Latarjet procedure is a good option for such bipolar lesions in non-epileptics. But when performed in epileptics, Latarjet procedure has high recurrence rate [1, 17]. The main reason for this is the recurrent episodes of epilepsy after the surgery [5, 16]. Seizure episodes cause abnormal anterior translation of humeral head

### Table 1 Patient demographics and outcomes

<table>
<thead>
<tr>
<th>S.no</th>
<th>Age at index surgery (year)</th>
<th>Sex</th>
<th>Previous Surgeries</th>
<th>WOSI score</th>
<th>Rowe score</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Preoperative</td>
<td>Post-operative</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>follow-up at 2 years</td>
<td>follow-up at 2 years</td>
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<tr>
<td>1</td>
<td>28</td>
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<td>L</td>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>Male</td>
<td>AB + L</td>
<td>70</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
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<td>L</td>
<td>78</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>Male</td>
<td>L</td>
<td>83</td>
<td>24</td>
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<td>L</td>
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<td>29</td>
</tr>
<tr>
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<td>26</td>
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<td>AB</td>
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<td>40</td>
<td>Male</td>
<td>AB</td>
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</tr>
</tbody>
</table>

*AB* arthroscopic Bankart, *L* Latarjet procedure
and violent contractions of conjoint muscle–tendon unit attached to the transferred coracoid process. This results in fracture of the graft and bending/breakage of screws. The other reason described for the failure of Latarjet procedure in epileptics is the small size of the coracoid bone block [17]. Hence, the most rationale solution would be good medical control of epilepsy and Eden-Hybinette procedure, where a robust iliac crest bone graft, devoid of any muscle attachment, is attached on the glenoid. Literature has shown that Eden–Hybinette procedure produced good results when performed after failure of Latarjet procedure [18–20]. These studies were performed in patients who were not epileptic. However, Eden-Hybinette procedure has shown good results in epileptics also. Hutchinson et al. performed this procedure as a primary surgery in 14 patients who had grand mal epilepsy [9]. All the patients were satisfied and none had any recurrence. Raiss et al. performed this procedure as a revision surgery in five patients out of six failures of Latarjet procedure in epilepsy patients [17]. They had used allograft bone for glenoid augmentation. Re-dislocation occurred in two of the revised shoulders during seizures in the follow-up.

We achieved good results in all our patients because of two reasons. One was good medical control of epilepsy before and after surgery and the other was the choice of Eden-Hybinette procedure. We found three advantages of Eden-Hybinette procedure over Latarjet procedure in patients with epilepsy. Firstly, it allowed better restoration of glenoid bone loss since iliac graft is bigger than coracoid process. Glenoid bone loss restoration converted all the ‘off track’ lesions into ‘on track’ lesions. Secondly, the bigger bone graft could accommodate bigger and more screws, which provided better stability to the graft. Thirdly, since there was no muscular attachment on the iliac bone graft, there were decreased deforming forces on the graft and less chances of fracture and non-union of the graft during any seizure after the surgery. The limitations of this study are that it is a retrospective study with absence of control group and has small number of cases. Follow-up is also relatively short to assess development of osteoarthritic changes in glenohumeral joint. The strength of the study lies in the fact that there was no patient lost to follow-up and a single team performed all the surgeries.

Conclusion

We conclude that Eden-Hybinette is a useful revision procedure to manage recurrent anterior shoulder dislocation in patients with epilepsy. Optimum medical control of seizure is also an important factor in preventing recurrent shoulder instability.

Declarations

Conflict of Interest We declare that no author has any conflict of interest in relation to this manuscript.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by any of the authors.

Informed consent For this type of study informed consent is not required.

References


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Multiple High-Energy Open Injuries in the Same Limb: Comparison of Outcomes Between Salvage and Amputation Groups

Santhosh Kumar Govindaraju · Dan B. Inja · Sandeep Albert · Manasseh Nithyananth · Vinoo Mathew Cherian

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Abstract
Aim To analyze the functional outcomes between limb salvage and amputation patients who had multiple open injuries in the same lower limb.

Materials and Methods This observational study analyzed 21 patients who were admitted with multiple open injuries in the same lower limb between January 2012 and December 2015 in our unit. Twelve patients underwent limb salvage and nine patients underwent amputation. The total number of surgeries, duration of hospital stays, ICU admission, complications, time to return to work and costs of inpatient treatment were analyzed. The functional outcome was assessed by using the lower extremity functional scale (LEFS) in both groups, SF-12 score was done for both groups and amputation specific scoring was done by using locomotors capabilities index (LCI).

Results The LEFS was lower in salvage group than amputation group. The SF-12 score was close to normal population in the amputation group and was higher than salvage group. The duration of hospital stays, total number of surgeries and the costs of inpatient admission were higher in salvage group. The time to return to work was earlier in amputation group. Sixty-seven percentage of patients in the salvage group developed complications.

Conclusion The functional outcome and SF-12 score was better in amputation group. Patients who had amputation returned to work earlier, had smaller number of secondary hospitalization and has less complications and incurred less expenditure for treatment. The treatment decision should be periodically reviewed when an initial choice of salvage is made. Amputation must be looked at as a treatment for early rehabilitation.

Keywords Multiple open injuries · Salvage · Amputation

Introduction
The incidence of open lower limb injuries in India is higher than that in other countries due to factors such as larger number of motorcycles, absence of stringent traffic rule implementation, and public negligence [1–3]. The ideal treatment choice between amputation and salvage for patients with severe open lower limb injuries is debatable. Most of the literature pertaining to this problem is from developed countries [4–7].

The Indian scenario is vastly different from that in developed countries due to overcrowded and underfunded public hospitals. Although private healthcare is also available, it is expensive, and the cost of treatment must be borne by the patients.

Additionally, patients who have two major open injuries to the same lower limb constitute another group. The therapeutic choice between limb salvage and amputation becomes more difficult when such patients are confronted in emergency services. Moreover, amputation is unacceptable among Indian population due to various cultural and social reasons.
If it is technically feasible, some surgeons advocate reconstruction despite the cost, resulting in situations where a patient must continuously undergo multiple reconstructive surgeries for 3 years. The psychological trauma, and costs to the patient, society, and healthcare system in terms of time and finances are substantial.

The present observational study was thus conducted to compare the differences in outcome and morbidity between limb salvage and amputation in patients who have multiple open injuries in the same lower limb.

We attempted to answer the following questions.

i. Does amputation lead to better functional outcomes?
ii. Does amputation reduce the total number of surgeries, duration of hospital stays, cost, and complications?
iii. Does amputation lead to an increased rate of return to work?

Materials and Methods

After institutional ethics clearance (IRB 11453), the present observational study was conducted in 21 consecutive patients with at least two open injuries to the same lower limb who were admitted to our unit in this tertiary care center between January 2012 and December 2015. Initially, 29 patients were selected for the study. Of these, eight patients had severe crush injury where reconstruction was not possible. These patients underwent amputation and were excluded from the study. The remaining 21 patients had two major high-energy open injuries in the same lower limb, where at least one of the fractures was a Gustilo–Anderson IIIB injury, and the other fracture was a Gustilo–Anderson IIIA or IIIB injury or a major soft tissue injury which required a flap cover. Among these 21 patients, 18 patients had two open fractures in the same lower limb, whereas the other three had one open fracture and a major soft tissue injury at an additional site in the same lower limb. The soft tissue injury was considered major if it was around a joint and warranted soft tissue cover, or a degloving injury to the foot with heel pad avulsion. The mangled extremity severity score (MESS) and Ganga Hospital Score was calculated for the leg fractures.

All the patients were evaluated by a multidisciplinary team on arrival, and resuscitation was initiated as per standard protocols. Of the 21 patients, 11 presented with a systolic blood pressure of less than 90 mmHg. After a thorough systemic secondary survey, the treatment plan was decided by the orthopedic consultant. A second opinion was also obtained from another orthopedic surgeon confirming the decision.

Patients underwent surgery on an emergency basis, followed by intensive care unit (ICU) admission, if required. Out of 21 patients, 12 had a limb salvage surgery, and nine underwent amputation as decided by the surgical team.

All patients who underwent limb salvage received wound wash, sterile dressings, and intravenous antibiotics, and their limbs were splinted in the emergency department. All fractures were classified using the AO Foundation/Orthopedic Trauma Association (AO/OTA) classification, whereas the grade of open injuries was classified using the Gustilo–Anderson classification. The skeletal stabilization was performed using an external fixator or internal fixation based on the contamination and severity of soft tissue injury decided by the operating surgeon. Further surgical procedures included soft tissue procedures such as re-debridement; skin graft; local flap cover; and bony procedures such as internal fixation, additional plating, and bone grafting, which were performed either during the same hospitalization or in subsequent admissions.

A total of three patients who underwent limb salvage initially had to be taken for a subsequent amputation within 4 days. In one patient, who was referred after initial resuscitation elsewhere and presented late (34 h with a vascular injury) with a type 2 limb ischemia (Rutherford classification), limb salvage was attempted initially but later underwent above-knee amputation later due to persisting sepsis. In the second patient, who had an open femur and foot injury associated with compartment syndrome of leg, limb salvage was initially attempted but he later underwent above-knee amputation as a lifesaving measure in view of sepsis and subsequently expired due to multiorgan dysfunction. In a third patient, who had a crush injury of the foot with an open leg fracture, despite an initial attempt at limb salvage with debridement and external fixator application a below knee amputation was subsequently required in view of infection and an insensitive foot.

All the 12 patients in the salvage group required further surgeries during the same hospital stay, ranging from 2 to 4 surgeries (Table 1). All patients underwent periodic clinical and radiological assessment, and standard rehabilitation procedures. In this group, ten patients required subsequent admission and surgeries later (Table 1).

For the purpose of analysis, the limb salvage and amputation group were studied separately. The three patients who underwent an initial attempt at salvage and later required amputation were included in the amputation group for analysis. The total number of surgeries, duration of hospital stays, ICU admission, complications, return to pre-injury work and inpatient treatment costs were analyzed.

The functional outcome was assessed using the lower extremity functional scale (LEFS). The physical and
mental health composite scoring SF 12 was calculated in both groups. Amputation functional scoring was assessed by locomotors capabilities index (LCI).

### Results

The study group consisted of 18 males and three females. The modes of injury are presented in Table 2.

The average age of the study group was 37.5 years (range: 17–71 years). The average age of patients in the salvage group was 40 years (range: 17–71 years) and in the amputation group was 38 years (range 24–52 years). The average time of presentation post-injury to the emergency services was 8 h (range: 1–48 h). The average time of presentation post-injury in the salvage group was 5 h, whereas it was 9 h in the amputation group. Except one patient who was a diabetic, no other patients in the study group had any systemic illness. The average injury severity score was 20 (range: 18–37). The various combinations of injuries are illustrated in Tables 3 and 4. The LEFS and LCI of amputation patients are exhibited in Table 5.
The LEFS was 25% in four patients, 25–50% in six patients, and more than 50% in one patient in the salvage group. The LEFS was more than 50% in five patients and 25–50% in one patient in amputation group. The LCI was best in five out of six patients and good in one. The average SF-12 physical score was 44 (range: 36.18–47.49) in the amputation group, whereas it was 30 (range: 24.94–33.78) in the salvage group. The average mental score in the amputation group was 50.37 (range: 46.51–54.53), whereas it was 44.45 (range: 38.82–52.14) in the salvage group. The average number of surgeries was 3 (range: 1–6) in the salvage group and 2 (range: 1–3) in the amputation group. The average hospital stay was 38 days (range: 26–72 days) in

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<td>Rt elbow dislocation, L2L3 fracture dislocation</td>
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<td>3</td>
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<tr>
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</tbody>
</table>

The LEFS was 25% in four patients, 25–50% in six patients, and more than 50% in one patient in the salvage group. The LEFS was more than 50% in five patients and 25–50% in one patient in amputation group. The LCI was best in five out of six patients and good in one. The average SF-12 physical score was 44 (range: 36.18–47.49) in the amputation group, whereas it was 30 (range: 24.94–33.78) in the salvage group. The average mental score in the amputation group was 50.37 (range: 46.51–54.53), whereas it was 44.45 (range: 38.82–52.14) in the salvage group. The average number of surgeries was 3 (range: 1–6) in the salvage group and 2 (range: 1–3) in the amputation group. The average hospital stay was 38 days (range: 26–72 days) in
the salvage group and 15 days (range: 5–29 days) in the amputation group.

The average cost of treatment excluding the pharmacy bill in the salvage group was three times higher than that in the amputation group. Only one patient in the amputation group, who required long-term ICU care due to sepsis exhibited a higher bill. ICU admission was required in 66% of patients in the amputation group and 46% of patients in the salvage group. The average total duration of treatment was 18.5 months (range: 6–48 months) in the salvage group and 15 days (range: 5–29 days) in the amputation group. The average Ganga hospital score was 14.6 (range: 6–11) in the amputation group and 5.5 (range: 4–7) in the salvage group. The locomotor capabilities index (LCI) in amputation group

| 1 | 48 | 43 | 67 |
| 2 | 30 | 55 | 96 |
| 3 | 27 | 50 | 85 |
| 4 | 36 | 66 | 87 |
| 5 | 25 | 52 | 96 |
| 6 | 40 | 56 | 100 |
| 7 | 38 | Lost follow up |
| 8 | 40 | Lost follow up |
| 9 | 18 | Expired |
| 10 | 22 |
| 11 | 56 |
| 12 | 22 |

Discussion

The orthopedic surgeon in the developing countries is faced with an increasing number of patients with multiple complex open injuries to the same lower limb [1, 3]. No guidelines or scores are currently available to prognosticate these injuries and to decide whether amputation or salvage is the best option in this scenario. In single open injury to the lower limb, multiple validated scores are available to assist in the decision on limb salvage or amputation [8–13]. Not much information is available regarding the morbidity, cost, duration of treatment, and functional outcome of these injuries. In the absence of this information, it is difficult for the treating surgeon and the patient to decide on the appropriate course of treatment.

In the present study, the functional outcome, time of return to work, duration of treatment, and other factors were assessed in patients with multiple open injuries in the same lower limb.

We used LEFS to assess functional outcome in both the amputation and the salvage group. In the amputation group, five out of six patients had scores more than 50%. Only one patient who had a IIIB patella fracture, proximal shaft of tibia fracture foot crush injury and intertrochanteric fracture and was managed with a through ankle amputation scored 43%. However, 11 out of 12 (91%) patients in the salvage group had less than 50% on the LEFS score after prolonged treatment and multiple surgeries. The time of return to work was 12 months in the amputation group, and three out of six patients returned to their pre-injury occupation. Among the six long-term follow-up patients in the salvage group, only two returned to their pre-injury occupation. This clear difference suggests that amputation may be a better choice in these patients. This hypothesis was further confirmed by the fact that the amputation-specific LCI score was consistently excellent (average 88.5%) in the amputation group, indicating excellent functional recovery in this group. Furthermore, the amputation group exhibited an SF-12 score close to that of the normal population. Among the salvage patients, SF-12 could be calculated only for four patients, which on an average, was less than the patients in the amputation group. All these facts can be used to judiciously decide between salvage and amputation for patients on an individual basis.

In our study, all salvage patients required additional surgeries during the same admission and nine out of 12 patients required rehospitalization for further procedures. The length of hospital stay was higher in salvage patients than in amputation patients during the primary admission. Considering only the inpatient admission bills, the cost of treatment in the amputation group was lower compared with the salvage group.
patients. In our study, 67% of patients in the salvage group developed complications, whereas no complications were observed in the amputation group.

Not much literature evidence is available on similar case series to compare with our study. However, there are studies which compared amputation vs limb salvage in leg-threatening severe lower limb injuries [5, 7, 14]. In contrast with our study, all these studies included patients with only one severe injury in the lower limb.

Busse et al. concluded in their meta-analysis involving severe open tibial fractures (leg-threatening injuries) that the functional outcome was similar in both amputation and salvage groups [5]. However, in our study, the functional outcome was lower in the salvage group. This might be because there were multiple injuries to the same lower limb in our study. They further concluded that the time of return to work was similar in both the groups. This was contrary to our findings, where we observed that the time to return to work was earlier in the amputation patients than in the limb salvage patients. The length of hospital stay was shorter in the amputation group compared with the salvage group. However, Busse et al. reported similar length of hospital stays between the two groups. The length of rehabilitation, total costs, additional procedures, rehospitalization, and complications in their study were higher for limb salvage patients, which was mirrored in our study.

The lower extremity assessment project (LEAP) of patients who had single severe open injury to the lower limbs exhibited similar functional outcomes between the salvage and amputation groups at the end of 2 years [14]. In our study, the amputation group had better functional outcomes than the limb salvage group at the end of 4 years. The patients who underwent reconstruction in this study were more likely to have a secondary hospitalization for major complications than those who underwent amputation. This finding was similar in our study group.

Currently, there are no scores which can help to decide between limb salvage and amputation in patients who have multiple open injuries to the same lower limb. For open leg injuries, scores such as MESS and Ganga hospital score have been used. Ganga hospital score has been validated to demonstrate 98% sensitivity and 100% specificity [15]. Further studies will be required to assess the possibility to develop a score to aid decision-making in this complex setting and the efficacy of the Ganga hospital score and MESS in decision-making. However, these scores were developed only for leg injuries.

Based on our study, we are unable to reach a definitive conclusion regarding poor prognostic factors in these injuries. However, in patients with three open injuries in the same lower limb, simultaneous open IIIB injuries in two areas of the same limb, other skeletal injuries, and vascular injury, the functional outcome was likely to be poor.

The limitations of this study are due to its retrospective nature. However, in this condition prospective randomized trials may not be ethical. In addition, the incidence of these injuries is not high. Hence retrospective studies are helpful. The patient follow-up in salvage group could have been better. All efforts were made to contact the patients including visits to the address provided by the patient by one of the authors.

Conclusion

The following differences were observed between the amputation and salvage group in patients with multiple open injuries to the same lower limb:

1. The functional outcome was better in the amputation group.
2. The SF-12 scores were better in the amputation group.
3. Patients who had amputation returned to work earlier, had a smaller number of secondary hospitalization and surgeries, exhibited fewer complications, and incurred less expenditure for treatment.

The choice between limb salvage and amputation is difficult in patients with single severe leg-threatening injuries. When patients have multiple open injuries to the same lower limb, the decision-making about salvage or amputation is much more complex. No clinical scores are available to help in this regard. Hence, a thorough evaluation of the patient considering all the injuries, decision-making by a team of orthopedic surgeons, and an individualized decision-making for each patient is necessary in managing these patients. The treatment decision should be periodically reviewed when an initial choice of salvage is made. Amputation should not be considered as a failure. Rather, it must be looked at as a treatment for early rehabilitation.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study informed consent is not required.
References


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How is Biodegradable Scaffold Effective in Gap Non-union? Insights from an Experiment

Vivek Veeresh 1 · Shivam Sinha 2 · Birju Manjhi 2 · B. N. Singh 3 · Amit Rastogi 2 · Pradeep Srivastava 3

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Abstract

Objective To evaluate the role of composite (Chitosan/Chondroitin sulphate/gelatin/nano-bioglass) scaffold in the union of critical size bone defect created in the rabbit’s ulna.
Methods The composite (Chitosan/Chondroitin sulphate/gelatin/nano-bioglass) scaffold was fabricated using the freeze-drying technique under standard laboratory conditions. The scaffold was cut into the appropriate size and transferred into the defect created (critical bone size defect 1 cm) over the right ulna in the rabbit. The scaffold was not implanted on the left side thus the left side ulna served as control. Results were assessed on serial radiological examination. Rabbits were sacrificed at 20 weeks for histopathological examination (Haematoxylin–Eosin staining and Mason’s trichrome staining) and scanning electron microscope observation. Radiological scoring was done by Lane and Sandhu’s scoring.
Results Among 12 rabbits, 10 could complete the follow-up. Among those 10 rabbits, 8 among the test group showed good evidence of bone formation at the gap non-union scaffold implanted site. Histological evidence of new bone formation, collagen synthesis, scaffold resorption, minimal chondrogenesis was evident by 20 weeks in the test group. Two rabbits had poor bone formation.
Conclusion The chitosan-chondroitin sulphate-gelatin-nano-bioglass composite scaffold is efficient in osteoconduction and osteoinduction in the gap non-union model as it is biocompatible, bioactive, and non-immunogenic as well.

Keywords Tissue engineering · Nano-bioglass scaffold · Gap non-union model · Osteogenesis · Composite substitute · Biodegradable

Introduction

Since the time of Hippocrates and Galen bone has been studied for its ability to self–regenerate [1]. Large bone defects as a result of trauma, infection, tumour excision, congenital malformation, stress shielding in prosthesis often require bone transplantation. Bone grafting is one of the most commonly performed surgeries accounting for half a million procedures per year within the United States and more than 2 million in the world. Although autograft is associated with donor site morbidity and limited availability, it is most often treated as gold-standard in these procedures because of its ideal bone graft characteristics [2–4].

Rarely, large bone defect heal by itself, moreover, critical size defect is defined as, the minimal length/segment which fails to unite by itself in a lifetime [5]. These bone defects can be filled by many different materials such as autograft, allograft, xenograft, or bone substitutes.
Ideal bone graft material to fill these defects should be osteoconductive, osteoinductive, biocompatible, bioreorbable, mechanically resistant, and easily available to use. It should be cost-effective to make it widely available. The sole substitute to fulfill all specifications is autologous bone but, it has its own share of disadvantages of donor site morbidity and limited availability \[6, 7\]. Although allograft had emerged as a suitable alternative to autograft, its use got limited due to potential risk of infection, limited osteoconduction, laborious harvesting & preserving procedures and necessity of a bone bank \[2\].

Bone substitutes which are defined as “synthetic, inorganic or biologically organic combinations can be implanted for the treatment of a bone defect instead of autogenous or allogeneous bone.” \[8–10\]. However, the majority of the available materials are osteoconductive but very few are osteoinductive. Few Bone substitutes in current use are demineralized bone matrix, Hydroxyapatite (HA), corals, β-tri-calcium phosphate (β-TCP) \((\text{Ca}_3 \text{(PO}_4)_2\)\), Biphasic calcium phosphates (HA and β-TCP ceramics), calcium sulphate \((\text{CaSO}_4)\), Calcium phosphate cements (CPCs), bioactive glasses, Polymer-based bone substitutes \[8\].

Very recently composite substitutes have given promising results in animal trials as an emerging field of regenerative medicine and tissue engineering. Composite substitutes are the one with a combination of more than one biomaterial which add their advantages synergistically \[2\].

In this study, we are presenting our results of a composite \((\text{CH/CS/G/nBG})\) material as a scaffolds to fill an artificially created bone gap (more than critical size defect) in an experiment on the rabbit and decipher its efficacy in being osteoconductive, osteoinductive and bio-compatible.

**Materials and Methods**

The present study was conducted in the Department of Orthopaedics, School of Biochemical Engineering, Centre of Experimental Medicine and Surgery from November 2016 to July 2018. Approval of CPCSEA was obtained before the start of the experiment.

4 months old healthy white 12 male adult rabbits of average 2–3 kg weight were chosen and left for 1 week before starting the experiment. The principle of laboratory care, feeding, and sacrifice was followed as per ICMR guidelines on the care of experimental animals.

**Characteristics and Preparation of Scaffold**

To prepare a scaffold, the biomaterial used should be nontoxic, easily available, biodegradable, and non-immunogenic. Chitosan, chondroitin sulphate, gelatin, nano-bioglass \((\text{CH/CS/G/nBG})\) scaffold was chosen and fabricated using Freeze-drying technique. Briefly, the nBG nanocrystal powder was dispersed in a CH/G/CS solution by sonication. The produced composite mixture was put in a Teflon vial to be sonicated again and then transferred into a freezeer maintained at \(-20\,\text{°C}\), which induced solid–liquid phase separation. Separated water was replaced with the gelatin to enhance the mechanical strength of the scaffold. The solidified mixture was kept at that temperature for 12 h and then transferred into a freeze-drying container maintained at \(-40\,\text{°C}\). The samples were then freeze-dried for 2–3 days under vacuum \((0.5\,\text{mmHg})\). Finally, the obtained scaffolds were cross-linked and used for in-vitro and in-vivo study for new bone tissue regeneration \[11, 12\].

**Transplantation**

The definitive procedure for implantation of the composite scaffold (Fig. 1) in rabbits was performed under anaesthesia using an I/M injection of titrated doses of ketamine and midazolam. In each rabbit, both forearms were shaved and disinfected with spirit and betadine. Defect (critical bone size defect 1 cm) was artificially created in the midshaft of the bilateral ulna. The periosteum at the defect site was removed to mimic clinical non-union and to avoid the formation of synostosis (Figs. 2 and 3). The 3-dimensional composite scaffold was cut into the appropriate size and transferred into the defect (critical bone size defect 1 cm) over the right ulna, namely the test side (Fig. 4). The scaffold was not implanted on the left side thus the left side ulna served as control. Intact radius served as an internal splint for the press-fit scaffold on the test side, while in controls it helped in bearing weight partially. Both the forearm wounds were closed in layers.

Follow-up of rabbits was done after a period of 4, 8, 12, and 20 weeks by radiographic examination (Table 1). Histopathological examination was done after sacrifice at 20 weeks by H&E and Mason’s trichrome staining (to assess collagen content in the matrix formed). Scanning Electron

![Fig. 1 Composite scaffold](image-url)
Microscope examination was done to look for scaffold integration, scaffold porosity, colonization, and growth of osteoblast by the end of 20 weeks.

**Statistical Analysis**

Descriptive statistics was applied for quantitative data, to test for normality of data, a Shapiro–Wilk test was applied. Descriptive statistics was applied for quantitative data, to test for normality of data, a Shapiro–Wilk test was applied. Quantitative variables were evaluated by the student’s two-tailed $t$-test amongst various subgroups (follow up period). $p$-value < 0.05 was taken as statistically significant.

**Results**

Among the 12 rabbits studied, 2 rabbits died in the immediate postoperative period. Clinical and histopathological examination of the fracture site did not show any signs of inflammation. The cause of death was concluded due to anaesthetic overdose or adverse drug reaction. 10 rabbits were subjected to radiological assessment as per Table 1 every 4, 8, 12, and 20 weeks by Lane and Sandhu’s scoring (Table 2) [13].

At the end of 20 weeks, rabbits were sacrificed by giving lethal doses of intramuscular midazolam and subjected to gross and histopathological examination.

For histopathological examination, en-bloc resection of ulna containing bone defect site with or without scaffold was done (Figs. 5 and 6). Each specimen was decalcified and embedded in paraffin. Sections 4 μm thick were prepared and stained with haematoxylin and eosin stain and Mason’s trichrome staining.

Among 10 rabbits, 8 rabbits showed good evidence of bone formation at the gap non-union site (Figs. 7 and 8). Table 3 showing union as per Lane and Sandhu scoring in test limb with a significant $p$-value. Histological
evidence of new bone formation, collagen synthesis, scaffold resorption, minimal chondrogenesis, was evident by 12 weeks in the test group (Figs. 9a, b, 10a, b). Two rabbits showed poor bone formation.

Scanning Electron Microscope examination of the retained scaffold showed good integration between the scaffold and host bone and porosity of implant, cell adherence (Fig. 11).

### Table 2
Lane and Sandhu scoring for radiological assessment of bone union

<table>
<thead>
<tr>
<th>Score</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No evidence of new bone formation</td>
</tr>
<tr>
<td>1</td>
<td>Little amount of callus formation</td>
</tr>
<tr>
<td>2</td>
<td>All around the margin of the scaffold there is increase in the radio opacity: calcification</td>
</tr>
<tr>
<td>3</td>
<td>Formation of bridging mass in the created defect: increased radio density</td>
</tr>
<tr>
<td>4</td>
<td>Increase in the girth / density reaching up to the periphery of the defect</td>
</tr>
</tbody>
</table>

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**Fig. 5** Serial x rays at 0, 4, 8 and 12 weeks showing new bone formation at defect site in right ulna

**Fig. 6** Serial x rays at 0, 4, 8 and 12 weeks showing no bone formation at defect site in left ulna

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**Discussion**

Even though autograft has been the gold standard for bone grafting procedures, it is an additional procedure for the patients. There are studies reporting donor site complications in up to 20.6% cases [6, 7]. Hence it has always been
the source of inquisitiveness for the researchers to find a better alternative for it.

Ideal material for the scaffold to promote new bone growth and integration with host tissue should have the following properties. First, it should be conducive for rapid vascular growth. Second, since the radiological identification of newly formed bone is easier, scaffold material should be radiolucent. Third, the scaffold material should be self-resorptive to create space for new bone. Fourth, a composite scaffold combination should be pliable for handling in a clinical setting. Finally, the material should promote osteoconductive bridging between the host bone and the new bone.

The results of this experiment demonstrate that new-bone formation is elicited in critical-sized defects in the ulna of a rabbit by the implantation of a novel 3D bio-degradable scaffold. Under the conditions utilized in this study, the implantation of the composite scaffold led to the formation of new bone. The new bone wasn’t uniformly distributed throughout the cell–matrix implant but integrated comprehensively with the host bone. Gross examination of the specimen revealed that there was progressive resorption of the implant by 16 weeks. Previously, similar studies done using low or poor biodegradable implants did not show any change in the consistency of the implant even after 20 weeks of follow up, since none of the implants were biodegradable \[14–16\]. Hence the biodegradability of the implant was desired and advantageous which was observed in our study and the sequential resorption of the implant associated with a corresponding new bone formation appreciated radiologically (Fig. 5).

Moreover, during postoperative follow-up, there was no sign of any immunological reaction either during clinical or histological examination heralding the biocompatibility of the scaffold.

The observation in this study suggests that the presence of new bone formation at the defect site indicates the osteoinductive, osteoconductive, and osteogenic properties of the composite scaffold (CH/CS/G/nBG). Also, avoidance of secondary fixation of the scaffold to bone provides indirect evidence that the composite achieved stability by rapidly adhering to the non-uniting ends.

Among various biopolymers, chitosan (CH) has shown promising results in osteoconductive properties \[17\]. It is positively charged at physiological pH and requires anionic polymer to form a stable complex. Chondroitin sulphate (CS) is an anionic polysaccharide that can stabilize chitosan. It has been proved to possess anti-inflammatory and tissue regenerating properties \[18, 19\]. CS, also facilitates mineralization of the newly forming bone by being an anionic polymer in the composite attracting cationic calcium ions \[20\]. The gelatin in this study was obtained by partial hydrolysis of the collagen. It showed significantly decreased immunogenicity as compared to

![Fig. 7 Gross examination of bone defect of right side at 20 weeks](image1)

![Fig. 8 En-block resection of right ulna containing bone defect site and adjacent bone](image2)

<table>
<thead>
<tr>
<th>Mean Follow up</th>
<th>Test (Right ulna with scaffold) X-ray score</th>
<th>Control (left ulna with bone gap) X-ray score</th>
<th>P-value (student’s 2-tailed t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 weeks</td>
<td>1</td>
<td>0</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>8 weeks</td>
<td>2</td>
<td>0</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>12 weeks</td>
<td>2.5</td>
<td>1</td>
<td>0.012</td>
</tr>
<tr>
<td>20 weeks</td>
<td>3.5</td>
<td>1</td>
<td>0.002</td>
</tr>
</tbody>
</table>
collagen. Moreover, gelatin has been shown to provide skeletal support for cellular adhesion, migration, and proliferation [21].

Studies have demonstrated that nano-bioglass has more osteogenic potential [22, 23]. As nBG helps in attaining appropriate pore size, both microporous and macroporous by liquid–liquid phase separation, the present study describes a freeze-drying technique to fabricate polymer/nBG-composite scaffolds with high porosity and controlled pore architecture [12].

The chitosan-based scaffold is known to have decreased mechanical strength and structural stability. To overcome this limitation, referring to the study by Singh et al. the nBG incorporated into the composite scaffold through polyelectrolyte complexation (PEC) was subjected to phase separation. Separated water was replaced with gelatin enhancing the mechanical strength of the scaffold. This sequential processing, use of PEC during scaffold preparation, incorporation of nBG increased the compressive strength of the scaffold [11, 12, 24].

In one study, bioactive glass (BG) was mixed with a collagen solution to create a composite scaffold with or without phosphatidylserine (PS). Rat MSCs were used in this study. Results indicated PS promoted attachment and proliferation of MSCs in the scaffold. Alkaline phosphatase, osteocalcin, and osteopontin were secreted more by MSCs in the COL-BG-PS composite. Similar results were observed in the rat femur defect model showing better bone formation in rats with COL-BG-PS/MSC composite scaffold as compared to COL-BG/MSC, and cell-free COL-BG-PS scaffolds at the defect [25]. The result of this study suggested that the addition of PS to scaffold has a synergistic effect on bone formation in scaffolds containing stem cells with its own set of limitations in certain mechanical properties such as low strength, toughness, and reliability [26, 27].

The gelatin, bioglass, chitosan, chondroitin sulphate scaffold used in this study degrades slowly in the initial hours, and the rate of degradation increases with time [28, 29]. The composite scaffold has a three-dimensional architectural similarity to that of natural bone, thus the scaffold that we provide as our implant should help in the new bone formation in a better way. The aligned structure should help the
mineralization of the newly formed bone in an oriented fashion thus hastening the process of bone remodelling at a faster rate. This is due to two broad reasons, first, the time taken for the reorientation of the newly formed bone to that of the natural bone texture will almost vanish and the presence of Hydroxyapatite at the site of new bone formation will help the healing process of bone regeneration.

Easy availability, large size, easy handling due to their docile nature, and suitable anatomy for the present study made rabbits as the most suitable candidates for this study. The ulna bone in rabbits is easily palpable, hence easy for surgical creation of bone defect and the anatomy of the intraosseous membrane in between the radius and ulna provides appreciable support for the implanted scaffold.

It can be criticized that the implant did provide a suitable scaffold for migration of bone-forming cells; as evidenced by the callus at the implant-bone interface. Absence of any frank signs of infection at the implanted site during the gross examination, clinical well-being of rabbit during follow up suggesting the good compatibility of the scaffold with the experimental subject. Intradermal immunological sensitivity testing revealed no signs of sensitivity on clinical grounds both at the implanted and skin tests sites.

In summary, the (CH/CS/G/nBG) scaffold is easy to handle, nearly radiolucent, biodegradable, and non-immunogenic. It is important to note that there were both macroscopic and microscopic evidence of new bone formation as per radiological and histological examination. Even though our study showed promising results to promote composite scaffold to fill defects, it has its share of limitations. Require a large multicentric study with an increased sample size for further confirmation of our results and the need for accessory fixation for larger tubular defects and load-bearing capabilities of the scaffold. Also, successful implantation of viable or lyophilized osteoblasts might be an avenue to work up.

**Conclusion**

We can conclude that the chitosan-chondroitin sulphate-gelatin-nano-bioglass scaffold is efficient in osteoconduction and osteoinduction in the gap non-union model and it is biocompatible, bioactive, and non-immunogenic as well.

**Compliance with Ethical Standards**

**Conflict of interest** We hereby declare that we do not have any sort of conflict of interest with any person or authority.

**Ethical standard statement** Approval of CPCSEA was obtained for animal experiment.

**Informed consent** None.

**References**


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Current Surgical Antibiotic Prophylaxis Practices: A Survey of Orthopaedic Surgeons in India

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Abstract
Background  Surgical antibiotic prophylaxis (SAP) has become the standard of care in orthopaedic surgery. Inappropriate usage of antibiotics (dosage, strength, and/or administration time and duration) can inadvertently result in superadded infections and antimicrobial resistance. The purpose of this study was to document and analyse the prescription patterns for SAP, and to investigate the factors associated with divergence from standard guidelines.

Methods  We conducted an online cross-sectional questionnaire-based study to collect information about the SAP practices of the members of the Indian Orthopaedic Association (IOA) using Google forms. A link to the questionnaire was sent by e-mails.

Results  The overall response rate was 5.73%. While 97.3% respondents practised SAP routinely, the practice was not aligned with standard guidelines’ recommendations. There was heterogeneity in the use of SAP in terms of choice of antibiotic(s), number of co-prescribed drugs, single- versus multiple-dose regimens, and the duration of therapy. The prescription practice patterns showed that orthopaedic surgeons almost always used broad-spectrum antibiotics for long durations, regardless of the type of surgery.

Conclusion  While Orthopaedic surgeons in India are practicing SAP, the pattern of antibiotic usage is heterogeneous. Variations were noted in the choice of antibiotics for different types of surgeries, time of administration, duration of usage in the postoperative period as well as co-prescriptions. This study highlights the urgent need for a comprehensive, rational, and robust national SAP policy for orthopaedic surgeries.

Keywords  Surgical antibiotic prophylaxis · Elective surgery · Trauma surgery · Antibiotic · Prescription practice · Perioperative antibiotic prophylaxis · Surgical site infection · Orthopaedic association

Introduction
Surgical site infections (SSI) are associated with significant morbidity and mortality. Perioperative antibiotic prophylaxis, also frequently known as surgical antibiotic prophylaxis (SAP), is prescribed with the aim to reduce...
the infection risk in conditions when the internal tissues are exposed to the external environment and has become the standard of care in orthopaedic surgery especially for cases involving the insertion of orthopaedic implants, as the infection once established becomes difficult to eradicate due to biofilm formation over the implanted foreign material [1]. The development of SSI is multifactorial with the number of bacteria present in the surgical wound being an important factor. SAP tries to decrease and delay the bacterial growth allowing the host immune mechanisms to prevent establishment of any infection.

The choice of antimicrobial agent and its duration of administration, to an extent, remains a matter of personal choice as local community standards, bacterial resistance, and local bacterial flora alter the antibiotic prophylaxis that is required [2]. It has been reported that antibiotics are frequently administered inappropriately (strength, dosage, time/duration) which can then result in their increased usage, increased costs and prolonged hospitalisation. The risk of superadded infection and the possibility of antimicrobial resistance (AMR) are increased too [3]. With the limited availability of therapeutic choices, it is imperative to restrict usage of broad-spectrum antibiotics [2]. Administration of SAP is an important component of the WHO surgical safety check list which is used for the prevention of complications [4].

Establishing a rational antibiotic policy is the first step to tackle the imprudent use of antibiotics. In countries where no formal policy on prescription of prophylactic antibiotics exists, or its recommendations are not strictly adhered to, the choices are often driven by individual or treating team’s cumulative experiences. In some counties with existing SAP guidelines/policies, attempts are being made to assess the compliance to those guidelines [1, 5–9]. In India, there have been sporadic attempts limited to a few hospitals [2, 10–12]. In 2017, the ministry of health and family welfare, Government of India, puts forward its first step towards understanding ‘evidence–practice gap’. To explore this discrepancy, a nationwide survey among orthopaedic surgeons registered with the Indian Orthopaedic Association (IOA) regarding SAP prescription practices in routine clinical situations was conducted. The purpose of the survey was to document and analyse the prescription patterns for SAP, and to investigate the factors associated with divergence, if any, from standard guidelines.

**Materials and Methods**

This cross-sectional questionnaire-based study was conducted after Institutional Review Board and ethics committee approval (IHEC-LOP/2020/IM0243). The study was designed to be anonymous and no personal details like name, phone number or address were sought, to maintain data confidentiality and maximise participation. The inclusion criteria were consent from the responding surgeons. There were no exclusion criteria. The participation of the respondents was voluntary, and no incentives of any sort were offered in lieu of their participation.

A web-based questionnaire was developed using Google Forms (Google LLC, California) which is free for non-commercial use. It consisted of a total of 23 questions enquiring about the respondents’ age, experience, their workplace, major field of orthopaedic practice, preferred number and type of antibiotic for SAP for elective cases and for open fractures. Additionally, the pattern of prescription of antibiotics in the perioperative period as well as co-prescription of other drugs was enquired. The questionnaire was circulated internally within the department of Orthopaedics and among colleagues of other specialties to examine the comprehensibility of the questions and to iron out ambiguities. Trial runs were performed to ensure that the questionnaire could be filled without glitches. Once satisfied, the collected data was cleared from the database. A link to the questionnaire was generated and was sent by e-mail to the members of the IOA along with a participant information sheet detailing the objectives of the study, information on the confidentiality of the data and the details of investigators to be contacted for any clarification. The e-mails were sent by three of the investigators from their own e-mail addresses starting from 8th March 2020. Two reminder e-mails requesting for participation were sent at an interval of two weeks to maximise the responses. However, the exact timelines were not notified to the participants. The first question of the questionnaire requested for consent for participation and only those respondents who consented could proceed further with other questions. After the first question, there were 22 mandatory questions, of which two had branching options. While the respondents had the option to review their responses prior to submission, a further change of ones’ response was not possible after the final submission. The questionnaire could be submitted only when all the mandatory questions were answered.

The automatically collected data were exported as a Microsoft Excel spreadsheet (Microsoft corp., Redmond, PA). All the responses were scanned for their completeness, and those responses where the participant had not consented and where the responses were either
inappropriate or were duplicate, were excluded. Entries with the exact same responses and consecutive time stamps were considered to be duplicates and only one entry was considered for further analysis, which was done using SPSS version 26 (IBM Corp., Armonk, NY) and R Studio desktop (free version, R Studio, Boston, MA). The frequency of responses of individual questions was reported as numbers (percentages). In case of continuous variables, the result was reported in terms of mean, median and standard deviation. Fisher’s exact test and Chi-square test were used to examine the significance of the association (contingency) between categorical variables. Further, statistical tests used were ANOVA for continuous variables and Kruskal–Wallis test for categorical variables. Statistical significance was set at ‘p’ < 0.05.

Results

7469 members of the IOA were contacted through e-mails; 362 e-mails could not be delivered due to technical reasons from the e-mail hosting sites. The details of the methodology adopted for data collection and analysis are shown in Fig. 1. The overall response rate to the survey was 5.73%. Table 1 summarises the demographic details of the respondents. The details of prescription practices of the respondents for SAP are shown in Table 2. Table 3 shows the details of antibiotic prophylaxis for open fractures.

Table 1 Summary of the demographic details of the respondents

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Numbers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Age</td>
<td></td>
</tr>
<tr>
<td>≤ 35 years</td>
<td>102 (25.4%)</td>
</tr>
<tr>
<td>36–45 years</td>
<td>156 (38.9%)</td>
</tr>
<tr>
<td>46–55 years</td>
<td>74 (18.5%)</td>
</tr>
<tr>
<td>56–65 years</td>
<td>60 (14.96%)</td>
</tr>
<tr>
<td>&gt; 65 years</td>
<td>9 (2.2%)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>43.44 years (SD, 10.45)</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>41 years (35–52)</td>
</tr>
<tr>
<td>2. Years of practice (experience in the field of orthopaedics)</td>
<td></td>
</tr>
<tr>
<td>≤ 10 years</td>
<td>155 (38.7%)</td>
</tr>
<tr>
<td>11–20 years</td>
<td>129 (32.2%)</td>
</tr>
<tr>
<td>21–30 years</td>
<td>74 (18.4%)</td>
</tr>
<tr>
<td>31–40 years</td>
<td>36 (8.98%)</td>
</tr>
<tr>
<td>41–50 years</td>
<td>5 (1.2%)</td>
</tr>
<tr>
<td>&gt; 50 years</td>
<td>2 (0.5%)</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>16.6 years (10.72)</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>14 years (8–25)</td>
</tr>
<tr>
<td>3. Place of work</td>
<td></td>
</tr>
<tr>
<td>Government hospital</td>
<td>136 (33.9%)</td>
</tr>
<tr>
<td>Private/corporate/trust hospital</td>
<td>169 (42.2%)</td>
</tr>
<tr>
<td>Own hospital or nursing home</td>
<td>96 (23.9%)</td>
</tr>
<tr>
<td>4. Type of workplace</td>
<td></td>
</tr>
<tr>
<td>Non-teaching hospital</td>
<td>203 (50.6%)</td>
</tr>
<tr>
<td>Teaching hospital</td>
<td>198 (49.4%)</td>
</tr>
<tr>
<td>5. Major field of orthopaedic practice</td>
<td></td>
</tr>
<tr>
<td>Trauma</td>
<td>257 (64.09%)</td>
</tr>
<tr>
<td>Arthroplasty</td>
<td>54 (13.45%)</td>
</tr>
<tr>
<td>Spine surgery</td>
<td>32 (7.98%)</td>
</tr>
<tr>
<td>Arthroscopy</td>
<td>15 (3.74%)</td>
</tr>
<tr>
<td>Paediatric orthopaedics</td>
<td>14 (3.49%)</td>
</tr>
<tr>
<td>Orthopaedic oncology</td>
<td>5 (1.25%)</td>
</tr>
<tr>
<td>Foot and ankle surgery</td>
<td>5 (1.25%)</td>
</tr>
<tr>
<td>Hand surgery</td>
<td>4 (0.997%)</td>
</tr>
<tr>
<td>Deformity correction</td>
<td>4 (0.997%)</td>
</tr>
<tr>
<td>Others/a combination of above options</td>
<td>11 (2.74%)</td>
</tr>
</tbody>
</table>

* 2 respondents did not consent for participation, 2 entries were duplicate, 2 participants mentioned erroneous ages

![Fig. 1 Summary of the details of email requests sent and the responses included for final analysis](image)

An inclination was noted for using more than one antibiotic when implant surgery was performed. Of the respondents whose major field of practice was trauma surgery and arthroplasty, 73.54% and 83.33%, respectively, preferred using a single antibiotic for a non-implant surgery but this number fell to 42% and 50%, respectively, when performing an implant surgery. This difference was found to be statistically significant using the Chi-square test (p values 0.000 and 0.002, for major field of practice being trauma and arthroplasty, respectively) (Supplementary Table S1).

Univariate analysis to assess if age, number of years of experience, or the place of work of a respondent had any association with the antibiotic prescription practices was
Table 2  Prescription practices of the respondents for surgical antibiotic prophylaxis

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Numbers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Regular use of pre-operative antibiotic</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>390 (97.3%)</td>
</tr>
<tr>
<td>No</td>
<td>4 (1.0%)</td>
</tr>
<tr>
<td>Sometimes</td>
<td>7 (1.7%)</td>
</tr>
<tr>
<td>2. Time of administration of prophylactic pre-operative antibiotic</td>
<td></td>
</tr>
<tr>
<td>Within 30 min of the incision</td>
<td>190 (47.38%)</td>
</tr>
<tr>
<td>Between 30 min and 1 h of the incision</td>
<td>172 (42.89%)</td>
</tr>
<tr>
<td>On the day surgery (in the ward/1–3 h prior to incision)</td>
<td>33 (8.23%)</td>
</tr>
<tr>
<td>3. Practice of repeating antibiotics during long surgeries</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>312 (77.8%)</td>
</tr>
<tr>
<td>No</td>
<td>39 (9.7%)</td>
</tr>
<tr>
<td>Occasionally</td>
<td>50 (12.5%)</td>
</tr>
<tr>
<td>4. Time of repeating the antibiotic for prolonged surgeries (% mentioned are of 362)</td>
<td></td>
</tr>
<tr>
<td>Every 2 h</td>
<td>121 (33.43%)</td>
</tr>
<tr>
<td>Every 3 h</td>
<td>8 (2.21%)</td>
</tr>
<tr>
<td>Every 4 h</td>
<td>167 (46.13%)</td>
</tr>
<tr>
<td>Every 6 h</td>
<td>36 (9.94%)</td>
</tr>
<tr>
<td>No fixed time interval</td>
<td>16 (4.42%)</td>
</tr>
<tr>
<td>5. Preferred cephalosporin/penicillin group antibiotic for elective orthopaedic surgeries</td>
<td></td>
</tr>
<tr>
<td>Ceftriaxone (alone)</td>
<td>45 (11.2%)</td>
</tr>
<tr>
<td>Ceftriaxone–sulbactam</td>
<td>104 (25.9%)</td>
</tr>
<tr>
<td>Amoxicillin–clavulanate</td>
<td>14 (3.5%)</td>
</tr>
<tr>
<td>Cefuroxime (alone)</td>
<td>157 (39.1%)</td>
</tr>
<tr>
<td>Cefuroxime–clavulanate</td>
<td>21 (5.2%)</td>
</tr>
<tr>
<td>Cefazolin</td>
<td>23 (5.8%)</td>
</tr>
<tr>
<td>Cefoperazone–sulbactam</td>
<td>15 (3.7%)</td>
</tr>
<tr>
<td>Piperacillin–tazobactam</td>
<td>12 (3.0%)</td>
</tr>
<tr>
<td>Others</td>
<td>10 (2.5%)</td>
</tr>
<tr>
<td>6. Preferred second antibiotic in addition to a cephalosporin/penicillin antibiotic in patients undergoing implant surgery</td>
<td></td>
</tr>
<tr>
<td>Aminoglycoside</td>
<td>264 (65.8%)</td>
</tr>
<tr>
<td>Clindamycin</td>
<td>12 (3.0%)</td>
</tr>
<tr>
<td>Fluoroquinolone</td>
<td>17 (4.2%)</td>
</tr>
<tr>
<td>Streptogramin</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>Vancomycin</td>
<td>6 (1.5%)</td>
</tr>
<tr>
<td>7. Preferred route of antibiotic administration in the postoperative period</td>
<td></td>
</tr>
<tr>
<td>Intravenous</td>
<td>136 (33.9%)</td>
</tr>
<tr>
<td>Oral</td>
<td>14 (3.5%)</td>
</tr>
<tr>
<td>Intravenous followed by oral</td>
<td>251 (62.6%)</td>
</tr>
<tr>
<td>8. Duration of antibiotic administration in the postoperative period</td>
<td></td>
</tr>
<tr>
<td>1 day</td>
<td>162 (40.4%)</td>
</tr>
<tr>
<td>2–7 days</td>
<td>178 (44.4%)</td>
</tr>
<tr>
<td>8–14 days</td>
<td>58 (14.5%)</td>
</tr>
<tr>
<td>&gt; 14 days</td>
<td>3 (0.7%)</td>
</tr>
<tr>
<td>9. Preference of antibiotic for open fracture surgeries when compared to elective orthopaedic surgeries</td>
<td></td>
</tr>
<tr>
<td>Stays same</td>
<td>36 (9.0%)</td>
</tr>
<tr>
<td>Varies according to grade</td>
<td>315 (78.5%)</td>
</tr>
<tr>
<td>Varies sometimes</td>
<td>50 (12.5%)</td>
</tr>
<tr>
<td>10. Co-prescription of other drugs alongside an antibiotic?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>257 (64.1%)</td>
</tr>
<tr>
<td>No</td>
<td>69 (17.2%)</td>
</tr>
</tbody>
</table>
done using one-way ANOVA and Chi-square test (Table 4). The age of a respondent had statistically significant association with the preferred route of post-operative antibiotic administration. Their number of years of experience in orthopaedics was significantly associated with their preference of cephalosporin/penicillin, the route of post-operative antibiotic administration, and the preference of antibiotics used in Gustilo–Anderson (GA) type I and II fractures. The workplace had a significant association with the number of antibiotics used in non-implant and implant surgeries, preference for cephalosporin/penicillin, and the duration of post-operative antibiotic administration. The type of workplace was significantly associated with the preference for cephalosporin or penicillin. The workplace and its type had no association with the preference of antibiotic prescription for SAP in any of the GA types of open fractures. Supplementary table S2 shows further details of the factors which showed statistical significance in univariate analysis.

257 (64.1%) respondents routinely co-prescribed other drugs with antibiotics. While the respondents reported prescribing drugs of varied classes, the most common co-prescription was of a proton pump inhibitor or an H-2
receptor blocker (n = 257), followed by calcium (n = 163), multivitamins (n = 152) and probiotics like spores of Bacillus clausii or lactic acid bacillus (n = 95). With regard to the question of keeping oneself updated on prophylactic antibiotic prescription practices, 62, 52, 16, and 11 respondents kept themselves updated based on scientific papers, conferences, textbooks and information from pharmaceutical representatives, respectively; the rest depended on two or more sources. The preferred source for most was scientific papers (n = 222, 55.4%) (Table 2).

Discussion

Even though the achieved response rate of the present survey was quite low, this was probably the first attempt to ascertain the antibiotic prescription practices of members of the Indian Orthopaedic Association. While we noted heterogeneity in many of the responses, an overwhelming number of orthopaedic surgeons (97.3%) practised SAP routinely.

Elective Surgery/Closed Trauma Surgery

International guidelines recommend that the agent used for SAP should be non-toxic, low cost, having a narrow spectrum with rapid action to be administered as an intravenous single-dose bolus within 30–60 min before the incision; in case the blood loss during surgery is > 1500 ml or if the duration of the surgery is > 240 min, additional doses of antibiotics are recommended. However, the recommended duration of SAP is for no > 24 h postoperatively [16, 17]. In this study, > 90% of surgeons stated administering SAP within one hour of incision and an equal number also reported re-administering antibiotics intra-operatively. However, the timing of the repeat dose and duration of therapy in the postoperative period was diverse (Table 2).

A first- or second-generation cephalosporin is recommended as the antibiotic of first choice, with vancomycin or fluoroquinolone being recommended in cases of beta-lactam allergy; metronidazole is added when prophylaxis against anaerobic bacteria is needed [16, 17]. Although single-dose antibiotic is also at times recommended for clean, non-implant surgery, the strength of evidence for this recommendation is low [16]. The National Centre for Disease Control (NCDC), India has broadly recommended on similar lines while leaving the choice of the prophylaxis to be based on the local antibiogram [18]. For routine orthopaedic surgery, it has recommended intravenous cefuroxime 1.5 g bolus followed by 12-hourly administration for 24 h (maximum) or intravenous cefazolin 2 g bolus; for trauma surgery, the recommendations are either intravenous cefuroxime 1.5 g bolus followed by 12-hourly administration for 24 h or intravenous ceftriaxone 2 g once daily. Figure 2 shows the compliance of the SAP practice of the respondents with NCDC recommendations.

Most international clinical practice guidelines for SAP recommend the use of cefazolin as the first choice of antibiotic unless contraindicated [16]. In this study, cefazolin was used by < 6% of the respondents. Cefuroxime (39.1%), which is a second-generation cephalosporin, was the most common SAP agent followed by ceftriaxone–sulbactam combination (25.9%). Though we did not specifically enquire the reason for the choice of agent for SAP, availability of cefazolin could be a factor apart from the broader antimicrobial cover (both Gram-positive and -negative) afforded by cefuroxime [2]. Both cefuroxime and ceftriaxone have been reported to reduce the incidence of SSI in orthopaedic surgery [1, 2]. Aminoglycosides (65.8%) were the most common co-prescribed second antibiotic when preferring a combination of antibiotics. When comparing the prescription practice for non-implant versus implant surgery, the majority of respondents (76.6%) preferred using a single drug SAP for the former; while for the latter, 50.9% respondents preferred a combination of two antibiotics of different groups. Almost 60% respondents reported continuing antibiotic prophylaxis in the postoperative period beyond 24 h. Ambiguity in the recommendations in the available literature on single- or multiple-dose antibiotic prophylaxis regimen could be the reason for this practice [19]. Multiple-dose regimens have the potential risk of promoting AMR, while adding to the cost of treatment. The duration of SAP was quite varied with few respondents continuing antibiotics for up to 2 weeks empirically.

Open Trauma Surgery

The responses for looking at the pattern of SAP for open fractures were interesting. While 9% respondents reported that their SAP regimen remained the same as for clean orthopaedic surgery, 78.5% respondents reported variation in SAP regimens depending on the grade of injury. For GA types I, II and III fractures, 57.9%, 51.3% and 9.5% respondents, respectively, preferred using a cephalosporin or penicillin along with an aminoglycoside. Notably, 41.2% and 84.0% respondents preferred using a combination of cephalexin/penicillin along with an aminoglycoside and metronidazole in GA types II and III fractures, respectively. Five respondents preferred using linezolid along with an aminoglycoside and metronidazole, while one respondent preferred using meropenem alone, in all GA type III fractures.

Globally, the management of open fractures is evolving not only with respect to improved wound management techniques but also with the SAP regimens adapting to emerging evidence, to optimise treatment outcomes. Over the years, routine use of expanded gram-negative coverage with aminoglycosides has decreased in popularity and has
been challenged for its utility, efficacy, and tolerability for all patients [15, 20]. There appears to be a trend towards considering only first-generation cephalosporins for GA types I and II fractures as the contamination in these fractures commonly reflects normal skin flora, which are generally covered by a first-generation cephalosporin [15]. These organisms are not the infecting organisms identified in subsequent SSI [21]. For GA type III fractures, treatment with a third-generation cephalosporin is recommended [20, 22]. For soil or potential clostridial contamination, addition of penicillin is recommended [15, 20, 22]. While the use of metronidazole for GA type III fractures was quite frequent among the respondents there appears a need for clear evidence for its use. Another trend regarding the duration of therapy is not to extend it beyond 24–72 h after definitive coverage or debridement and coverage with a sterile dressing [15, 20].

**Effect of Age, Years of Experience and Place of Work on Prescription Practice**

Respondents younger than 45 years preferred to use intravenous (IV) followed by oral route more commonly than IV route alone (ratio being 2.3:1). However, this ratio was 1.27:1 for those who were older than 45 years. Also, the majority of respondents with ≤ 15 years of experience preferred administering SAP through the IV route followed by oral drugs over IV route alone (2.5:1) in the post-operative period. This ratio for those with > 15 years of experience was 1.25:1. Antibiotic prescription for elective orthopaedic surgery was as per the NCDC guidelines in 45.6% and 43.9% of respondents with experience of ≤ 15 years and > 15 years, respectively.

Of the 307 respondents who preferred a single antibiotic in elective non-implant cases, 139 (45.3%) worked in a private/corporate/trust hospital, 104 (33.9%) worked in a government hospital/institution, while 64 (20.8%) respondents worked in their own hospitals/nursing homes. Among all the respondents working in a private/corporate/trust hospital, 82.2% preferred a single antibiotic for non-implant cases. In cases where an implant was to be used, a greater number of respondents who worked in private/corporate/trust hospitals preferred using a single antibiotic when compared to those who worked in government hospitals (98 and 58, respectively). The preferred cephalosporin was as per the NCDC recommendations in 44.8% (61/136) and 53.8% (91/169) of respondents working in government hospitals and private/corporate/trust hospitals, respectively. Of the

![Fig. 2 Depicting the concordance of responses with the National centre for disease control (NCDC) guidelines](image-url)
162 participants who administered SAP usually up to 24 h, 88 (54.3%) and 38 (23.5%) worked in private/corporate/trust and government hospitals, respectively, while the rest worked in their own hospitals/nursing homes. The cephalosporin/penicillin of choice was as per NCDC recommendations in 52% and 37.9% of respondents working in a teaching and a non-teaching hospital, respectively.

Co-prescriptions with Antibiotics

Almost 64% of respondents replied in the affirmative regarding co-prescription of other drugs with antibiotics (Table 2). Caution needs to be exercised when co-prescribing proton pump inhibitors or H2-receptor blockers, as these are known to increase the risk of Clostridium difficile infection; while antacids, minerals, and calcium supplements could affect the absorption of oral antibiotics [23, 24]. Multivitamins are found to have a synergistic action with antibiotics and have been suggested as tools to treat multi-drug resistant superbugs [25]. Probiotics help to replenish the natural gastrointestinal flora with non-pathogenic organisms and are frequently promoted as co-prescriptions with antibiotics for the prevention and treatment of antibiotic-associated diarrhoea; however, care needs to be exercised in immunosuppressed patients as sepsis and fungemia associated with their use has been reported [26]. Co-prescriptions of vitamin D have been reported to decrease antibiotic consumption and seem to protect patients from respiratory tract infections [27]. There are mixed reports regarding the use of vitamin C along with antibiotics with synergy as well antagonism reported with various antibiotics and due caution should be exercised in co-prescribing vitamin C with antibiotics [28, 29].

Limitations

We acknowledge the limitations of this study. The overall response rate to the survey was quite poor. One probable reason was the survey being online only and surgeons who are not tech-savvy could not participate. As the e-mails were sent from a pre-existing list of addresses, there is a possibility that some of them were sent to addresses not being actively used by some members which could have affected the response rate. However, we believe that we have served the important purpose of sensitisation of orthopaedic surgeons to this issue of SAP practice. Second, this being a survey also suffered with the inherent limitations of this methodology like non-responder bias, as the prescription patterns of the responders may not reflect the variation within the orthopaedic fraternity, and self-reporting bias, with respondents possibly answering in a way that is a positive reflection of their practice.

Recommendations

The usual fear in the mind of orthopaedic surgeons in India is that ours being a hot and humid country, the risk of co-infection with both gram-positive and -negative organisms is high, and that the prophylactic antibiotics should continue till the epithelisation of a wound occurs [30]. However, in this era of increasing AMR, antimicrobial stewardship from the orthopaedic fraternity is needed to address the challenge of AMR. Discussion on SAP protocols need to be an integral part of our national and state chapter conferences so that broad guidelines may be formulated, which can then be used for expanding the NCDC guidelines.

Conclusion

This survey has brought out the antibiotic prescription practices of members of the IOA. While most of the respondents administer SAP; there is heterogeneity in terms of choice of antibiotic, number of co-prescribed drugs, single- versus multiple-dose regimens, and the duration of therapy. The study shows that orthopaedic surgeons prefer using broad-spectrum antibiotics for a long duration, regardless of the type of surgery.

In this era of increasing AMR, it is high time that the orthopaedic fraternity come together to conduct large, multicentre, well-designed randomised controlled trials to create the evidence for best practice. We believe, with this survey, we have served twin purposes of sensitizing the orthopaedic fraternity to this critical issue and building the database of current practice.

Author contributions Conceptualisation: JAS, PB. Methodology: JAS, MN, RS. Formal analysis and investigation: PB, AC. Writing—original draft preparation: JAS, PB, MN. Writing—review and editing: RS. Funding acquisition: not applicable. Resources: AC (software for statistical analysis). Supervision: RS.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Human Ethics Committee, All India Institute of Medical Sciences, Bhopal, MP, India, IHEC-LOP/2020/IM0243, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.
References


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Closed Transverse Pinning for Reduction and Fixation of Metatarsal Neck Fractures: Surgical Technique

Navneet Kumar Goel · Ankit Khurana · Varun Narula · Ashish Goyal

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Abstract
Most metatarsal neck fractures can be successfully treated non-operatively in a cast boot. Displaced metatarsal neck fractures tend to be less stable and have a propensity for the distal fragment to angulate, secondary to the strong flexor tendons, which often forces the distal fracture fragment in a plantar direction and leads to relative metatarsal shortening. Most literature is focussed on ante-grade fixation of metatarsal neck fractures using pre-bent K wires or thin elastic nails. Apart from the technical challenges, this technique is limited when bones are osteoporotic as the pre-bent distal end of the K-wire may penetrate the plantar cortex of the proximal metatarsal and prevent the wire from entering the medullary canal of the metatarsal and advancing to the fracture site. Furthermore, when the medullary canal is narrow especially in Asian patients, it may be difficult to pass a bent K-wire through the isthmus of the metatarsal shaft. We describe an innovative technique of closed transverse wiring of the metatarsal head necks that has a distinct advantage in Asian population with osteoporotic bones. With percutaneous manipulation using digital pressure, closed reduction of fracture fragments of the most displaced fracture is done under fluoroscopic guidance to achieve a satisfactory alignment followed by closed transverse wiring of the metatarsal heads. With this procedure, adjacent fractures remain stable within an acceptable range because of intermetatarsal ligaments connected to the adjacent intact head. Our technique has a relatively short operating time and allows for early motion of the metatarso-phalangeal joint. This is especially useful for those with osteoporosis, narrow canal, soft tissue compromise, intra-operative failure of ante-grade pinning and in scenarios of limited surgical equipment/expertise.

Keywords Forefoot · Metatarsal neck · K-wire · Foot trauma · Fracture

Introduction
Most metatarsal neck fractures can be successfully treated non-operatively in a cast-boot [1, 2]. Displaced metatarsal neck fractures tend to be less stable and have a propensity for the distal fragment to angulate, secondary to the strong flexor action of tendons, which often forces the distal fracture fragment in a plantar direction [3]. Metatarsal fractures that are displaced and have over 50% translation and/or angulated in the sagittal or coronal plane more than 20 degrees, and fractures involving 2 or more metatarsals are best treated surgically [3, 4]. This is to avoid significant post-traumatic metatarsalgia and prevent an imbalance of metatarsal cascade.

Various authors have described techniques for reduction and fixation of these fractures. Most literature is focused on ante-grade fixation of metatarsal neck fractures using pre-bent K wires or thin Elastic nails [6–10]. Others have used open reduction and plate fixation for these injuries [11]. There are also reports of intra-focal Kapandji pinning of the metatarsal neck fracture [12]. We describe an innovative technique of closed transverse wiring of the Metatarsal head necks that has a distinct advantage in the Asian population with osteoporotic bones and failed ante-grade pinning.

Methodology
This technique was used in patients with multiple metatarsal neck fractures with displacement. While under regional ankle block/spinal anesthesia, the patient was placed in the supine position. Under the guidance of an image intensifier, gentle longitudinal traction was applied and percutaneous
manipulation was done using k wires and digital pressure. Closed reduction of fracture fragments of the most displaced fracture was first done under fluoroscopic observation to achieve a satisfactory alignment. With this procedure, adjacent fractures became reduced and stable within an acceptable range because of inter-metatarsal ligaments connected to the adjacent fractured head/s (Fig. 1).

A 1.5 mm Kirshner wire was then inserted transversely beginning in the distal-out aspect of the 1st or 5th metatarsal. An intact 1st or 5th metatarsal would buttress the adjacent fractured metatarsal and an additional K-wire would impart stability to the fracture-implant construct. The K-wire was subsequently advanced through the heads of the fractured metatarsals. Maintenance of reduction and stability of the immobilization was then confirmed under fluoroscopy. The goals of the reduction were to re-establish metatarsal angulation in the sagittal plane and to maintain the normal metatarsal head cascade in frontal plane. K-wires were bent over the skin (Fig. 2).

Postoperatively, we allowed immediate motion of the MTP joint and partial weight-bearing in a stiff-soled shoe or a removable fracture boot. Full weight-bearing was allowed 6 weeks after the operation. The Kirschner wire was removed usually at 6–8 weeks when the fracture sites had become non-tender. Union was confirmed in radiographs taken at 12 weeks. All fractures treated by use of this technique progressed to asymptomatic union by 12th week (Fig. 3).

**Fig. 1** a Pre-reduction image of metatarsal neck with plantar flexed metatarsal head and relative metatarsal shortening. b, c Digital manipulation and linear traction used to reduce the metatarsal neck. d, e K-wire inserted through the 5th metatarsal head into the remaining metatarsal heads to secure the fixation and maintain the same within an acceptable range using the intermetatarsal ligaments connecting intact metatarsal head to the adjacent fractured head.

**Fig. 2** a, b Preoperative radiographs showing displaced fractures of 2nd, 3rd and 4th metatarsal necks marked by arrow heads along with fracture of 1st proximal phalanx of the great toe with significant osteopenia with 2 (a) showing the oblique X-ray with significant metatarsal head plantar flexion which needed reduction to prevent future transfer metatarsalgia. c, d Postoperative radiographs showing acceptable reduction in AP and oblique views following transverse pinning and fixation to intact metatarsals (1st and 5th). The intact inter-metatarsal ligament aids in maintenance of accurate reduction.
Results

The authors have operated seven cases with this technique and our inclusion criteria for this technique were osteoporotic metatarsals or thin metatarsal medullary cavity. Otherwise, we customarily use ante-grade elastic nailing for metatarsal neck fracture fixation and in two of such cases we had to switch to this method as elastic nailing was not successful in reducing or maintaining reduction. With evolving experience, we thus have adopted this technique as a backup for intra-operative failures of elastic nailing. One of the seven patients reported interdigital neuropathic pain in the initial 6 weeks that subsided over time. There have been no wound complication apart from occasional pin loosening and no loss of reduction in any of our cases. All patients went on to full weight-bearing by 6–8 weeks when fracture sites became non tender and radiographic union was confirmed at 12 weeks in all our cases. None of the patients developed plantar pain, callosities or transfer metatarsalgia till latest follow-up (1 year).

Discussion

K wire is a versatile device and used in trauma surgery in very novel ways. This technique is one such use of this versatile implant to achieve a stable reduction for metatarsal neck fractures with a relatively simple technique. Metatarsal neck fractures may result from either direct injury due to fall of a heavy object over forefoot or indirect which occurs when the forefoot is held fixed and the leg or foot is twisted, a situation often seen in athletes who present with injuries to the foot [3, 5]. Displacement of the fracture fragments in the frontal plane (medial to lateral) can be tolerated to a certain extent. However, a displacement of more than 50% or an angulation of more than 20 in the sagittal plane (dorsal to plantar) requires reduction [13, 14]. The strong flexor tendons usually force the distal fractured fragment of the metatarsal fracture in plantar flexion and proximal migration. When malreduced, healing of fractures with significant plantar displacement of the distal fragment increases the
prominence of metatarsal head and can result in pain during weight-bearing and thus gait abnormalities. Furthermore, shortening of the length of a metatarsal, and loss of cascade may lead to altered weight distribution and can cause transfer metatarsalgia.

Most authors have used elastic nails or K-wires for ante-grade pinning of metatarsal necks starting from the base of the metatarsal and passing the wire through the shaft up to the metatarsal head and using the Metaizeau’s technique for reduction [6–10]. Apart from the technical challenges this technique is limited when bones are osteoporotic as the present distal end of the pin may penetrate the plantar cortex of the proximal metatarsal and prevent the wire from entering the medullary canal of the metatarsal and further advancement to the fracture site. Furthermore, when the medullary canal is narrow especially in Asian patients, it may be difficult to pass a bent pin through the isthmus of the metatarsal shaft. When closed reduction is unsuccessful, open reduction has been recommended with this technique [13]. Moreover, in many cases soft tissue compromise of dorsal skin may lead to wound problems after opening the fracture site. Sammarco et al. reported risks of infection, non-union, and a possibility of metatarsal phalangeal joint stiffness with this technique when the fracture was opened [15].

There are reports of open reduction and plate/inter-fragmentary screw fixation of metatarsal neck fractures [16]. Authors have reported delayed union due to devascularization and peri-implant fracture as a complication. Open reduction and internal fixation is often frustrating when the fracture fragment (metatarsal head) is small and in cases of soft tissue compromise of dorsal skin which may lead to wound problems after opening the fracture site. Lack of adequate patient compliance and proper postoperative management have been postulated to contribute to poor outcomes for open reduction and inter-fragmentary screw fixation for metatarsal neck fractures [4].

With our technique of closed technique of transverse wiring, the fracture site is not opened and the articular surface and the capsuloligamentous structures are not injured, which allows early motion of the MTP joint. Moreover our technique is easy, needing basic surgical experience with very basic equipment. Also the operative time is relatively much shorter compared to all other described techniques. This technique was described way back in 2004 by Donahue et al. but we have not found any description of a similar technique in subsequent literature [17]. The present surgical technique is a much refined description of method described by Donahue et al. in terms of detailed description, reduction methodology, reduction biomechanics and follow-up radiographs describing outcomes as well as elucidating the indications of this technique i.e. in osteoporotic metatarsals and narrow medullary canals. This technique is also suitable in cases of intra-operative failures of ante-grade pinning.

The authors of present study emphasize that the described technique requires minimal skills, is easy to perform and is much more suitable for Asian population in view of above mentioned indications.

Transverse wiring has been sufficiently described in hand for boxer’s fracture with randomized control trials comparing outcomes and complication rates of transverse pinning versus ante-grade pinning [18, 19]. One such randomized trial [19] reports superiority of transverse wiring over intra-medullary pinning for fixing 5th metacarpal neck fracture. We propose a similar advantage of transverse wiring in the foot however high quality evidence for the same is lacking. This technique description paves way for future comparison of transverse pinning with elastic nailing or ante-grade wire insertion for metatarsal neck fractures. Authors of present study have proposed separate indications for use of this technique based on their experience. Till proven superiority ante-grade intra-medullary pinning and elastic nailing remain gold standard for fixing metatarsal neck fractures.

In conclusion, closed transverse pinning was found to be a useful method for treating displaced metatarsal neck fractures to allow immediate joint motion and early rehabilitation. This technical description is limited by its non-comparative nature and lack of detailed outcome analysis in the form of functional scores, which prevents the described method from being used as a definite surgical choice for metatarsal fractures. Nevertheless, we believe the described method can be an effective option for metatarsal neck fractures, especially for those with osteoporosis, narrow canal, soft tissue compromise, failed ante-grade pinning and limited surgical equipment/expertise.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

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Surgical Technique

Modification of the Traditional Open Latarjet Technique with the Use of Sutures and Cortical Buttons Instead of Screws

Dimitrios Kotzamitelos · Socrates Kalogrianitis

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Abstract
In this article we describe a modification of the open Latarjet technique, using sutures and cortical buttons, for the fixation of the coracoid. The transfer of the coracoid to the anterior glenoid is a popular technique used for complex shoulder instability. The technique is proven to be effective with consistently good results but complications have been reported related to the screws used for the fixation of the coracoid. Recent studies confirm that the suture-button technique for the fixation of the coracoid is biomechanically comparable to the screw fixation. The proposed technique combines the advantages of the open approach and avoids the use of metal screws, potentially minimizing hardware-related complications.

Keywords Glenohumeral joint · Coracoid process · Fixation devices · Latarjet · Buttons

Introduction
The Latarjet procedure has been proven to be an effective and reliable treatment for recurrent anterior shoulder instability and in cases with glenoid bone loss [1–3]. Walch and Boileau [4] reported on 2000 cases treated with Latarjet with 98% excellent or good results and only 1% recurrence instability rate. In 2007 Burkhart et al. [5], reported 4% recurrence rate in 102 patients with anterior instability and significant bone loss, treated with a modified Latarjet.

The procedure, as popularised by Walch [6] relies on 2 parallel malleolar screws for the fixation of the coracoid on to the glenoid. However, the use of screws has been related to complications such as nonunion (9.4–10.1%), resorption of the bone block (1.6%), intraoperative and post-operative fracture (1.1–1.5%) as well as screw avulsion, twisting, or breakage and impingement with the humeral head (2.4–6.5%) [7, 8]. LeBus et al. [9] in 2017 reported 46% hardware-related complications in a small number of NFL players. Griesser et al. [7] in a systematic review that included 45 studies, reported 7% reoperation rate, 35% of which consisted of removal of symptomatic metalwork.

In 2016 Gendre et al. [10] demonstrated an excellent rate of bone union in arthroscopic Latarjet using a suture-button fixation system. Seventy patients underwent arthroscopic coracoid transfer (Bristow or Latarjet) using suture buttons instead of screws. They reported bone union in 83% of the cases (58/70) with 74% bone union in the Bristow group and 91% in the Latarjet group. The coracoid position was considered to be ideal in 93% of the cases with the graft below the equator and tangential with the glenoid surface. No hardware complications were reported at a mean follow-up of 14 months.

In a more recent cadaveric biomechanical study, Provencer et al. [11] compared screw to suture fixation for the Latarjet procedure in sixteen male cadaver shoulders. The mean failure load (yield load) for screw fixation was $226 \pm 114 \text{ N}$ (95% CI), compared to $266 \pm 73 \text{ N}$ (95% CI) for suture-button fixation. There was no significant difference in failure load between the two groups ($P=0.257$). The mean strain at failure for screw fixation was $63 \pm 21\%$ (95% CI) of the measured gauge length, compared with $86 \pm 26\%$ (95% CI) of the measured gauge length for suture button. The most common mode of failure for the screw fixation method was a fracture through the bone drill holes, while for...
the suture-button construct was rupture through the muscle at the clamp-muscle interface.

We propose a modified open Latarjet technique using suture-button fixation avoiding the use of screws.

**Technique**

**Patient Positioning**

The patient is placed on a shoulder table in the beach chair position. The arm is draped free and placed into an arm support device (Trimano, ARTHREX).

**Approach**

The limited deltopectoral approach is used with a nearly vertical skin incision from the tip of the coracoid towards the axillary fold. The cephalic vein is taken laterally and a self-retaining retractor is used between the deltoid and pectoralis major. The arm is positioned in abduction and external rotation and a Hofmann retractor is placed on top of the coracoid process.

**Coracoid Preparation**

The coracoacromial (CA) ligament is exposed and divided 1 cm from the coracoid attachment, with the arm kept in external rotation. Then with the arm in adduction and internal rotation the pectoralis minor is released exposing the medial side of the coracoid.

The coracoid is osteotomised at about 2.5 cm from its tip, using an angular 90° oscillating saw, with direction from medial to lateral and from superior to inferior in a perpendicular fashion. The coracoid is mobilised and extra care is taken to avoid traction injury of the musculocutaneous nerve.

The undersurface of the coracoid is flattened using the saw. Two 1.6 mm Kirschner wires are used to drill the coracoid (Fig. 1). They are placed 1 cm apart and 6 mm from the medial edge of the coracoid. This can be done either with a freehand technique or using a glenoid offset parallel drill guide (Arthrex).

**Glenoid Exposure**

The arm is placed in adduction and external rotation and the subscapularis is exposed. The superior and inferior borders of the tendon are identified and a horizontal split is made at the junction between superior 2/3 and inferior 1/3 of the muscle–tendon junction. The split is made with Mayo scissors, in line with the muscle fibres extending laterally to the lesser tuberosity.

Following blunt dissection, a Hohmann retractor is placed in the subscapularis fossa against the glenoid neck. A self-retaining Gelpi retractor can be used to maintain the subscapularis split open. The capsule is incised vertically at the
level of the joint and a Fukuda type of retractor is inserted in the joint improving the exposure of the anterior glenoid.

**Glenoid Preparation**

The anterior labrum is debrided and an osteotome is used to decorticate and flatten the anterior glenoid neck area. Then two parallel Kirschner wires (1.6 mm) are inserted to the glenoid in position 4 and 5 o’clock using the ARTHREX 6 mm glenoid offset guide. A 3.2 mm cannulated drill bit is used to drill 2 parallel tunnels in the glenoid over the Kirschner wires, with direction from anterior to posterior, going through both cortices. Then the Kirschner wires are removed (Fig. 2).

**Coracoid Fixation**

We load onto a cortical button (2.6 x 10.9 mm) (pectoralis repair button, Arthrex), a fibre wire suture folded in half, so in one end we have a closed-loop and in the other end we have two free suture ends. The button which is mounted on a threaded inserted (Arthrex), is passed into the glenoid tunnel until it exits through the back. The inserter is then released and whilst still in the glenoid tunnel, the button is flipped over the posterior cortex of the glenoid by pulling on the fibre wire. The inserter is then removed. The same procedure is repeated for the other glenoid tunnel using the same equipment (Fig. 3).

We pass all four sutures of the inferior button through the inferior coracoid drill hole which is closer to the conjoint tendon insertion entering first the decorticated side of the bone. We repeat the procedure for the sutures of the superior button through the other coracoid drill hole. The sutures of each button are loaded through a Dog Bone (Arthrex) in a way that the closed-loop goes through one slot and the two free suture ends through the other. The coracoid is placed on to the glenoid, making sure that there is good surface apposition and contact and the coracoid is flush with the glenoid surface. A sliding NICE knot is used to tighten the buttons sequentially on to the coracoid. We use a suture tensioner up to 100 N, to tension the construct which is finally secured with 3 half-hitches (Fig. 4).

The capsule is reattached to the CA ligament stump and the lateral side of the coracoid using absorbable interrupted sutures. The wound is closed in layers. A drain is typically not used.

**Postoperative Rehabilitation**

Following this procedure we still use our standard rehabilitation protocol for a Latarjet procedure.
Discussion

The use of screws for the fixation of the coracoid on to the glenoid has been related to complications including screw loosening, prominence and irritation or breakage. Gendre et al. [10] were the first to describe the arthroscopic Latarjet procedure with the use of suture buttons for the fixation of the coracoid reporting no hardware complications and a union rate at least as good as the rate achieved with...
cortical screws. Recent studies confirm good outcomes and lower complications rate with the use of suture-button fixation, with similar biomechanical properties and no significant differences in the maximal load to failure comparing to screw fixation [12–14].

In 2019 Xu et al. [15] reported clinical and radiological results on 128 patients who underwent arthroscopic Latarjet with a single suture-button fixation. The patient outcomes were satisfactory and the graft demonstrated excellent remodelling to a new concentric circle with the humeral head analogous to the original glenoid. They also noticed that the grafts positioned laterally did not cause arthropathy of the joints within the 3 years to follow-up period.

**Conclusion**

The latarjet procedure is a proven technique for managing the anterior shoulder instability but it has hardware-related complications.

It has been already shown that the use of suture buttons in arthroscopic Latarjet using a posterior guide can result in excellent rates of bone union. A similar type of fixation can be used in open Latarjet coracoid transfer avoiding the use of screws and potential associated complications.

We present a modification of the open Latarjet technique without the use of screws (Fig. 5). We do thing that this is a simple and reproducible technique offering the benefits of the traditional fixation (Fig. 6), potentially minimizing hardware-related complications.
Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

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Abstract
Chevron osteotomy of the olecranon during the posterior approach of the elbow joint has become universally common. We modified the technique to see if it is better than the standard technique to perform, reconstruct and finally evaluate the results. A prospective study was done in 17 cases of comminuted distal humeral intercondylar fractures. A modified osteotomy was done using a Gigli saw instead of a power saw. The indications remained the same. After fixing the distal humerus fracture, the olecranon fragment was stabilised with tension band wire technique. The post-operative management was similar to that of standard AO technique. There were no per-operative difficulties with the new technique. The osteotomy was easy to do with no risk of damage to the distal humeral cartilage, as the direction of the osteotomy was away from the joint. Gigli saw produced congruent antero-posterior chevron surfaces which helped the fragment to sit well in its trough with good bony apposition. Stable reduction of the olecranon facilitated easy fixation. In this series, all osteotomies united well. There were no osteotomy-related complications. Two cases had prominent wires which were removed after the union of the osteotomy. We feel that this osteotomy is easy to perform, safe and takes less time than the standard technique, though a comparative study in a large number of cases by different surgeons needs to confirm the benefits.

Keywords Olecranon chevron osteotomy · Tension band wiring of olecranon · Distal humeral fractures · Modified chevron osteotomy of olecranon · Olecranon osteotomy with gigli saw

Introduction
Olecranon osteotomy is a well-established technique during the posterior approach of the elbow joint. Though ‘non-articular’ olecranon osteotomies are commonly used for non-articular fractures of the distal humerus, ‘trans articular’ osteotomy makes fixation of condylar and intercondylar fractures of the humerus, much easier [1–3]. There is a small bare area on the articular side of the olecranon through which osteotomy is generally made [4, 5]. A chevron osteotomy is well established by the AO foundation and has stood the test of time. Normally, a ’V’-shaped osteotomy is made with the apex distal and the chevron in a medio-lateral direction in the coronal plane (Fig. 1) [6]. This study aims to present a safe and easy technique of olecranon osteotomy, where the apex of the ‘V’ is still distal but the chevron is in an antero-posterior direction in the sagittal plane and is performed using a Gigli saw (Fig. 2).

Materials and Methods
In a prospective series of 17 cases, modified chevron olecranon osteotomy was done to expose comminuted intercondylar fracture of the distal humerus from September 2013 to April 2017. There were 12 men and 5 women in this series, age ranging from 19 to 54 years. The average age of male patients was 34 years and it was 27 years in female patients (Table 1). Uniform technique as described below was followed for olecranon osteotomies and all were fixed with tension band wire (TBW) technique after completion of internal fixation of distal humeral fractures.
Technique of Osteotomy

Patient selection, Indications for osteotomy and preparation were the same as for standard chevron osteotomy [1, 6]. The patient was positioned on the side with the arm placed over an armrest, leaving the forearm free to move. Under a tourniquet control, a midline incision was made on the posterior aspect of the elbow. The ulnar nerve was dissected free and protected. Insertion of the triceps tendon over the olecranon was protected and the muscle is elevated from the medial and lateral inter-muscular septae. The sides of the olecranon were exposed. A curved artery forceps was passed anterior to the olecranon transversely through the joint to check the space and ease of passing. Then a Gigli saw was passed through the joint by holding

**Table 1** Age and sex distribution of the cases

<table>
<thead>
<tr>
<th>Age (Yrs)</th>
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it with the same artery forceps and retrieved from the other side, taking care that it lies close to the olecranon (Fig. 3). The wire usually sits in the bare area of the olecranon as there is an anatomical notch, which is devoid of articular cartilage [4, 5]. The osteotomy is performed under direct vision, the direction, force and the speed of osteotomy being fully under the control of the surgeon. The initial direction of ‘sawing’ movement was perpendicular to the axis of the ulna with ‘pull’ in a posterior direction. Once the Gigli saw got a purchase in the bone, the direction of pull on the Gigli saw was changed towards the wrist joint, i.e. posterior and inferior direction till the Gigli saw wire reached half the thickness of the olecranon under our direct vision (Fig. 4). Then the direction of pull was changed postero-superiorly until the remaining half of the ulna was cut (Fig. 5). This resulted in a ‘V’ osteotomy in an antero-posterior direction. This would be at 90° to the procedure done using a power saw in a medio-lateral direction. The average time to complete the osteotomy with a power saw and Gigli saw was not compared. But the first author took less than 2 min to complete the osteotomy with Gigli saw and about 5 min with an oscillating saw. Since the positioning of the wire and osteotomy is done under direct vision, there would be no need to check with the C-arm. Once the exposure of the elbow joint was complete, the distal humeral fracture was fixed appropriately with plates, screws and wires as necessary. Then the
olecranon was fixed to the ulna by the tension band wire technique (Fig. 6). The post-operative protocol was same as in standard osteotomy cases, dictated largely by the primary distal humeral fractures.

**Results**

The authors had no per-operative problems with this procedure. Towards the end of the surgery, the fragment always sat well in its trough, as the osteotomy surface is uniformly congruent. It is easy to hold it reduced with the elbow held in about 30 degrees of flexion. A stable reduction made fixation easy. All Olecranon osteotomies united by 12–16 weeks (mean 14.8 weeks). There were no problems related to the osteotomy, but two cases had pain over the olecranon due to prominent metalwork. These two patients had removal of K’wires and wire loop, one after 11 months and the other, 14 months following surgery. In another case, TBW was removed when the surgery was done for removal of the distal humeral implants at 15 months following surgery. The results of this study were restricted to the technical aspects of the osteotomy-ease of doing, reduction, fixation, time to union and any complications. The results of the union of the distal humerus fracture, range of movement and function of the elbow joint, which are primarily those of distal humerus fractures, were not included.

**Discussion**

A chevron osteotomy is preferred over a transverse osteotomy as it provides a large area of bony contact and also offers medio-lateral and rotational stability [6] (Table 2). A standard chevron osteotomy is done with a thin oscillating saw. To avoid damage to the humeral articular cartilage the saw cut is stopped short of the subchondral cortex and the final step of completing the osteotomy is done with an osteotome. Caution should be applied while using a power saw, as vigorous uncontrolled oscillations may result in loss of bone at the osteotomy, more so at the apex of the chevron where the saw cuts from medial and lateral directions converge. It is not always easy to judge the depth of the saw while it is entering the subchondral...
area of the olecranon, as the articular surface is not flat. In one area the saw blade may still be in the subchondral bone while in another place it may have entered the joint damaging the humeral articular surface. Finishing the last part of the osteotomy with an osteotome, with tension break of the far cortex and articular cartilage may at times produce a bone spike and an irregular flap of articular cartilage [7]. This hinders accurate approximation of the olecranon fragment during fixation which tends to sit in slight extension due to a relatively wider gap posteriorly. Ramsey DC et al. recently described a technique of olec- ranon osteotomy using a Gigli saw [3]. However, they performed a transverse osteotomy which has the drawbacks of being inherently unstable. They fixed osteotomy with a plate and screws with pre-drilled holes prior to osteotomy. This may not allow adequate compression at the osteotomy site.

The technique described in this study avoids these complications. A Gigli saw is used instead of a power saw or an osteotome. We found this procedure simple, easy and safe. The humeral articular surface remains protected from any abrasion as the pull of the Gigli saw is away from it. The olecranon fragment always sits back in its trough without any step or angulations, as the chevron surfaces are fully congruent allowing stable reduction. Since there is no ‘play’, it is easy to hold it reduced with one hand and to pass wires with the other hand to fix it. In all cases included in this study, the elbow joint is mobilised after the change of the dressing on day 2 following surgery. In this series of 17 cases, there were no delayed unions or non-unions of the olecranon. However, the potential complications associated with prominent metalwork of TBW fixation may remain the same as in the other olecranon fixations which were reported to be about 8% [8].

## Conclusion

This modified technique of olecranon osteotomy has all the advantages of the standard AO chevron technique. In addition, we found osteotomy with Gigli saw to be simple and easy to do, and it took less time in the hands of the first author compared to the procedure done with an oscillating saw. There is no chance of damaging the humeral articular cartilage as the direction of osteotomy is inside-out, and hence safe. It needs fewer inventories. Gigli saw produced minimum bone loss and gave a uniform cut surface with no steps at the apex of the chevron. It made the reduction of fragment easy and had good bony apposition. Hence it facilitated easy fixation. We had no complications during the procedure. It has a short learning curve. The authors found that it is safer even in the hands of surgeons in training. We do not claim that this technique is superior to the standard technique in terms of post-op complications and the rate of union of the osteotomy and accept that this is not a comparative study. The authors acknowledge a limited number of cases in this series and the findings needs to be validated with more number of cases by different surgeons.

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### Compliance with Ethical Standards

#### Conflict of Interest

The authors declare that they have no conflict of interest.

#### Ethical Standard

This article does not contain any studies with human or animal subjects performed by the any of the authors.
Informed Consent  Appropriate informed consents have been taken as per the hospital policy on the prescribed format.

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An Unexpected Intra-operative Encounter of Anterior Tibial Vessels Entrapment in the Fracture of Tibial Pilon: A Case Report and Literature Review

Abhinav Mishra · Saubhik Das · Hariom Prasad · Arvind Kumar · Prabhat Agrawal

Abstract
We present a rare case of a comminuted tibial pilon fracture with entrapment of anterior tibial vessels in fracture site, which was unexpectedly discovered intra-operatively. Following safe extrication of vessels and fracture fixation through minimally invasive approach, the patient recovered uneventfully. Phenomenon of anterior neurovascular entrapment should be kept in mind while dealing with high-energy tibial pilon fractures. Astute clinical examination, judicious use of imaging modality, and strict intra-operative vigilance are key to successful outcome.

Keywords Tibial pilon · Fracture · Vessels · Entrapment · Management

Introduction
Entrapment of neurovascular structures in fractures is not uncommon, frequently observed in upper limb; sporadic cases have also been reported following tibial shaft fractures [1–3]. However, to the best of our knowledge, there is no such mention of neurovascular entrapment in tibial pilon fractures in literature. The anterior tibial vessels and the deep peroneal nerve are at such risk in cases of tibial pilon fractures due to its location in close proximity to distal tibia [4–6].

We report a case of a highly comminuted fracture of the distal tibia (AO/OTA 43-C3) with entrapment of anterior tibial vessels with sparing of deep peroneal nerve, managed with a combination of the conventional technique and minimally invasive approach to preserve the soft-tissue envelope while carefully extracting the incarcerated vessel from the fracture site. The patient was informed that data concerning the case would be submitted for publication, and he gave consent for the same.

Case Report
A 42-year-old male patient, manual laborer, had sustained injury following fall from tree. He was initially taken to a nearby hospital; relevant radiographs and CT scan of the involved extremity suggested comminuted fracture of tibial pilon (43-C3) with spiral extension of fracture proximally in diaphysis, and concomitant fibular fracture. He was operated upon with external fixator application and open reduction and internal fixation (ORIF) of fibula fracture. Two days after operation, he was referred to our centre for further management. Clinically, there was swelling, no distal sensory-motor deficit; dorsalis pedis artery (DPA) and posterior tibial artery (PTA) pulsations and capillary refill were well appreciated. However, DPA pulsation was feeble which was attributed to swelling. Repeat CT scan could not be obtained due to cost constraints on part of patient. A second-stage surgery was planned 15 days after the first procedure once swelling reduced and clinically wrinkle sign was observed.

Fixation with minimally invasive plate osteosynthesis (MIPO) through anterolateral approach was planned. Upon sufficient exposure of articular fragments, an unusual sight unfolded when the anterior tibial vessels were appeared to be coming out of the medullary canal of tibia. The vessels
were traced proximally and were found to be passing precariously between the fragments across the meta-diaphyseal spiral fracture line. A decision for conversion to minimal ORIF was taken; the incision was extended minimally to trace the vessels proximally, and the fragments were distracted using bone hooks and lamina spreader. The vessels were gently guided out of the fracture with a cotton patty, carefully preventing any undue traction and injury. Arterial pulsation was checked immediately and the entire length of exposed vessels was examined to look for any apparent tear or thrombus. Once the health of the vessels was ascertained, the procedure was completed with articular reconstruction and fixation with anterolateral distal tibial LCP using percutaneous technique. The medial malleolar fragment was buttressed with a plate through a separate medial incision. Skin incisions were planned so as to maintain sufficient skin bridge, and soft-tissue dissection and retraction were scrupulously executed (Fig. 1).

Post-operatively, patient was kept on posterior POP splint. Close regular monitoring was afforded for timely identification of late vascular embarrassment. Patient was kept on subcutaneous low-molecular-weight heparin (LMWH) until hospital discharge, followed by aspirin (150 mg) for 4 weeks. Duplex ultrasonography, before hospital discharge, demonstrated patency of anterior tibial vessels. A repeat duplex ultrasound, after suture removal at 2 weeks post-operatively, elicited satisfactory findings. At the end of 4 months of follow-up, the surgical site healed uneventfully, and radiological sign of callus formation and ongoing union was noted. Patient has no neurovascular deficit and has been allowed to bear weight partially (Fig. 2).

Discussion

High-energy tibial pilon fractures continue to test judgement and skill of orthopaedic traumatologist. Despite evolution of management strategy and surgical tactics, it is fraught with unsatisfactory sequel in many patients [7]. Apart from rendering heightened vigilance for tenuous soft-tissue envelope, phenomena of various soft-tissue entrapments between fracture fragments have caught attention of surgeons lately. Posteromedial structure entrapments (PMSEs) are recognized eventualities around pilon fractures, particularly in high-energy fractures (43-B/-C). Early recognition of this phenomenon is imperative, since it has implication on

![Fig. 1 Pre-operative plain radiograph (a), and axial (b), sagittal (c), coronal (d), and 3D images (e) of CT scan of the involved extremity. Intra-operative photographs (f, g) revealing entrapped anterior tibial vessels emerging from the fracture site (white arrow). Anterolateral incision was extended proximally and entrapped vessels were meticulously extricated (h). Post-operative radiograph (i) depicting satisfactory reconstruction and fixation of fibula fracture, and pilon fracture with restoration of articular congruency](image-url)
subsequent management, selection of appropriate surgical approach, and subsequent follow-up [8–10]. Eastman et al. had found 9.5% incidence of PMSE, with entrapment of posterior neurovascular bundle in 10% of cases [8]; whereas Fokin et al. reported higher frequency of PMSE (19%), albeit they did not notice any posterior neurovascular involvement
Routine CT scan obtained for characterizing fracture geometry is not ideal for delineation of soft-tissue entrapment, which remain undiagnosed by radiologist and orthopaedist alike in as much as 70% of cases [8, 9]. CT scan of our patient at presentation was innocuous; furthermore, we could not get additional CT scan following external fixator application due to cost constraints that is commonplace in this developing country where surgeons are very often confronted with resource constraints and are required to strike a balance to render safe and effective treatment.

Vascular embarrassment following pilon fractures can lead to sinister sequelae if not recognized and intervened early. Wynes et al. identified late vascular insult weeks after injury and surgical treatment in a tibial pilon fracture (43-C2) that subsequently resulted in amputation. They have provided algorithm for timely identification of occult vascular insult with highly specific and sensitive imaging modalities, such as arterial duplex sonography, arteriogram, computed tomography, or magnetic resonance angiography (CTA or MRA) in the presence of high clinical suspicion [11]. LeBus et al. reported computed tomography angiography (CTA) findings on 25 patients with high-energy tibial pilon fractures and showed that more than half of them were associated with arterial abnormality of distal leg, and injury most commonly involved anterior tibial artery (69%). They asserted angiography component can judiciously be added to CT for routine evaluation of high-energy tibial pilon fracture before contemplating surgical reconstruction. Intriguingly, none of the patients with vascular insult in their series have had any wound complications following surgical fixation which was attributed to liberal use of temporizing external fixator, staged treatment, and adoption of minimally invasive approach [12]. To the best of our knowledge, only couple of reports are available in the literature depicting entrapment of anterior tibial vessels and deep peroneal nerve in spiral distal third tibia shaft fractures [2, 3]. Tan et al. attributed non-union of distal third tibia shaft fracture to entrapment of neurovascular structures. They have emphasized limitations of routine non-contrast CT for identifying this distinct possibility and stressed for MRI scan to buttress high suspicion when surgical fixation is contemplated or in the presence of non-healing of fracture at this location, even in the absence of signs or symptoms of neurovascular entrapment [3]. However, routine angiogram and MRA have its own limitations and may not always be pragmatic due to added cost, logistic, and resource. In our present case, sound clinical findings and palpable distal pulses did not raise suspicion of occult proximal vascular embarrassment, which is not unusual due to the presence of rich anastomotic network providing ample distal pulses that mask the clinical evaluation [12]. On intra-operative identification of anterior tibial vessels entrapment, we had to extend the surgical approach proximally to safely extricate the entrapped vessels. Immediate post-operative and follow-up duplex sonography showed patency of vascular trunk. We concur with Wedler et al. for adoption of Doppler sonography for early visualization of vascular anatomy and function—this modality is particularly relevant in a resource constrained orthopaedic facility [1].

Proximity of anterior neurovascular structure to distal tibia, which are located at a mean of 3 mm from anterior tibial cortex, makes it vulnerable to injury in tibial pilon fractures and also during minimally invasive plating [4–6]. No such evidence is available in the literature hitherto of anterior vascular entrapment in tibial pilon fractures. It is possible that fracture displacement that occur during injury could create potential space for intrusion of soft-tissue structures as they course through the distal leg and ankle [8]. However, selective involvement of anterior tibial vessels without deep peroneal nerve was intriguing; we speculate that fracture spike could have entrapped more laterally located vessels.
It is further speculated that entrapment could have happened following ligamentotaxis during external fixator application.

Our present case purportedly represents first such report of anterior tibial vessels entrapment in high-energy tibial pilon fracture. Our meticulous soft-tissue handling and minimally invasive fixation strategy have resulted in uneventful wound healing. We believe that high index of suspicion is imperative for comminuted tibial pilon fractures; careful clinical examination coupled with liberal use of imaging modality, such as arterial duplex sonography or CTA, should be instituted for timely identification of vascular embarrassment before planning definitive surgical treatment. While performing MIPO for comminuted tibial pilon fractures, this entity should be kept in mind, and if need arises, exposure can be converted to minimal ORIF to expose the fracture site in its entirety for better delineation without devitalizing soft tissues.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interests.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent The patient was informed that data concerning the case would be submitted for publication, and he gave consent for the same.

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Lateral Buttress Plate Along with Cancellous Screw Fixation for Hoffa Fracture Using Swashbuckler Approach

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Abstract
Coronal plane fracture of the posterior femoral condyle, Hoffa fracture, is a rare injury pattern. We report a case of a 32-year-old male with closed Lateral Hoffa fracture along with patella and medial condyle of tibia fracture. Patient was treated using 02 cannulated cancellous screws and a lateral recon plate for Hoffa fracture, tension band wiring for patella fracture and 02 cannulated cancellous screws for tibia fracture through modified swashbuckler approach. Twenty-four months postoperatively, the range of movement in the knee was 0°–130°. In this complex case, our technique provided stable fixation of the fragments and a satisfactory final functional outcome.

Keywords Buttress plate · Hoffa fracture · Swashbuckler approach

Introduction
Fracture of the distal end of femur usually occurs in sagittal plane. The coronal plane fracture of the posterior femoral condyle, the Hoffa fracture, is a rare injury pattern. The first known description of this fracture pattern dates back to 1869 described by Busch [1]. It was first named by Albert Hoffa in 1904[1]. These fractures are intraarticular fractures and commonly unicortylar. The prevalence of lateral condylar involvement is more. The pre-dominance of lateral condyle involvement is due to the physiological genu valgum [2]. This fracture usually results from high-energy trauma, which causes a split of the posterior femoral condyle and displaces it proximally and posteriorly [2].

Lag screw can only provide inter fragmentary compression, and additional hardware is needed to neutralize the shearing stress along the fracture plane. Plate fixation in Hoffa fracture is new concept and studies have found plate fixation along with screw fixation to be a more stable and rigid method of fracture management than screw fixation alone [2].

We describe a rare case of Lateral Hoffa fracture associated with patella and proximal tibia fracture which was successfully treated with cancellous screws along with buttress plate fixation for Hoffa fracture and tension band wiring for patella fracture using swashbuckler approach (Figs. 1, 2, 3, 4, 5, 6, 7).

Case Report
A 32-year-old man presented to us with complains of pain and swelling in the left knee and unable to bear weight over left lower limb. Patient had a history of road traffic accident. Patient did not sustain any head or chest trauma. On physical examination, knee was grossly swollen, and diffuse tenderness was present with restricted knee range of motion. There was no distal neurovascular deficit of the affected lower limb. Patient was then evaluated using plain radiograph. Anteroposterior radiograph revealed fracture patella and Schatzker Type 4 proximal tibia fracture. Lateral radiograph revealed Lateral Hoffa fracture. CT scan of the knee was done and Hoffa fracture was classified as Letenneur type 2. Since open reduction and internal fixation of Lateral Hoffa along with patella was to be done, swashbuckler (modified anterior) approach was planned for fixation.

The patient was operated in supine position under regional anesthesia using a tourniquet over the left thigh. Using the swashbuckler (modified anterior) approach, lateral parapatellar arthrotomy was done. Extensor mechanism was retracted medially. Intraoperatively, cruciate...
ligaments and menisci were found to be normal. Fixation of Hoffa fracture was done using two anteroposteriorly directed 6.5-mm partially threaded cannulated cancellous screws and a lateral buttress plate (Recon plate). Fracture patella was fixed with a tension band wiring construct and for fracture medial condyle proximal tibia closed reduction and fixation was done using two 6.5-mm partially threaded cannulated cancellous screws under fluoroscopic guidance. Due to technical problem, C-Arm stopped working intraoperatively so screw size could not be taken accurately. ACL and PCL were found to be intact on intraoperative assessment. The wound was closed in layers. Postoperative X-rays demonstrated acceptable articular reduction with protrusion of screws from the posterior condylar surface. Postoperatively an above knee back splint was given with knee in 20° flexion for 1 week. Active knee range of motion was started after 1 week and toe touch walking was started at 6 weeks post-surgery. Full weight bearing was started at 3 months. AP screws from the lateral condyle of femur and tension band wire over the patella were removed after fracture union was seen, because of complaints of impingement during knee flexion. Patient at 24 months follow-up had a knee range of motion of 0–130° and Knee society score was 175 with final knee score of 95 and functional score of 80.

Discussion

Hoffa fracture is a rare fracture which usually results from high-energy trauma such as road traffic accident like in our case. According to some researchers [3], it is currently believed that when the knee is in ≥ 90° of flexion and emergency braking is performed while driving a car, an axial force in either a varus or valgus direction is transferred from the proximal femur to the femoral condyle. Due to the physiologic genu valgum, lateral condyle is injured before the medial condyle in cases of high-energy trauma involving distal femur. Thus, Lateral Hoffa is more common than medial Hoffa fracture [2].

It is accepted that Hoffa fracture requires surgical fixation since closed reduction using traction/casting is usually not achieved due to absence of soft tissue attachments. This also explains the frequent avascular necrosis and malunion in cases of neglected or conservatively managed Hoffa fracture [3].

For simple lateral condylar Hoffa fractures, a patellar anterolateral approach is most commonly used. This approach fully exposes the fracture and does not risk damaging the nerves and blood vessels, making the operation simple and safe [3]. However, a swashbuckler approach
can be used to treat Lateral Hoffa with patella fracture because more anterior position of the skin incision as compared to the classical lateral approach obviates the need of two incisions. It also protects the quadriceps femoris abdomen during surgery, allowing quick postoperative recovery of muscle strength and range of motion. The skin incision used will not interfere with subsequent total knee arthroplasty, if posttraumatic arthritis develops and arthroplasty is necessary [4].

In the literature, many authors have used two partially threaded cancellous screws for fixation of Hoffa fracture but according to the study by Sun et al. [2], two partially threaded screws along with a buttress plate is a more rigid construct and leads to better stability. Hoffa fracture is
Fig. 3  Postoperative radiograph. a AP view b Lateral view

Fig. 4  Anteroposterior radiograph of knee at final followup

Fig. 5  Lateral radiograph of knee at final followup
caused by shear stress between the femoral condyle and tibial plateau in a semi-flexed knee. According to the internal fixation principle, the antiglide plate should be fixed in the posterior position [4]. However, Sun et al. [2] reported that lateral antiglide plate has greater anti-shearing strength than posterior fixation. Moreover, more soft tissue dissection and stripping is required especially, the insertion of gastrocnemius heads for the placement of a posterior antiglide plate with screws, and this will eventually destroy the blood supply to the fragments leading to avascular necrosis. Thus, surgical treatment provides early functional rehabilitation and also decreases the chances of future posttraumatic osteoarthritis, as evident from the final result in our case.

Compliance with Ethical Standards

Conflict of Interest Each author certifies that he has no commercial associations (e.g., consultancies, stock ownership, equity interest, and patent/licensing arrangements) that might pose a conflict of interest in connection with the submitted article.

Ethical Board Review Statement Each author certifies that his institution has approved the reporting of this case report, that all investigations were conducted in conformity with ethical principles of research.

Informed consent Informed consent was obtained.
References


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CASE REPORT

3D Printed Acetabular Components for Complex Revision Arthroplasty

Angela Yao¹ · Daniel Mark George² · Vijai Ranawat³ · Chris John Wilson²

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Abstract
Recent studies have shown high early failure rates with Cup Cage constructs in complex revision surgery for Paprosky 3B acetabular defects. As a result, the use of 3D printed custom-made acetabular components has become more common. In this case series, we present two cases that demonstrate the latest advancement in 3D printed implants for severe acetabular bone loss. The follow up was 3 and 7 years. Neither patient has undergone revision surgery of the acetabular component to date. One patient sustained a femoral peri-prosthetic fracture requiring plate fixation. This case study demonstrates that 3D printed implants have excellent intraoperative and immediate postoperative outcomes in revision surgery for severe acetabular bone defects.

Keywords Acetabular implants · Acetabular defects · Revision surgery · Acetabular replacement

Introduction
Total hip arthroplasty is becoming more common with revision hip arthroplasty expected to nearly double in the next 10 years [1]. Severe acetabular defects are encountered in the revision setting with Paprosky type 3A or greater defects becoming more common with one center reporting that they now constitute 14% of their revision cases [2]. Custom acetabular implant technology has steadily been progressing since the late 70’s and now incorporates computer design and 3D printing of the acetabular implant through additive manufacturing technology [3]. Previously 3D printing was used only for the hemipelvis models or model implant and the final implant was machined from wrought titanium.

Materials and Methods
We present two cases of severe acetabular bone loss undergoing revision total hip arthroplasty with a completely digitally designed and 3D printed acetabular implant. Both cases gave informed consent and the local ethics and governance committees approved this report prior to publication.

Results
Case 1
A 56-year-old female presented with protrusio 1 year after a previously failed revision hip arthroplasty performed for loosening (Fig. 1). Patient demographics can be found in Table 1. This case was found to have severely deficient acetabular bone stock with pelvic discontinuity from a severely deficient posterior column and a fracture through the anterior column. This was reconstructed with a custom 3D printed acetabular implant.

Five years following this revision the stability of this acetabular construct was tested when she fell sustaining a Vancouver type B1 peri-prosthetic femur fracture. This required...
fixation with a peri-prosthetic plate and cables. There was no need to revise any of the hip prosthesis, proving the stability of her 3D printed acetabular implant (Fig. 2). At the most recent 7-year follow up she was mobilising independently with a frame.

**Case 2**

A 63-year-old female presented with 3 years of progressive pain associated with reduced function and mobility (Fig. 3). A custom 3D printed acetabular implant was used as the primary revision implant for this case (Figs. 4, 5). Intraoperatively, this case was found to have a Paprosky type 3B defect. The patient was discharged home on the second day following the operation, and was mobilising independently without gait aids, and exhibited no limp at her 12-week review. All premorbid activities were able to be performed prior to 12-month review, and she has returned to work and aerobics. There was good progression with full range of motion of the hip and no signs of loosening on X-ray at the 3-year review (Fig. 6).

**Table 1** Patient demographics

<table>
<thead>
<tr>
<th>Age at surgery</th>
<th>Operated side</th>
<th>Acetabular defect</th>
<th>Medical history</th>
<th>Duration from previous revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>56</td>
<td>Left</td>
<td>Paprosky type 3C Pelvic discontinuity</td>
<td>Rheumatoid arthritis Diabetes type 2 Hypertension Bilateral knee arthroplasty Bilateral hip arthroplasty</td>
</tr>
<tr>
<td>Case 2</td>
<td>60</td>
<td>Right</td>
<td>Paprosky type 3B</td>
<td>Diabetes type 2 Hypertension Hypothyroidism</td>
</tr>
</tbody>
</table>

Demographics of case reports
Revision hip arthroplasty is becoming more common and the incidence is expected to nearly double in the next 10 years [1]. Christie and colleagues found that Paprosky type 3A and 3B defects constituted 14% (78 hips) of the total hip arthroplasty revisions at their center over a 6-year period between 1992 and 1998 [2].

Severe acetabular defects have previously been treated with various approaches with poor results reported in the published literature. Pelvic discontinuity repaired with a plate fixation resulted in revision in 47% of cases, ranging between three weeks to 124 months postoperatively [4].
Acetabular Antiprotrusio cages were re-revised in 29–66% in other studies [5–7].

Cup-cage reconstruction is another method for managing severe acetabular bone loss and pelvic discontinuity. Implant survivorship from revision for any reason was 89% at the mid-term follow-up [8, 9]. Complications included hip dislocation, periprosthetic infection, and sciatic nerve irritation [8].

Fig. 4 Case 2: sterilisable 3D printed hemipelvis, resection guide, trial implant, custom implant

Fig. 5 Case 2: intraoperative trial then final implant
Porous tantalum augments demonstrated two of the 58 hips followed up required revision for aseptic loosening at the 5-year review. An additional six hips demonstrated radiographic evidence of progressive separation of the acetabular component from the bone in zone three. There was a significant improvement in function beyond the 5-year review as demonstrated by the Mayo hip scores [10].

In patients with large acetabular defects, the use of structural allografts with Tantalum coated Acetabular cups is another viable option. In one study it was noted that one out of 20 patients was found to have asymptomatic cup migration that did not require revision [11]. Another cohort had 59 hips in 58 patients requiring allografting combined with cementless cup undergoing revision for Paprosky II or III acetabular defects. In this group, two type IIIB and one type IIIA hip failed at four, seven, and nine years respectively for aseptic loosening and subsequently required revision [12].

The double-cup construct had no aseptic loosening and no revisions for acetabular loosening in a group of 20 cases with a mean follow up period of 2.4 years. Complications included hip dislocation in six cases with one case requiring revision, deep infection in four cases and delayed wound healing in three cases [13].

The first installment of 3D printing technology enabled 3D models of the hemi pelvis to be printed. These models were used to build a clay prototype which was then reverse engineered to produce a custom implant. The custom implant was machined from wrought titanium with the option of hydroxyapatite plasma-sprayed or porous coats added to the backing to stimulate osteointegration. Outcomes improved but were still less than ideal with failure rates ranging from 7.4–35% over 16 months to 7 years [2, 14–21].

The latest advancement in custom implants incorporates completely digital models which can be customised by the surgeon online without the need to review physical models. This allows the technology to be distributed more widely and reduces the design lead time. Previously there was an 8-week to 3-month delay from Computed Tomography (CT) to implant [14]. However our experience has been of a 3 to 4-week lead-time. Additionally, the entire acetabular implant including the porous backing is now printed using additive manufacturing technology fusing each layer of titanium using electron beam melting ensuring the strength of the implant. The model hemipelvis, with a model of the projected bone to be resected, along with a model implant for trialing are all 3D printed and sterilisable for intraoperative reference (Fig. 4).

There are currently minimal published reports demonstrating the outcomes of this latest advancement. A conference paper by Hooper in 2016 suggests promising results, with reduced revision rates after two years compared to previous custom implants. A similar study to this reviewing nine patients undergoing the same technique demonstrated an implant-associated survival rate of 88.8% with a mean follow up time of 28.8 months. In this study, the one patient who required revision had a bilateral pelvic discontinuity, which can be associated with higher failure rates [22]. In a 2018 retrospective study with a mean follow-up of 38-months, one of
the 36 patients had recurrent dislocations, one had revision for deep infection, one with early implant migration requiring stabilization, and two had radiological features concerning the failure of osteointegration. There were no recorded cases of aseptic loosening in the abovementioned cohort at the time of publishing [23].

With each advancement in technology, the price of the implant has been increasing with Joshi et al. in 2001 reporting the custom machined implants built from clay models costing $5000 USD, while Taunton et al. in 2012 reported a cost of $12,500 for computer designed implants machined from wrought titanium. The cost of this latest advancement in technology with the final implant created using 3D printing technology was $19,000 AUD at the time of writing.

In comparison, the cost of a double-cup construct without an additional augment is approximately $3451.10 USD and the cost of cup-cage construct with an additional augment is $5316.21 USD [13].

**Conclusion**

If the use of 3D printed custom acetabular implants for Paprosky type 3A or greater defects leads to a reduction in revision surgery then this would lead to a significant reduction in morbidity and mortality. The reduction of further revisions would lead to overall cost saving for our health service far outweighing the initial increase in cost.

Our preliminary findings confirm the excellent intraoperative and postoperative results for severely deficient acetabulum undergoing revision hip arthroplasty. Ongoing follow up of these new implants needs to continue to ensure the longevity of outcomes to ensure cost-effectiveness.

**Compliance with Ethical Standards**

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Ethical standard statement** This article does not contain any studies with human or animal subjects performed by the any of the authors.

**Patient declaration statement** The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

**References**


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To the editor:

Sir, we read with great interest the article published by Hwang KT et al. [1] which compared the outcomes of balloon kyphoplasty (KP) performed to treat osteoporotic vertebral compression fracture (OVCF) in rheumatoid arthritis (RA) patients with the outcomes in non-RA patients. It was an interesting and novel study in which the author suggested that the use of KP to treat OVCF in RA group exhibited similar outcomes to non-RA group in terms of pain reduction, vertebral height restoration, and kyphosis correction. However, RA group had significantly higher rate of complications involving adjacent segment fracture and recollapse. However, we have certain concerns regarding the methodology and results which need to be addressed before meaningful conclusions can be drawn from the study.

1. Association of OVCF with neurological deficit is rare, but, well documented in the literature. Gradual onset neurological deficit which necessitated the decompression of spinal cord and stabilization is also reported [2, 3]. In the present study, information about OVCF with neurological deficit is not available. Since this would have affected the functional outcome, it would be pertinent to know if patients with neurological deficit were included or excluded from study.

2. 5 (22%) patients were not receiving methotrexate in the RA group. It would be more informative to know the status of other disease modifying antirheumatic drugs as biological/targeted synthetic disease modifying anti-rheumatic drugs (b/tsDMARD) have protective effects on bone mineral density (BMD) whereas conventional synthetic DMARD (csDMARD) decrease the BMD [4].

3. Information about the medical management after kyphoplasty in RA group and non-RA group would have been informative. As in osteoporotic fractures, treatment with anti-osteoporotic therapy (teriparatide, bisphosphonates, calcitonin and raloxifen) reduces the incidence of adjacent vertebral fractures, recollapse and new vertebral fracture after kyphoplasty [5, 6]. If patients in either group received anti-osteoporotic therapy then comparison of complication rates would give erroneous results.

4. There appears to be typographical error in the result section, Table 1 (demographic data) and Table 4 (post-operative complications) which needs clarification.

A. According to the result section and Table 4—recollapse occurred in six patients (19.3%) in the RA group and in five patients (4.0%) in the non-RA group, whereas since

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recollapse was noted in six of 23 patients it should read as 26% in RA, 5 out of 107 patients as 4.67% in the non-RA group.

B. According to the result section and Table 4—adjacent segment fracture occurred in three patients (9.6%) in RA group and in six patients (4.8%) in the non-RA group, whereas since it was three of 23 patients (13.04%) in RA group and 6 out of 107 patients (5.60%) in the non-RA group.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent For this type of study informed consent is not required.

References


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LETTER TO THE EDITOR

Focused Amputee Clinics: The need of the hour

Mandeep Singh Dhillon¹ · Aman Hooda¹ · Uttam Chand Saini¹

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Amputations associated with road traffic accidents (RTA) are particularly devastating and life-changing; the ensuing functional disability and psychological trauma can often ruin the life of both the patient and his family [1]. Amputation surgery, despite often being the best that a surgeon can do under the circumstances, unfortunately embodies a failure of therapy in the minds of most patients [2]. The social stigma attached to the disability creates a negative impact on the psyche of the patients and their families, which could significantly affect both the physical and mental rehabilitation of the individual. Post amputation situations often lead to medical and social scenarios that are beyond the scope of treatment that an ordinary orthopedic surgeon can offer.

According to an old estimate, there were nearly 62 amputees in India per 1 lakh population which translates to almost 1 million individuals living with amputations in the country [3]. The indications for amputation vary across the studies; trauma (motor vehicle, railway track accidents, machinery injury, blasts etc.), complications of diabetes and peripheral vascular disease are some of the commonly reported indications. As compared with the developed world where atherosclerosis and peripheral vascular disease constitute the majority of cases of limb amputation, developing countries report trauma and diabetes to be the major causes. Important factors contributing to limb loss include the severity and complexity of trauma, lack of primary care, delay in proper management and often neglected injuries. Motor vehicle accidents (82%) followed by pedestrian injury were the most common cause of lower extremity vascular trauma as well as amputation noted at our center [4]. The impact of such an amputation is significant, as it comes without warning, and often happens in a young, active bread earner of the family; not only does it create a life-long disability, but also there is a need for constant rehabilitation, which often involves rejuvenation of self-esteem.

Limb amputation is no longer considered a pure orthopedic problem nowadays. The involvement of general surgeons, plastic surgeons, occupational therapists, orthotists and prosthetists along with psychiatrist are essential for post-operative rehabilitation, and the aim should be return to preinjury profession and activities. With advances in medical science and widespread availability of microvascular surgeries, plus modern prosthesis that allow much better function, a reasonably good quality of life can be expected even after a major amputation. One big issue that is often neglected is the prevalence of psychiatric disorders among traumatic amputees, which has been estimated to be 32–84%, and includes depression in 10–63%, anxiety in 25–57%, post-traumatic stress disorder in 3–56%, phantom-limb phenomenon in 14–92% [5]. This is a key component of rehabilitation, which an orthopedic surgeon cannot manage. Significant clinical and functional limitations may persist for long-duration (up to 2–3 decades) after amputation surgeries.

This kind of rehabilitation needs a multidisciplinary approach; a perfect example is US army personnel who re-join the army after traumatic amputations during the war, which was possible due to a combination of skilled primary surgery, appropriate physical and mental rehabilitation, and fitting of the high-end prosthesis, that allowed them to serve in the army as they did before amputations.

To the best of our knowledge, no such focused “Amputee clinics” are available in India, or for that matter in the underdeveloped world. Amputee clinics involve a multidisciplinary team approach, with trained surgeons carrying out amputations, and rehabilitation is done by trained Occupational therapists and psychological counsellors, who not only assess recovery and rehabilitation but also help both the patient and family to adjust to life in a better way. Developing such amputation clinics is a complex task but is the need...
of the hour in a country like India, with limited funding both for the clinics and for the amputee in need of rehabilitation. A positive step in this regard was taken at Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh, where we have recently started an ‘Amputee Clinic’: in this clinic, we assess the recovery and comorbidities of patients who undergo amputation, and we have a team of occupational therapists and a psychologist who become involved in patient care immediately. Further multidisciplinary management included prosthesis fitting and long-term care of prosthesis, along with stump care looked after by orthopaedic surgeons. Such clinics, we believe, can be instrumental in providing holistic care to the patients under one roof, which can be offered by most hospitals due to the availability of medical, surgical, psychiatric, physiotherapy and occupational therapy specialists; they just need to be formally clubbed together and given the responsibility at one particular venue, rather than the patient being referred to various different areas, which adds to his anxiety levels and stress. Many patients could potentially fall out of the rehabilitation process, which often has disastrous consequences. Additional benefits would be the development of a comprehensive database, which not only provides a platform for future research but also more significantly gives essential information about the burden, long-term complications and rehabilitation issues of these amputees. Amputee clinics also offer a forum for these patients where they can bring their problems and discuss with the team as dedicated time slots are provided to the patients. There is also the additional benefit of the patient to patient bonding, which shows these unfortunate victims that they are not alone, as they see other similar cases and relate to them, with a boost to recovery after seeing rehabilitated cases. Amputee clinics, therefore, are a major step in the rehabilitation of this significant proportion of our trauma victims, with potential links to vocational institutes and job opportunities, so that the quality of life can be improved in a personalized manner.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

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LETTER TO THE EDITOR

Early Experience with the Trochanteric Fixation Nail-Advanced (TFN-A): A Descriptive Review of Thirty-Four Cases from a Single Center

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Sirs,

We read with strong curiosity the article entitled, “Early Experience with the Trochanteric Fixation Nail-Advanced (TFN-A): A Descriptive Review of Thirty-Four Cases from a Single Center” [1]. The study describes the newly designed Trochanteric Fixation Nail-Advanced with some modifications, as a solution to the ever-increasing incidence of per-trochanteric and intertrochanteric fractures, particularly in elderly patients with poor bone quality by reducing complications and need for subsequent revision surgery. Failure of such fractures is a common problem encountered in orthopaedic practice and is a management challenge. Nevertheless, we have a few concerns which we would like to share.

• Article introduces TFN-A as a solution to pertrochanteric and intertrochanteric fractures, particularly in elderly patients with poor bone quality, but as we go through the article the fractures included in the study were representing a non-homogeneous group in terms of fracture pattern and age distribution [1]. Moreover, the authors have also included femoral shaft fractures. Hence, the results of the study cannot be generalized to elderly population with proximal femur fractures.

• Author has emphasized the small radius of curvature of TFN-A closely matches the native femoral bow and thus reduces anterior cortical impingement and blowout. Apparently, it seems that the article gives message that the improvement in nail design alone is responsible for reducing anterior cortical impingement, and the surgical technique (especially the entry point) has nothing to do with such complication.

• Furthermore, author emphasizes a smaller, specially contoured proximal portion of the TFN-A reduces lateral impingement and varus malreduction during nail insertion. However, the issues of lateral impingement and varus malreduction are not only related to nail design or geometry, but also to surgical technique (lateral anterior trochanteric entry point vs medial posterior trochanteric entry point) [2].

• Authors have experienced failure of the distal locking screws in two cases following union of fracture. However, literature describes breakage of locking screws as a process of “self-dynamization” or “auto-dynamization” of a statically locked nail, which may perhaps indicate progression of fracture healing [3]. As evident in Figs. 1 and 2 of the article, the nail was locked in static mode in both cases, thus preventing axial compression. Weight-bearing stresses lead to breakage of screws, subsequently allowing axial compression and eventually healing of fracture.

• Although authors have not experienced any implant failure with TFN-A in their study. However, Lambers et al. reported 16 cases of implant failure with TFN-A [4]. Seventy-five percent of the implant failures were associated with reverse oblique fracture pattern, and nail failed at proximal aperture in 94% cases. Moreover, the patients were having well-reduced fractures at the time of the index surgery with near-normal mean BMI, demonstrating some inherent fault in nail design responsible for failure. Lambers et al. hypothesized that implant breakage was attributable to the reduced cross-sectional area of TFN-A at the level of the proximal aperture compared with its predecessors. New design characteristics of TFN-A, along with abnormal stress concentration in specific type of fracture, may have affected the vulnerability of the nail and consequent failure. Hence, repercussions of nail design modification will unfold in future with more

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prospective comparative studies addressing the implant failure and revision rates.

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Compliance with Ethical Standards

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