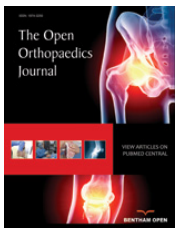

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REVIEW ARTICLE

Humeral Shaft Fractures: A Literature Review on Current Treatment Methods

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Abstract:

In this review, we aim to provide a concise yet comprehensive summation of the assessment and management of humeral shaft fractures. These are uncommon but prevalent enough that they are part of any trauma surgeon's scope of practice. They have historically been treated using non-operative methods, including braces and casts, supported by published excellent results in the rate of the bone union. However, recently published studies challenge these results and suggest the outcomes might be better with surgery, but the complications of an operation such as infection and nerve injury can not be overlooked. In summary, non-surgical treatment is still the gold standard in the treatment of these fractures, but the indications for surgical management are now clearer and include early signs of delayed union and patients who are unable to have a brace fitted or are uncompliant. It is likely that these new developments will start to change practice, and therefore the treatment of humeral shaft fractures should be a topic of interest of any clinician who deals with them.

Keywords: Humerus, Humeral shaft, Fracture, Humeras MIPO, Humeral diaphysis, Corpus hippocraticum, Intraoperative blood loss, Neurotmetic, Axonotmetic injury, Polytrauma.

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1. INTRODUCTION

Humeral shaft fractures may be defined as the disruption of the bony cortex along the diaphyseal aspect of the humerus. The earliest records of this injury come from around 1600 BC in ancient Egypt, with references in Greco-Roman texts such as Corpus Hippocraticum [1]. More recent twentieth-century literature demonstrates that this was a difficult fracture to treat, and in 1924 Campbell stated 'that delayed, and non-union occurred more often in fractures of the shaft of the humerus than in any other long bone', which was later corroborated in 1935 by Ghormley and Mroz of the Mayo Clinic who found a 65% non-union rate [2]. Caldwell, in 1933 recommended the use of what became known as the hanging cast as an ambulatory device, such that the weight of the limb distal to the fracture would provide traction and force to re-align the fragments [3]. Treatment of these fractures has since evolved significantly, appreciating both non-surgical and surgical management. In the years following Campbell, a multitude of non-surgical interventions was utilised, such as shoulder spicas, abduction splints, Velpeau bandages, and Thomas arm splints [4 - 6]. Surgical fixation by means of open reduction and internal fixation, intramedullary nailing, and minimally invasive plate osteosynthesis has subsequently gained recognition, which helps achieve fracture healing and early mobilisation of adjacent joints [7]. There is a bimodal distribution of injury which peaks in the third and seventh decades, with high energy mechanisms for younger populations and low energy mechanisms for the elderly [8 - 10]. Age-specific incidence was 13.4- 14.5 per 100 000 per year, gradually increasing to nearly 90 per 100,000 in the ninth decade [11, 12]. Within the context of humerus fractures, shaft injuries account for 13%, with proximal humerus injuries being most common at 79% [12].

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2. DIAGNOSIS/ RADIOLOGICAL EVALUATION

Humeral shaft fractures are usually the result of falls from height and, for the most part isolated injuries [13]. They can also occur as result of road traffic collisions or other high energy mechanisms, so a comprehensive clinical history is required and with high index of suspicion for associated injuries, which may be identified through systematic assessment.

People sustaining a humeral shaft fracture will generally present with significant discomfort in the affected arm, and

they tend to support it with the contralateral upper limb. Instability and crepitus at the fracture site are often clinically apparent on examination.

These fractures carry a significant risk of neurovascular injuries, and thus they require a careful examination of the structures distal to the fracture, in particular, the motor and sensory distributions of the radial nerve and the radial arterial pulse. The examination needs to be repeated after every intervention and manipulation [7, 13, 14].

3. IMAGING

Simple Anteroposterior (AP) and lateral radiographs of the humerus are used to diagnose humeral shaft fractures [7]. If unable to position the arm for the lateral radiograph, a transthoracic lateral can be used. The shoulder and elbow should be included in the images to avoid missing adjacent injuries. If a dislocation of the shoulder is suspected clinically or radiologically, axial or Velpeau views of the shoulder are indicated [7]. There is little role for other imaging methods unless a brachial artery injury is suspected. An angiogram or CT angiogram would then be useful to clarify the diagnosis and localise the injury to the vessel [7].

4. NON-OPERATIVE

Non-operative treatment is the gold standard in the management of uncomplicated humeral shaft fractures, and it can be done effectively with a plaster cast or commercially available cylindrical braces [15 - 17]. True immobilisation is not achievable since the shoulder is a very mobile joint. However, both “hanging U-slabs” made plaster of Paris and commercial braces create enough stability and allow controlled micromotion, which promotes osteogenesis by secondary bone healing [15 - 17].

The two methods can be used as definitive treatment but used in combination; the U-slab helps reduce the fracture for the first week to two weeks and can then be changed to a brace that allows elbow motion, which is very important for functional recovery. Full treatment in the cast might have the advantage of a quicker time to bone union [18].

Patients should be reviewed every week, especially if using a cylindrical brace, to ensure the skin is not macerated and allow removal of the brace in a controlled environment for hygiene [7, 13, 19, 20].

Very good outcomes are generally reported with non-operative treatment, especially in uncomplicated, isolated fractures. Varus angulation might be a common outcome but with few functional sequelae [7, 21].

A historical paper from Sarmiento *et al*. reported good functional results with conservative treatment of distal humeral shaft fractures in a brace, despite including patients with open fractures and peripheral nerve injuries. They have reported an average 9 degrees of varus angulation post union, but without functional implications [22].

On the other hand, several studies found high rates of non-union with conservative management, such as the HUMMER trial, which suggests surgical intervention should be offered if the union is not achieved at 6 months [23 - 25].

Westrick also reached the same conclusions in a paper from 2017, which reports significantly higher rates of non-union in patients treated conservatively, even when the surgical group had more significant injuries and higher energy mechanisms of injury. However, it also reports 2 cases of iatrogenic radial nerve injury and 3,5% infection in the operative group [20].

Very recently, Serrano *et al*. published the results of a large multicentre study and showed the rate of non-union to be 29% in 9 trauma centres in the United States. These results contradict very with the results shown by Sarmiento directly [26].

Rämö *et al.* have an ongoing RCT with large numbers comparing results and cost-effectiveness of surgical *versus* conservative management of humeral shaft fractures. Their results might help bring more clarity to the discussion [27].

5. SURGICAL MANAGEMENT

Surgical intervention should aim to achieve stability and restoration of length, axis, and rotation, which will allow for the early mobilisation of the nearby joints [7]. The use of surgical techniques in the fixation of diaphyseal humeral fractures has increased in the last few years [7]. Indications for fixation include polytrauma patients with multiple fractures, floating elbow, periprosthetic fracture, pathological fracture, open fracture, neurovascular injury, compartment syndrome, failed conservative treatment, patient preference, and obesity [7, 28]. The surgical techniques include open reduction and internal fixation (ORIF) using plates, minimally invasive plate osteosynthesis (MIPO), intramedullary nailing (IM nail), and external fixation (Ex-Fix) [7].

Harkin *et al*., in a study of 30 out of 126 humeral shaft fractures treated operatively, found the operative treatment to have a low rate of non-union when compared to conservative treatment, respectively, 4% and 33%. Furthermore, it was recommended that patients with a significant history of psychiatric conditions would benefit from an operative intervention [29]. As mentioned, Westrick *et al*. also showed in their study that the non-union rate in the operative group was significantly lower with a rate of 10.2% compared to 23.2% in the conservative group [20] (Table **1**).

Table 1. Muscular anatomy of the arm.

Anterior Compartment of Arm				
Muscle	**Innervation**	**Action**	**Origin**	**Insertion**
Coracobrachialis	Musculocutaneous Nerve (C6 - C7)	Flexion, adduction, internal rotation of arm	Coracoid Process of scapula	Middle third and medical side of humerus

(Table 1) contd.....

Anterior Compartment of Arm				
Muscle	**Innervation**	**Action**	**Origin**	**Insertion**
Brachialis	Musculocutaneous Nerve (C5-6) Radial Nerve (C7)	Flexion of the elbow joint	Anterior surface distal half of the humerus and intermuscular septum	Ulna- coronoid process
Biceps Brachii Long head Short Head	Musculocutaneous Nerve (C5-6)	Shoulder - flexion, abduction, Elbow- flexion Radioulnar- supination	Long - supraglenoid tubercule of the scapula Short - coracoid process of the the scapula	Radius- tuberosity
Posterior Compartment of Arm				
Muscle	**Innervation**	**Action**	**Origin**	**Insertion**
Anconeus	Radial Nerve (C6-8)	Extension of the elbow	Lateral epicondyle Humerus	Ulnar- olecranon- lateral aspect
Triceps brachii Lateral Head Long Head Medial Head	Radial Nerve (C6-8)	Extension of elbow Shoulder- adduction and extension	Lateral - posterolateral humerus& lateral intermuscular septum Long - infraglenoid tubercle of the scapula Medial - posteromedial surface of the distal half of the humerus	Olecranon process

5.1. Open Reduction and Internal Fixation (ORIF)

Plate fixation following ORIF is considered to be the gold standard when it comes to surgical treatment of diaphyseal humeral fractures [28]. The fracture can be visualised using different approaches, and a plate with screws is used. Advantages include direct visualisation of the fracture site and a high probability of anatomic reduction, with absolute stability and direct bone healing. Disadvantages include extensive dissection, iatrogenic injuries, infection, and the possibility of further operation. Van de Wall *et al*. demonstrated a low complication rate in a study of 102 patients treated with plate fixation [28].

There are several options for the surgical approach, and the choice is dependent on surgeon preference, patient factors, radial nerve, and vascular integrity [7, 30]. The anterolateral approach is common, especially in more proximal fractures. The radial nerve is identified and protected through the entire length of the incision. In the medial approach, the nerve is avoided, and the brachial artery identified, which can be helpful in cases with concomitant vascular injuries [7]. Lastly, in the posterior approach, variations exist in terms of triceps splitting or sparing. The radial nerve will be in close proximity, and careful dissection is required [7, 31]. Iatrogenic radial nerve palsy occurs at similar rates irrespective of which approach is used [30]. In a single-surgeon case series of 66 cases, the posterior triceps-sparing approach showed a high union rate and low incidence of radial nerve palsy (3%) [31].

A biomechanical study comparing ten-hole locking compression plates in sawbones was conducted to identify mechanical properties of anteromedial, anterolateral, and posterior fixations. The anteromedial plating was superior to the rest in all mechanical tests, except four-point bending. Although this study favours anteromedial fixation, an anteromedial approach is not recommended in patients presenting with concurrent radial nerve palsy [32].

5.2. Intramedullary Nailing (IM Nail)

Intramedullary nailing (IM nail) for diaphyseal humeral fractures gained popularity due to the minimal dissection needed and the preservation of the fracture haematoma, utilising relative stability and indirect healing. The disadvantages of IM nails are a higher rate of shoulder pain and re-operation [20], as well as an increased risk of rotational malignment.

Anterograde IM nails have an entry point at the greater tuberosity or apex of the humeral head, whereas retrograde IM nails have their entry point at the midline posterior triceps-splitting area. The retrograde approach is not as popular due to the specific risk of distal humerus fracture on insertion or extraction of this type of nail [7].

IM nailing is associated with iatrogenic rotator cuff injury, which can lead to shoulder pain and stiffness. As the IM nail design and technique evolves, the above symptoms have become less prominent [33, 34]. In particular, an entry point slightly lateral to the humeral shaft axis is recommended [34].

Fan *et al*., in a study comparing ORIF and IM nail in 60 patients, demonstrated that IM nailing had a lower intraoperative blood loss, decreased operative time, decreased hospital stay, and less incidence of serious complications, whereas union rates and functional outcomes were similar in both groups [35].

5.3. Minimally Invasive Plate Osteosynthesis (MIPO)

The MIPO technique is a relatively novel concept in which the aim is to achieve relative stability and indirect bone healing. The plate is placed anteriorly to reduce the risk of iatrogenic radial nerve injury in bridging mode using a minimal surgical approach. Benefits include minimal dissection, a decrease in conventional plating complications, and avoiding any shoulder complications that can arise when an intramedullary nail is used [36]. Although the MIPO technique is quite promising, the fact that a direct reduction of the fracture is not achieved leads to a possible rotational difference between the two sides. In a small study, this has been shown to be of little clinical significance, as patients have been found to have good or excellent functional results [37].

5.4. External Fixation (Ex-Fix)

The use of the external fixation (Ex-Fix) technique is quite limited. It is usually a temporising option in the poly traumatised patients requiring stability with minimal systemic insult and when the soft tissues do not allow internal fixation, but they can also be used in severely comminuted fractures, open fractures, or infection cases. Bicortical pins are inserted at the lateral aspect of the humerus, taking care to avoid a neurovascular injury on insertion. Rods are used to connect the pins with each other. Particular care should be taken to achieve length and avoid mal-rotation. The average time to union with an Ex-Fix is fourteen weeks [7, 20].

6. COMPLICATIONS

6.1. Nerve Palsy

The most common complication of humeral shaft fractures is radial nerve palsy [38]. A primary palsy is caused by the initial injury whilst a secondary palsy can be caused by fracture callus or scar tissue compromising the nerve during conservative treatment. In iatrogenic injury, iatrogenic secondary palsies can be a result of closed management with or without fracture manipulation or surgical intervention [39].

This manifests as paraesthesia of the dorsum of the hand with weakness of thumb abduction, finger and thumb extension at the MCPJs, and dorsiflexion of the wrist [7]. The absence of brachioradialis or extensor carpi radialis longus could also help identify a more proximal lesion. About 50-68% are reported to present as complete palsies [40 - 42]. Chang and Ilyas recommend that radial nerve palsies with humerus fractures can be classified as type 1 neuropraxia, type 2 incarcerated, type 3 partial transection, and type 4 complete transaction [43].

The incidence of primary radial nerve palsy with closed humeral shaft fractures ranges from 2% to 19% [30, 41, 42, 44 - 48]. Two literature reviews on the subject suggest the average incidence is 11.8% or 16.3% [49, 50].

Both primary and secondary radial nerve palsies are associated with fractures of the middle third or at the junction of the middle and distal third [7, 30]. A cadaveric study identified that the radial nerve was at risk in the posterior midshaft region at the distal aspect of the deltoid tuberosity and the lateral distal third of the humerus around 11cm proximal to the lateral epicondyle [51]. There are reports suggesting a higher incidence in either region, with another finding equal incidence [41, 42, 52].

Operative iatrogenic injuries are common complications ranging from 0 to 43% and are more common following plate fixation (2-18%) than intramedullary nailing (0-5%). The surgical approach does not seem to significantly impact the incidence [30, 31, 35, 53 - 68].

Rarely, ulnar and median nerves can also be injured. These typically occur in open fractures with significant soft tissue injury. Stahl *et al*. reported a case of a closed humeral shaft fracture managed with intramedullary nailing where the ulnar nerve was found to be transected on subsequent exploration. It is unknown whether this was a primary or secondary injury, as no pre-operative neurological deficit was documented [69]. Streufert *et al*. noted iatrogenic ulnar palsy in 1.2% when plating [30].

1.6-3% of cases can be associated with a partial or total plexus injury. As such, a thorough neurology exam is crucial. The presence of a combined axillary and radial nerve palsy would suggest damage to the posterior fascicle of the brachial plexus [7].

Thankfully recovery rates are quite good. Primary palsies have a spontaneous recovery rate of 70.7%, increasing to 88.1% following delayed exploration [49]. Streufert *et al*. reported similar findings (74%) [30].

Primary palsies that do not recover are likely to have been associated with more significant energy trauma. As a result, more primary palsy patients go on to require tendon transfers or wrist fusion (22% *vs*. 0%) [30].

Palsies of iatrogenic nature are usually temporary and resolve spontaneously in 70-100% of cases with a shorter recovery period than primary palsies (4.1 *vs*. 5.5 months) [30, 31, 42, 44, 54 - 65, 68, 70 - 76]. However, if the palsy is caused by local soft tissue compression, it might not improve and require surgical exploration.

There is a clear consensus that fractures requiring fixation (open fractures, associated vascular injuries, and fracture configurations not amenable to non-operative management) with concomitant radial nerve palsies should have early exploration of the nerve. However, the management of nerve palsy in the remainder of the injured is somewhat contentious.

Traditional teaching dictates that primary palsies should be managed expectantly and only explored if there is no evidence of recovery by 2-3 months [48, 76, 77]. Given most patients recover spontaneously, this would avoid risks associated with surgery. Furthermore, patients managed with early exploration compared to observation have been shown to have no difference in outcomes [43, 49, 78].

Recent studies have, however, made arguments to the contrary, as follows:

- Late exploration prolongs disability, rehabilitation and could compromise nerve recovery, particularly if delayed by 12 months and possibly from as early as 5 months [40, 43, 48, 79].
- A significant number of primary palsies do not recover spontaneously (approximately 30%) [49].
- Early exploration allows characterisation and classification of the injury to guide treatment, inform prognosis, and provide peace of mind [43].
- Fracture stabilisation can prevent late nerve injury or incarceration. Furthermore, a repaired nerve will benefit from a better healing environment (less traction, motion, or callus formation to impede nerve regeneration) [43].
- Delayed repair can lead to increased muscular atrophy and motor endplate loss compromising recovery and thus a significant interval loss of patient function and livelihood [43].
    - Early surgical repair is technically safer and

easier due to the lack of scarring, nerve retraction & risk of nerve entrapment in the callus. Furthermore, fixation would facilitate primary bone healing and decrease the chances of nerve entrapment or compression in the callus [43].

- Yesil *et al*. describe a case where the sharp tip of the fracture had penetrated into the nerve dividing the nerve into two bands which would have been unlikely to recover with conservative management and could have been damaged further in case of fracture site movement or encasement in callus [80]. Another case required sharp dissection of the nerve at the bone for repair due to callus encasement [81].

Electrodiagnostic studies can be used to monitor recovery after 3 weeks and repeated after 8 weeks if no clinical improvement [40, 82]. Ongoing work suggests diffusion-tensor MRI could distinguish between neurotmetic and axonotmetic injury [83, 84].

With regard to secondary palsies, recent studies have demonstrated that they can be managed similarly to primary palsies [30, 39, 49, 68].

6.2. Delayed/Non-Union

Closed humeral fractures were always believed to have a high union rate. Multiple studies have reported >90% non-operative union rates [15 - 17, 21, 22, 29, 38, 85]. Recently, however, some studies have reported higher non-union rates of 13-23% [18, 20, 24, 86], and a large multicentre study published in 2020 showed an even higher rate of 29% in North American hospitals [26] as previously discussed.

Aside from the common systemic factors associated with non-unions (*e.g*., advanced age, smoking, alcoholism, and nonsteroidal anti-inflammatories), psychiatric pathology (psychotic/bipolar disorder, dementia, or multiple involuntary psychiatric admissions), long oblique and spiral fracture patterns, as well as, proximal-third fractures and distal-third fractures are also associated with non-union when managed conservatively [25, 29, 87].

The reported incidence of post-operative non-union ranges from 2-10%, with no difference between IM nailing and plating [20, 29, 35, 53, 65, 66, 88].

An interesting score called RUSHU (Radiographic Union Score for Humeral fractures) aims to predict fractures that will not unite by evaluating the characteristics of a radiograph 6 weeks after the injury. This is pending external validation but might be a very useful tool in the future [89].

6.3. Mal Union

The humerus is quite forgiving when it comes to deformities; up to 20° anterior angulation or 30° varus angulation are generally well tolerated [19, 80]. With regards to rotation, a study found that an average difference of 6° internal rotation and 9° external rotation resulted in no significant difference in functional scores [37].

6.4. Infection

It is a fact of life for any surgical treatment, but especially plate fixation. Infection rates range from 2-4% [53, 65, 66]. Pidhorz *et al*. broke these down by fixation methods and reported an average of 4% for plating, 1.6% for IM nails, and 4% for external fixation [7]. In contrast infection is rarely a problem in non-operative management (0%) [20].

6.5. Vascular Injury

Vascular injuries are rare (0.5-3%) and are mainly due to brachial artery rupture. These require urgent support from the vascular surgeons since a provisional shunt might be required, which allows the fracture to be stabilised before any blood vessels can be definitively repaired [7].

6.6. Shoulder Problems

Antegrade nailing is associated with shoulder pain and a worse range of motion [54]. 56% experienced pain at the shoulder or fracture site, and 41% had poor shoulder function [73]. Shoulder function impairment can result from a violation of the rotator cuff, tendon injury, impingement (17%), and adhesive capsulitis [35, 54, 90]. In a cadaveric study, Schwarz *et al*. found an incidence of iatrogenic infraspinatus tendon injury in 17.5% [34].

Muccioli *et al*. found the incidence of supraspinatus tendon lesions to be 12.5% in his study of 40 antegrade humeral nails, with 2 attributed to the high nail positioning. All, however, were asymptomatic. Supraspinatus tendon lesions are likely to be of little significance given the prevalence in asymptomatic healthy individuals was 16% in ultrasound studies. The long head of biceps tendinopathy, however, was symptomatic and half of which were attributed to a technical error in placement of the locking screws [33].

CONCLUSION

Fractures of the humeral diaphysis are common in clinical trauma practice and are mostly seen in the middle third of the shaft. They have a bimodal distribution, affecting the young and active and the elderly and frail. A fairly common complication of this injury is radial nerve palsy, but fortunately, it tends to resolve by itself. However, it requires monitoring since some secondary injuries will require exploration.

Historically, these fractures have been treated non-operatively with reportedly excellent results. Surgical management was reserved for cases with open fractures, arterial injury, unacceptable displacement, and polytrauma.

There is a new school of thought and provoking papers showing conservative management has a much higher risk of non-union compared to surgery, with a quicker time to union and functional recovery.

In some centres, new indications for surgery have emerged, such as in patients with psychiatric issues or those who will not cooperate with casting or bracing, and obese patients for whom bracing is impossible and casting is subject to displacement.

Some surgeons prefer to investigate all radial nerve palsies to ensure there is no nerve entrapment.

It is still fair to say that non-operative management is the gold standard that provides most patients with excellent functional results. Nevertheless, there is a role for conversion to surgical management in the case of the delayed union since the risks of surgery are outweighed by the benefits of a quicker recovery. Multiple clinic appointments for brace changes and radiographs can be cumbersome for the patients, and therefore some might be keen on a more acute surgical intervention.

There are ongoing studies about the outcomes and cost-effectiveness of surgical *versus* non-surgical treatment of humeral shaft fractures, and thus, orthopaedic surgeons should keep their minds open to new treatment modalities and surgical techniques since it is likely that the mentioned developments will change the way we view these fractures.

AUTHORS' CONTRIBUTION

Ahmed Daoub is responsible for biomechanics, anatomy, and classification sections.

Pedro Ferreira is responsible for diagnosis, non-operative management, and conclusion sections.

Matthew Walker is responsible for reference management, proofreading.

Introduction and Anatomy sections were written by Srinivas Cheruvu.

Sections on Post-operative Management and Complications were written by William Gibson

Surgical Management section was written by Giorgios Orfanos

Rohit Singh is responsible for providing senior guidance, supervision, and proofreading services

CONSENT FOR PUBLICATION

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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