JSES Reviews, Reports, and Techniques 4 (2024) 615–624

Contents lists available at ScienceDirect

JSES Reviews, Reports, and Techniques

journal homepage: www.jsesreviewsreportstech.org

Intramedullary versus locking plate fixation for proximal humerus fractures: indications and technical considerations

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ARTICLE INFO

Keywords:
Proximal humerus
Fracture
Intramedullary nailing
Plating
Outcomes
Indications

Level of evidence: Level V; Literature Review/ Expert Opinion

Background: The incidence of proximal humerus fractures (PHFs) continues to increase with an aging population, and intramedullary nailing (IMN) and locking plate fixation are two commonly employed techniques for the surgical management of PHF. However, the optimal fixation method can be a source of ongoing controversy. Some influencing factors include the extent of humeral head involvement, fracture complexity, patient age, and surgeon preference. There are many studies that provide a mix of data either when comparing the two techniques or analyzing them in isolation. The aim of this review is to further elucidate the indications and technical considerations involved specifically in IMN vs. locking plate fixation for PHF to further aid orthopedic surgeons when choosing surgical management.

Methods: A narrative approach was chosen for this review allowing for a comprehensive review of literature, including recent findings pertaining to the comparison of management options for PHF. A comprehensive literature search was conducted using the PubMed, Embase, and Cochrane Library databases. The inclusion criteria involved studies that discussed "proximal humerus fracture" and either "intramedullary nail" or "locking plate fixation."

Results: Complications such as avascular necrosis, hardware failure, additional surgical interventions, infection, fracture redisplacement, rotator cuff rupture, and nonunion did not show significant differences between the two groups. Newer generation humeral nails have minimized early complications. As both techniques undergo further refinement and utilization when specifically indicated, functional outcomes, potential complications, and postoperative pain continue to be improved.

Conclusion: The available evidence suggests that both intramedullary nails and locking plates can effectively restore shoulder function in the treatment of displaced proximal humeral fractures, with unclear superiority of either method. The choice of technique should be tailored to patient factors such as fracture type, age, bone quality, and functional expectations. Surgeon experience also plays a role. While certain presentations may exhibit trends that favor one fixation, no specific technique can be universally recommended. Both IMN and LP have shown comparable and satisfactory outcomes, and the final fixation method chosen should take into account the unique characteristics of each patient.

Upper extremity fractures are common with an annual incidence of 67.6 fractures per 10,000 persons.[41] Proximal humerus fractures (PHFs) make up the majority of these fractures. These occur at a rate of 6.0 per 10,000 people.[41] Additional studies have found that incidence rates of PHF are increasing exponentially in older age groups, with an expected 50% increase in future emergency department visits due to these fractures.[42] About 87% of PHF are caused by low-energy trauma, as these are osteoporotic, fragility fractures. Osteoporosis further complicates surgical management of these injuries.[10] Nonoperative management is pursued in approximately 85% of cases.[68] Classification systems such as Neer and Association of Osteosynthesis classification have been developed and can be used to evaluate the fracture. However, studies have shown poor reliability for these classification systems even with 3-dimensional computed tomography enhancement.[29]

Institutional review board approval was not required for this literature review.

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https://doi.org/10.1016/j.xrrt.2024.01.001

Although these classification systems may not be entirely reliable, they may have some prognostic significance, as three- and four-part fractures are associated with more complications and worse outcomes compared to less complex fracture patterns.[5]

There is no consensus as to when surgical management should be pursued. Current surgical indications are largely a combination of surgeon preference and patient factors. However, relative indications for surgery include when displacement of the greater tuberosity is more than 5 mm superiorly (to reduce the risk of subacromial impingement), when there is a displacement of two articular pieces relative to one another of greater than 2 mm, if there is greater than 100% displacement of the surgical neck, if there is substantial varus or valgus angulation of the head, or if the head is no longer engaged within the glenoid fossa.[5,12] Additionally, surgery can be considered if either the lesser or greater tuberosities are sufficiently displaced medially to either cause impingement with rotation or reduce cuff efficiency.[40]

Even when surgical management is selected, there is some continued controversy as to which surgical method to pursue.[6,49] Options include closed reduction and percutaneous pinning, hemiarthroplasty, intramedullary nailing (IMN), open reduction internal fixation, and reverse total shoulder arthroplasty, with the latter becoming more popular with time.[21,68] Reasons for choosing one surgical method over another include humeral head involvement, fracture complexity, patient age, and surgeon preference.[5,32,90] Intramedullary nail and locking plate fixation (LPF) are common techniques with good outcomes.[13,59,89] Metanalysis and comparison studies have mixed results with most studies showing no significant difference in function scores and complication rates between the two.[8,30,51] The aim of this review is to further elucidate the indications and technical considerations involved specifically in intramedullary vs. LPF for PHFs to further aid orthopedists when choosing surgical management.

Intramedullary nailing indications

While nonoperative treatment is common for PHFs, there are several indications that normally necessitate surgical intervention. These presentations include three- or four-part fractures, open fractures, pathologic fractures, displacement between the humeral shaft and humeral head, and fractures with severely displaced tuberosities, particularly the greater tuberosity.[37,57,61,84] IMN may be recommended in cases involving pathologic fractures, surgical neck fractures, or combined proximal humerus and humeral shaft fractures. Nevertheless, there remains a lack of consensus regarding fracture presentations that unequivocally advocate for its preference over plate fixation.[50]

Locking plate indications

Fixed-angle locking plate technology has expanded indications for plate osteosynthesis of PHFs, particularly with osteoporotic bone, articular fractures, and increasing fracture complexity.[40,65] Indications for plate fixation include displaced two-part fractures, three- and four-part fractures with tuberosity displacement, physiologically younger patients (ie, <65 years old) with higher energy injuries, fracture dislocations, or high activity levels.[40,65,70] Additionally, to attain the best possible fracture reduction and mitigate the risk of postreduction complications, such as varus collapse or fixation failure, it is recommended to consider LPF as the surgical intervention in cases where the medial calcar remains non-comminuted and displays favorable bone quality.[40,65]

Intramedullary nailing technical considerations

Evolution of intramedullary nailing

Prior to the adoption of IMN as a treatment option for PHFs, considerable endeavors were undertaken to devise nails capable of significantly bolstering stability in reduced fractures. The overarching goal was to enable earlier recovery and enhance long-term outcomes for patients facing these fractures. Even though there has been no evidence that one technique is better than the other, plate fixation has been the more traditionally used method for operative fixation of PHFs.[17,45,80,88] However, LPF is associated with a spectrum of potential risk factors, including surgeon factors such as screw cutout and suboptimal anatomic reduction, and patient factors such as poor bone quality and medial calcar support. The interplay of these diverse factors contributes to the inherently high overall complication rates and subsequent revision procedures often associated with LPF.[9,39,46,79,82] Some additional risks of plate fixation include the need for an open approach, with the subsequent surgical dissection increasing the risk of iatrogenic damage to the surrounding anatomy.[25] As a result, IMN evolved into a key alternative technique for the fixation of PHFs.

Martinez-Catalan et al detailed that the initial generation of humeral nails which involved straight nails with a large diameter. These nails did not feature locking screws and thus provided poor rotational control. This made it difficult to stabilize unstable fracture patterns.[57] The second-generation nails aimed to overcome this issue by incorporating proximal interlocking screws. However, the poor security of these screws posed a significant challenge, as they were prone to loosening and ultimate fixation failure. Additionally, the entry site for these nails resulted in iatrogenic supraspinatus tears. Revision surgeries for hardware removal were common, as screw back-out was common.[16] This was further elucidated by a Nolan et al study that demonstrated a 94% healing rate but a malunion rate was 50% of second-generation nails. It was concluded that the nail's curved design forced it to enter the humeral head more laterally, where the subchondral bone is less dense. This positioning caused damage to the rotator cuff and made the nail inadequate in preventing loss of reduction and varus collapse.[64] To address this problem and enhance the stability of humeral nails, third-generation nails were developed. These newer nails implemented improved locking methods for proximal screw fixation, leading to the creation of fixed angle stable structures. Numerous studies have shown the current intramedullary nails having the advantages of increased stiffness for valgus/varus, extension/flexion, and torsional strain, and preservation of soft tissue and periosteal blood supply at the fracture site.[4,22]

Although there are many benefits of IMN, the efficacy of IMN may differ based on the indication. It has been suggested that complex fractures, especially three- and four-part fractures or those with severe displacement (>5 mm) of the tuberosity, may not be optimally treated by an IMN.[38,50] Rather it has been stated that intramedullary locking nails are best applicable for two-part fractures or three- and four-part fractures with metaphyseal or diaphyseal involvement and no significant displacement of the tuberosities.[56] Over the past decade, this traditional perspective regarding a limited list of indications has been called into question, as several studies have reported favorable outcomes for 3- and 4-part fractures. These studies have demonstrated satisfactory results, with low complication and nonunion rates, good patient-reported outcomes, and positive functional results such as postoperative range of motion and strength.[8,43,75] Overall, with improved implant design for intramedullary devices, added biomechanical benefits, increasing literature showcasing good results in more complex fracture presentation, and increasing

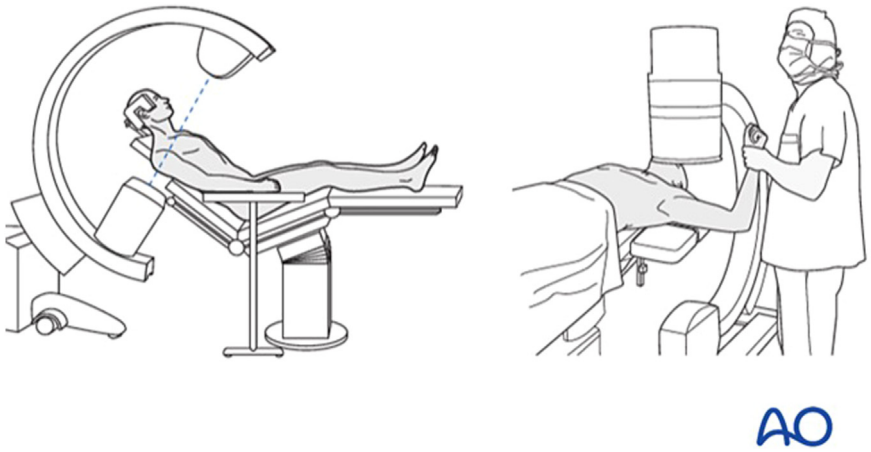

Figure 1 Recommended imaging procedure with the patient in a standard beach chair position. Source: AO Surgery Reference, surgeryreference.aofoundation.org.

surgeon experience with these techniques in these pathologies, humeral IMN has emerged as a good alternative to plating.[48]

Nail biomechanics

Even though IMNs have a shorter torque and superior biomechanical stability to prevent varus collapse and produce overall good outcomes, certain physical characteristics of the nail must always be considered. The diameter of the nail must be carefully selected to ensure a secure fit within the medullary canal. An oversized nail may cause damage to the cortical bone, lead to suboptimal fixation, and cause rotator cuff injury, while an undersized nail may result in rotational instability. Moreover, a larger diameter proximal nail diameter may be an additional risk factor for an iatrogenic fracture of the greater tuberosity through the entry point.[52] Another key consideration is the curvature of the nail being implanted, because the incidence of iatrogenic fracture through the entry point is largely associated with bent nails.[1,27,63,69] However, with the evolution of third-generation nails, the aforementioned complications are no longer as frequently reported in the literature, with more reports displaying evidence of safe and effective usage of IMN.

Patient positioning and imaging

In regard to patient setup, individual preferences drive much of the variability seen across orthopedic surgeons. The C-arm imagers can be positioned from the opposite side of the table, or the patient can sit in a beach chair while the C-arm approaches from the top of the bed or the other side of the table. This enables true anteroposterior imaging for coronal alignment and medial-lateral nail position.[16] Some surgeons have also described their preferred patient position to be semi-recumbent, with the head of the bed raised between 20 and 40 degrees (Fig. 1).

Radiographs can be challenging to obtain during IMN procedures. Sears et al have commonly detailed obtaining images as follows, “The first is a Grashey view taken with the C-arm tilted horizontally to match the semi-recumbent orientation of the patient and orbiting the machine 30-45 degrees to obtain a perpendicular view of the glenoid face. With this image, if the arm is positioned in neutral rotation (gunslinger position), it will reproduce the standard anterior-posterior view of the humeral head familiar to most surgeons. The second radiograph is a Y-lateral view in which the C-arm is orbited the other way over the patient to approximately 30-45 degrees. This view allows for interpretation of the position of the tuberosities.”[74,75] If desired, a surgeon could additionally obtain axillary views of the shoulder to evaluate flexion-extension at the fracture site, in particular the lesser tuberosity and any potential involvement (Figs. 2 and 3).

Entry site

There are multiple entry sites that can be utilized for humeral nailing. Essentially all are through the rotator cuff muscle or tendon. The traditional approach was through the tendon—in this approach the supraspinatus tendon is divided laterally in the traditional approach to the shoulder when an IMN is placed. This approach has been found to be associated with possible aggravation or exacerbation of rotator cuff pathology.[16] Unless in the case of a valgus fracture, laterally inserted nails have been correlated with higher rates of varus malalignment, iatrogenic greater tuberosity fractures, and loss of fixation.[52,54,60,64] To mitigate the increased incidence of shoulder pain following antegrade intramedullary humeral nailing, which is thought to be caused by rotator cuff injury, various entry sites have been suggested. More medial starting points can be used to avoid the rotator cuff tendon insertion, with the nail entering either through the rotator cuff muscle or through the rotator interval.[15,67,84] Alternatively, the lateral articular border of the humeral head can also be used as a point of entry. With this point of entry, the supraspinatus muscle is more likely to be injured than the supraspinatus tendon with this more medial starting point. Neviaser's portal can also provide a reliable entryway to better access the more medial entry point without harming the tendon[15,44] (Figs. 4 and 5).

Fracture reduction

Avoiding varus positioning or distracting the fracture are two important tips when attempting fracture reduction with IMN. Regardless of the techniques employed, an ideal guide pin starting point should also be confirmed on both the anteroposterior and lateral radiographs before continuing to ream for the nail.[16,75] To properly align the humeral head in surgical neck fractures, the shaft is positioned in a manner that is parallel to the humeral head through the application of a directed force to the shaft, traction, and rotation. It is essential to ensure correct alignment of the humeral head in cases of varus or valgus position. To aid in fracture reduction, manipulation of the fracture with the nail itself can be used. In

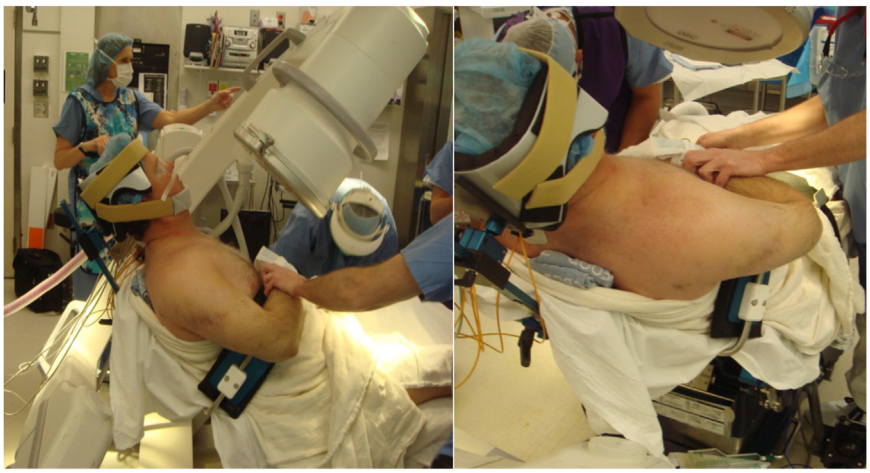

Figure 2 C-arm position for AP and scapular-Y views. Note: If using this technique, it is critical to get preoperative x-rays as it can be challenging to obtain non-obstructed intraoperative x-rays with the C-arm coming from the contralateral side.

Figure 3 Image demonstrating supine positioning on a Jackson flat table for humeral nail positioning. Note: It is critical to use a large bump under the shoulder to gain access for the starting point.

cases where both tuberosities are affected, reduction of the head and tuberosities may be carried out prior to nail insertion. This can be achieved through a percutaneous method involving the use of Steinmann pins or Kirschner wires, or alternatively, an open approach can be chosen. In the open approach, traction sutures are positioned around the bone-tendon junction to facilitate the realignment of displaced tuberosities and offer temporary stabilization[57] (Fig. 6).

Locking plate technical considerations

Plate biomechanics and positioning

Understanding the anatomy of the proximal humerus is essential to achieve an anatomic reduction, as malreduction leads to worse outcomes.[65] Neer divided the proximal humerus into four key anatomic segments—lesser tuberosity, greater tuberosity, shaft, and the head or articular piece.[62,65] On average, the head-shaft inclination angle is 135-140 degrees in the coronal plane and the head-shaft retroversion angle is 20-30 degrees in the sagittal plane.[65] The head is posteromedially offset relative to the shaft.[65] The posteromedial metaphyseal extension, known as the calcar, is of critical importance due to its association with the posterior humeral circumflex artery, which is the primary blood supply to the humeral head.[65] Its disruption is associated with humeral head ischemia.[35]

Thus, the plate position on the lateral humerus should be guided by the position of the calcar screw to maximize its fixation. Ideally, its position is as close to the head-neck junction as possible, specifically within the lower 25% or 12 mm of the humeral head and within 5 mm of the subchondral bone. Numerous biomechanical studies have demonstrated the importance of this screw as it relates to construct strength and stability, and being malpositioned either too cranially or too caudally is associated with construct failure.[24,58,65,66] Additionally, a plate placed too proximally, that is, cranial to the superior aspect of the greater tuberosity, can cause impingement.[2] Finally, the plate should lie posterior to the bicipital groove to avoid irritation of the long head biceps tendon and damage to the arcuate and anterior humeral circumflex arteries which may increase the risk for osteonecrosis.[2,65]

In addition to the calcar screw, the plate position should allow for maximal screw density, at least five locking screws within the humeral head.[20,53,65] Screw position, including the calcar screw, has been extensively studied. Screw purchase and construct stability are maximized with divergent screws, and newer variable angle locking technology allows surgeons to account for this principle.[19,65] Screws that engage subchondral bone are preferred to cancellous bone, particularly in the case of osteoporotic bone which is frequently encountered in PHFs.[19] Notably, screw pull-out strength is weakest in the anterosuperior quadrant of the humeral head and more likely to penetrate the joint.[2,83]

Incisional approach

Generally, the deltopectoral approach is the most commonly used approach for open treatment of PHFs, but the deltoid split can be used as well when direct access to the tuberosities is needed. Advantages of the deltopectoral approach include its extensile nature, surgeon familiarity, and ease of revision to an arthroplasty for failures. However, it provides limited exposure of the greater tuberosity.[34] Advantages of the deltoid-split approach include direct access to the greater tuberosity and lateral humerus for plating and potentially improved cosmesis of the surgical scar.

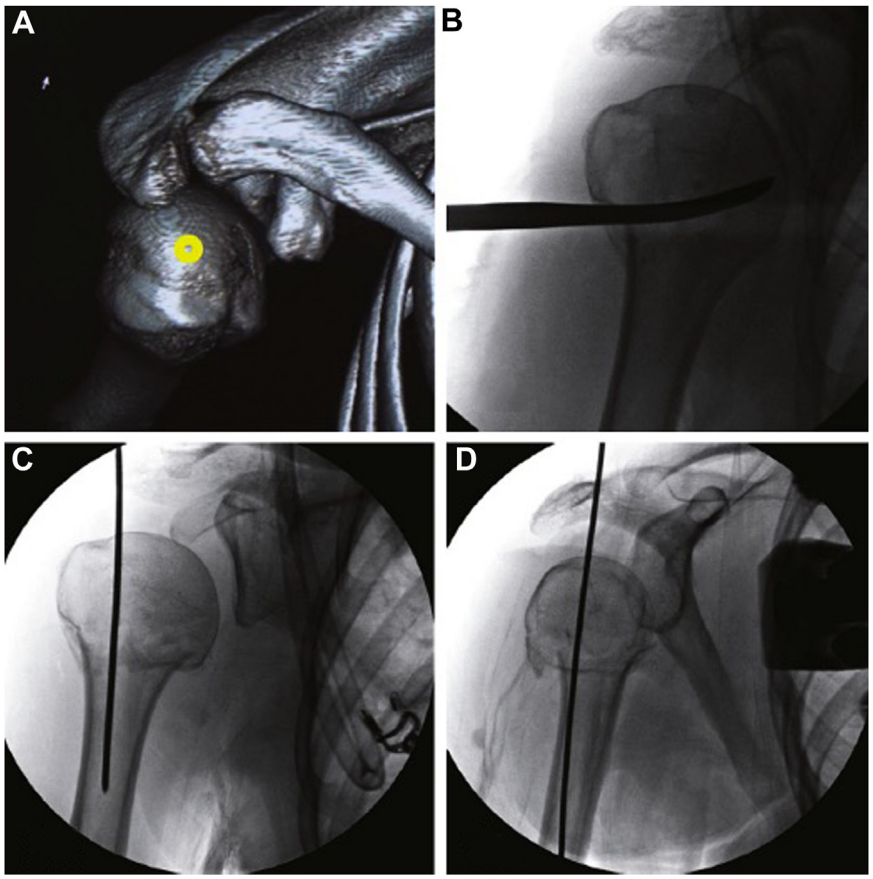

Figure 4 Radiographic depiction of the rotator cuff split entry point for humeral nailing; a commonly used approach. Note: This approach sacrifices the articular surface with a longitudinal incision through the rotator cuff, but with the benefit of easy access especially with arm extension.

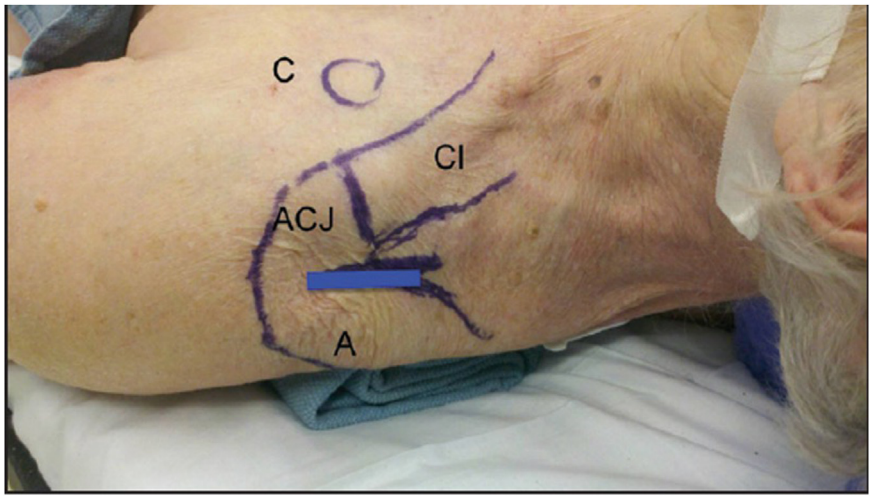

Figure 5 Demonstration of the percutaneous Neviaser portal, which utilizes a medial starting point through the muscle belly protecting the tendon. Note: A straight thin nail is needed for this technique. *C*, coracoid; *Cl*, clavicle; *ACJ*, acromioclavicular joint; *A*, acromion.

However, this approach causes scarring within the deltoid and is not extensile because of the axillary nerve.[3,12]

Locking plate augmentation

The benefits of conventional plate fixation encompass the capability to establish multiple points of fixation within the humeral head, while providing the opportunity for enhanced tuberosity reduction and reinforcement by utilizing the suture holes available on the plate; facilitating direct reduction and the potential for augmented reduction with the assistance of the implant.[50] To augment LPF, a tension-band construct that provides essential support for tuberosity repair without the need for direct suturing to the plate can be accomplished. In this surgical technique, robust

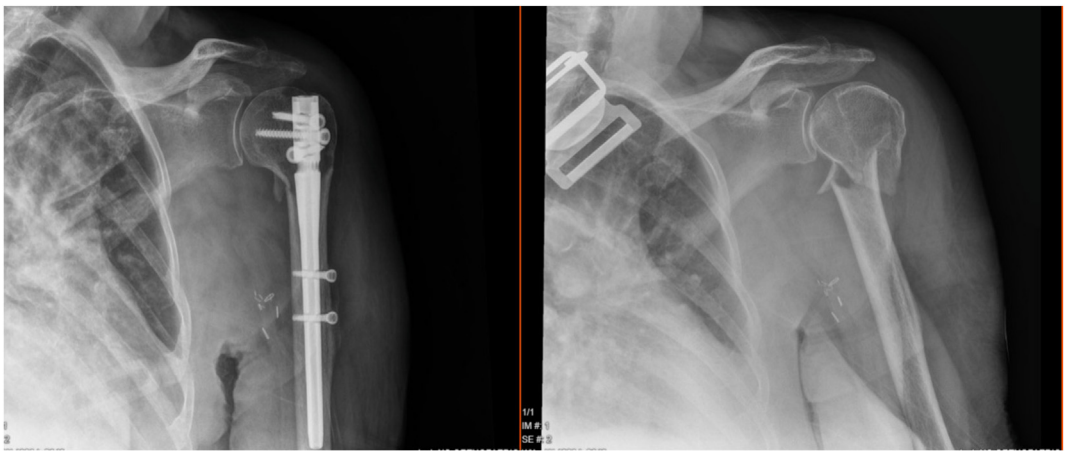

Figure 6 Successful anatomic reduction of a proximal humerus fracture using the intramedullary nailing technique.

nonabsorbable sutures, such as Fiberwire, are carefully threaded through the tendon insertions of the rotator cuff muscles, precisely at their bone-tendon junctions. These sutures are then passed through specialized eyelets integrated into a proximal humerus plate. Moreover, the sutures responsible for maintaining rotator cuff tension are retained and firmly anchored to the plate using these dedicated eyelets.[2,65,77] In cases with medial calcar comminution, structural bone allograft like the fibular strut allograft should be considered to recreate the posteromedial buttress and bridge the comminution. Last, particularly in the setting of osteoporosis, there is significant impaction and loss of cancellous bone. This can be augmented with various autograft, allograft, or synthetic bone void fillers which have been shown to increase construct stability[2,7,65] (Fig. 7).

Postoperative protocol

The postoperative rehabilitation varies between surgeons, fracture type, and patient-specific factors. However, the same principles are generally followed. In the acute/immediate postoperative period, that is, within two to four weeks of surgery, the shoulder is generally immobilized with exception of pendulum exercises and passive range of motion which can be started so long as pain remains well controlled. Patients are encouraged to work on elbow range of motion to prevent stiffness. In the subsequent four weeks or so patients should be encouraged to regain full shoulder passive range of motion and begin working on active-assisted range of motion. Elbow strengthening begins as well. Finally, by twelve weeks postoperative, patients should have regained full shoulder active range of motion and begin strengthening. They can start returning to their activities of daily living.

Intramedullary nailing vs. plate comparison studies

Functional outcomes

Sun and colleagues published a systematic review and meta-analysis of 13 comparative studies, functional outcome measures such as the Constant-Murley and Disabilities of the Arm, Shoulder and Hand (DASH) scores were used to assess outcomes postoperatively. They found no evidence of a significant difference in the Constant-Murley scores ($P = .45$) and DASH ($P = .85$) scores between the two fixation groups.[81] Gracitelli et al also published findings similar to Sun et al where there were no statistically or clinically different outcomes as measured by Constant-Murley and DASH scores.[26] In a retrospective study conducted by Zhu et al, the group treated with plates had significantly higher American Shoulder and Elbow Surgeons scores and supraspinatus strength at 1-year follow-up. However, after three years, these significant differences were no longer observed between the two groups.[92] Multiple studies also had similar results in which a lack of difference in functional outcome and overall reduction quality between nail fixation and plate fixation groups, seemingly pointing toward a conclusion that no single method can definitively be valued over the other in the absence of an absolute indication for one or the other.[8,23,92] Another nonrandomized comparative study of plate fixation and antegrade nailing was performed showing no difference in the functional outcome between the two techniques but found four-part fractures treated with antegrade nailing had lower functional shoulder scores.[47]

It is difficult to label one method as having the superior outcomes over the other. Some studies have described differences in external rotation of the shoulder, favoring locking plates.[23,81,85] While in other studies detailing outcomes, there has been no difference between IMN and plating cohorts in pooled estimates of forward elevation, stability for axial and torsional loading, nor equivalent neck-shaft angles and range of motion after 1 year.[14,26,81] Conversely, Gradl et al found that the proximal humeral nail was more effective than the semielastic locking plate for unstable PHFs based on biomechanical data.[28,36] Ultimately there are mixed data on IMN vs. plating, indicating that fracture presentation and implant design on a case-by-case basis may play a greater role in postoperative results rather than simply considering the type of fixation utilized.

Complications

A concern with IMN that played a part in the preference of plating is increased postoperative complication rates. These include, but are not limited to, shoulder pain, increased reoperation rates, avascular necrosis (AVN), and screw penetration.[11,55,71,84,87] However, recent data have put this into question. Sun et al found that there was no discernible difference in the overall complication rate between the intramedullary nail (30.4%) and locking plates (29.1%) groups in the treatment ofPHFs. The only statistically significant difference was a higher screw penetration rate in the locking plate group compared to the intramedullary nail group. Complications such as AVN, additional surgery intervention, infection, fracture redisplacement, rotator cuff rupture, and nonunion did not significantly differ between the two groups.[81]

Figure 7 Successful anatomic reduction of a comminuted, valgus-impacted proximal humerus fracture using a proximal humerus locking plate. Note the screw density in the humeral head and the inferior position of the calcar screw.

Another systematic review and meta-analysis comparing nail and plate fixation found no difference in the rate of union, radial nerve injury, or infection, but differed from the Sun et al study as a significant increase in the risk for subsequent reoperation and complications was higher with IMN use.[91] Contrasting this, Zhu et al published findings with a plate fixation group having a 31% complication rate vs. 4% in the IMN group after 1 year.[92] A previous systematic review showed complication rates of 2.0% for hardware failure, 0.3% for malunion, 0.5% for nonunion, and 0.4% for neurologic injury.[31] Furthermore, LPF has commonly been reported to be associated with postoperative plate impingement with resultant stiffness and loss of range of motion, mechanical failure/nonunion, screw cutout, infection, and AVN.[70,73] These highly variant complication rates between studies suggest that there is a lack of standardization as to what is considered a complication between investigators, which limits our ability to effectively synthesize the literature. When compared to hemiarthroplasty, IMN, nonoperative treatment, and reverse shoulder arthroplasty, a meta-analysis found that although AVN rates were higher in plating, there was no statistically significant difference in AVN rates when compared to other treatment methods.[13] Numerous other comparative studies have also reported complication rates higher in plate fixation groups. The emergence of these data, along with others that ultimately show a lack of difference in outcomes, supports the argument that as IMN fixation has evolved, it can generally be considered an equal alternative to plating unless in complex fractures three- and four-part fractures, especially those involving significant displacement (>5 mm) of either tuberosity.[8,23,76,92]

Pain

Shoulder discomfort is a well-documented consequence of antegrade humeral nailing and is regarded as technique-specific, attributable to iatrogenic rotator cuff damage sustained during nail preparation and insertion.[3,16] The occurrence of shoulder pain after surgical fixation of PHFs has long been recognized as a real issue associated with IMN.[18,86] Baltov et al highlighted that subacromial impingement and persistent pain are found in one of every 5 patients undergoing IMN for PHFs.[3] Other reports have cited no significant difference in relation to pain scores following treatment of PHF with IMN and plating.[26,81,92] In a study involving 22 patients who underwent IMN for displaced Neer's two- and three-part PHFs, no shoulder pain was reported 12 months later. It should be noted that the nails used in the study were of the current generation, which are designed to eliminate the risk of iatrogenic injury to the rotator cuff and subsequent postoperative pain.[33,78] In addition, Konrad et al discovered that patients who underwent IMN and those who received proximal plate constructs had similar functional scores after one year. Moreover, patients in the IMN group reported experiencing significantly less pain than those in the plate fixation group at 3, 6, and 12 months following surgery.[45] As newer generation nails and surgical techniques continue to improve, it has been suggested that the persistent baseline apprehension associated with IMN may no longer be warranted.[72]

Conclusion

Available evidence indicates that both intramedullary nails and locking plates can achieve satisfactory shoulder function in the treatment of displaced PHFs, without any clear superiority of one method over the other. The choice of technique should be tailored to individual patient factors such as fracture type, age, bone quality, and functional expectations. Although trends suggest better outcomes for the respective fixation methods in certain fracture types, no specific treatment strategy can be recommended. Thus, there is no one method that is significantly superior to the other in treating these fractures. Rather, both techniques can achieve comparable and satisfactory shoulder function, and the choice of surgical technique should be made on a case-by-case basis as the optimal technique is likely to differ depending on the unique presentations. Overall, both locking plates and intramedullary nails are valuable options for treating proximal humeral fractures.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Christopher D. Joyce, MD, reports that he has received royalties/consultant fees/stock options (etc) from Zimmer for work related to the subject of this article. Oke A. Anakwenze, MD, MBAreports that he has received royalties/consultant fees/stock options (etc) from Exactech, Inc., LIMA, Responsive Arthroscopy, Smith & Nephew, and Suture Tech for work related to the subject of this article. Christopher S. Klifto, MD, reports that he has received royalties/consultant fees/stock options (etc) from Acumed, LLC, GE Healthcare, Johnson & Johnson, Merck, Pfizer, Restore3d, and Smith & Nephew for work related to the subject of this article.

Peter N. Chalmers, MD, reports that he has received royalties/consultant fees/stock options (etc) from DePuy, Johnson & Johnson, DJ Orthopaedics, Exactech, Inc., *Journal of Shoulder and Elbow Surgery*, Responsive Arthroscopy, Smith & Nephew, and TitinKM Biomedical for work related to the subject of this article. The other authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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