Review Article

Intramedullary Fixation for Proximal Humeral Fractures

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Abstract

Proximal humeral fractures are a commonly encountered injury; however, no consensus has been reached for the ideal treatment. Current surgical fixation options include plate, plate with fibular strut allograft, intramedullary fixation, pinning, suture constructs, and external fixation. Each of these options possesses distinct advantages and disadvantages. With the evolution of implant design, a greater understanding of the mechanisms of failure of fixation, and the ability to preserve fracture biology, the management of proximal humeral fractures with intramedullary fixation has become an accepted treatment option. From a biomechanical perspective, intramedullary fixation may have advantages over laterally based fixation, in particular with fractures associated with significant calcar comminution. The ability to insert the implant from a superior starting point may help preserve vascular supply to the humeral head and tuberosities. With reported outcomes comparable with the aforementioned techniques and an evolving understanding of fracture characteristics and failures of fixation, intramedullary fixation represents an alternative treatment option for proximal humeral fractures with specific fixation and biologic advantages.

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Fractures of the proximal humerus are the third most common fracture in patients older than 65 years, following the hip and distal radius fractures,[1] with projected rates of emergency visits to exceed 275,000 annually by 2030.[2] Although most proximal humeral fractures are treated nonsurgically,[3] there still remains a significant subset of patients who are treated surgically based on fracture severity, displacement, risk of nonunion or varus malunion, and concerns for functional outcomes. For patients deemed surgical candidates, several current fixation options are available.

The most commonly used implant for the management of proximal humeral fractures remains plate fixation. Standard plate fixation requires an open approach through the deltopectoral interval or less commonly through a lateral deltoid split. The implant typically uses a multitude of fixed or variable angle, locked screws that project into the head and support fracture reduction. Advantages to plate fixation include the opportunity to obtain multiple points of fixation within the humeral head, tuberosity reduction and fixation using suture holes in the plate, and potential for the implant to assist with fracture reduction.[4]

However, plate fixation has several inherent disadvantages. Plate fixation requires an open approach for placement, inevitably requiring surgical dissection and potentially placing the vascular supply to the fracture site, humeral head, and tuberosities at risk for iatrogenic injury.[5] Additionally, open dissection and placement of the implant under the deltoid creates adhesions that can contribute to postoperative stiffness. Also, secondary to humeral head morphology and difficulty with intraoperative imaging, plate fixation is associated with the risk of intra-articular hardware issues and increased revision surgery rates for hardware removal.[6,7] For these reasons, alternative fixation methods have been developed, including all suture fixation, external fixation, percutaneous pin fixation, and intramedullary fixation.

Intramedullary Implant Design

Nail design has evolved with a greater understanding of humeral anatomy and the known factors that contribute to adverse and successful outcomes. Early intramedullary nail designs consisted of curvilinear implants designed for insertion through a lateral entry point to avoid injury to the humeral head superior articular cartilage; however, this design likely is the reason for past perceptions of poor outcomes after humeral nailing as the lateral insertion places the rotator cuff tendon and tuberosity footprint at risk for iatrogenic injury during nail insertion, contributing to postoperative pain (Figure 1). In a prospective, comparative clinical investigation, Lopiz et al[8] demonstrated that 73% of fractures fixed with a bent nail design led to rotator cuff disease symptoms compared with 34.6% of straight nails. Furthermore, these authors also reported a significantly higher revision surgery rate of 42% in the bent nail group compared with 11.5% in the straight nail group. In a case study of 18 patients treated with curvilinear nails, Nolan et al reported rotator cuff symptoms in more than 50% of patients. These authors also reported a high rate of loss of fixation, concluding that the curvilinear nail violates the rotator cuff and is unable to resist deforming forces that contribute to varus collapse.[9] In three- and four-part fractures, the curvilinear entry point is commonly at the level of the fracture zone, thereby diminishing implant fixation of the head segment. Straight nail designs, which allow for a more medial entry point from the footprint and central placement into the humeral head, preserve the surrounding bone stock around the implant, contributing to biomechanical stability and anchoring of the implant.[10] Additionally, newer nail designs have widely angled tuberosity screws that reduce the potential for intra-articular screw penetration and capture tuberosity fracture segments by locking into polyethylene bushings built into the device.

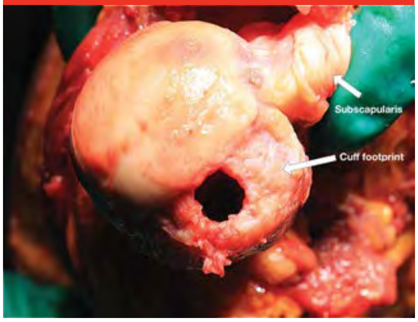
Although a more medial starting point for the straight nail appears to impart less risk to the rotator cuff tendon and tuberosity footprint, it does require violation of the head articular cartilage. To minimize cartilage damage, newer straight nail designs have reduced the diameter of the implant and focused on an entry point at the zenith of the head (Figure 2), limiting injury to the cartilage that articulates directly with the glenoid. At this time, no data are available on the effects of cartilage injury caused by nail insertion, and long duration studies may be required to determine potential sequelae after the removal of this segment of articular cartilage. Further investigations on this aspect of nail placement are needed to identify the optimal placement of the intramedullary device.

Vascular Considerations

The main vascular supply to the proximal humerus arises from the anterolateral branch of the anterior humeral circumflex artery and the posterior humeral circumflex artery.[11] The anterior humeral circumflex artery enters the humeral head in the area of intertubercular groove and gives branches to the lesser and greater tuberosities. The posterior humeral circumflex artery contains perforating branches within the quadrilateral space which enter the humeral calcar and perfuse the head, as well as multiple terminal branches that insert on the lateral humeral periosteum in the subdeltoid recess.[12] Gerber et al[5] also identified an important large anastomosis between the deltoid branch of the thoracoacromial artery and anterolateral anterior circumflex artery inserting into the anterolateral proximal humerus (Figure 3). Preservation of this collateral circulation helps promote healing and decrease the risk of osteonecrosis after reduction and fixation of proximal humeral fractures.

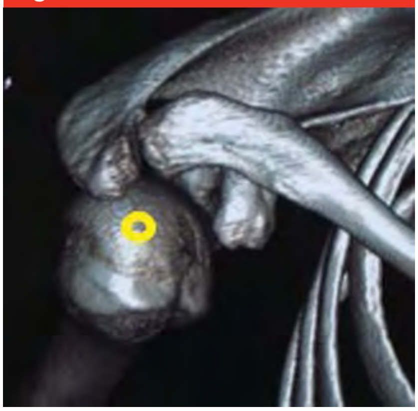
One of the more apparent differences between plate and nail fixation for proximal humeral fractures is the required approach for the placement of the device. Humeral nail design allows for several alternative approaches for implant placement outside the standard deltopectoral approach. Most commonly the nail placement uses a lateral acromial approach, in which the rotator cuff is identified and split longitudinally, giving access to the articular segment of the humeral head where the implant is inserted. Nail placement may also be performed with a percutaneous technique, in which very limited surgical dissection is performed at the level of the fracture. The nail is inserted just anterior to the acromioclavicular joint, where risk to the proximal humeral blood supply is limited, thereby preserving vascularity to the humeral head, tuberosities, and proximal humeral fracture site, contributing to fracture healing (Figure 4). By contrast, the

Figure 1



Rotator cuff insertion violation on greater tuberosity.

Figure 2



Ideal starting point for intramedullary nail at the zenith of the humeral head.

deltopectoral approach required for plate fixation may place terminal and ascending branches from the circumflex vessels at direct risk during the surgical approach and positioning of the plate on the lateral cortex of the proximal humerus. In addition, deltoid anastomoses to the proximal humerus are likely to be violated by this approach.[12] This mandatory exposure for plate fixation may contribute to a reported osteonecrosis rate of 10.8% in patients undergoing locked plating.[13] In comparison, Wong et al[14] performed a systematic review on 14 investigations and found the reported osteonecrosis rate after intramedullary nailing to be 4%.

Biomechanics

Although biomechanical characteristics of intramedullary nailing are different from those of plate fixation of the proximal humerus, there remains controversy regarding which fixation type provides superior biomechanical fixation, likely secondary to inconsistencies in the methodology between investigations and differences in implant designs tested. Foruria et al[15] evaluated rotational stability with cadavers with two-part surgical neck osteotomy fractures, reporting that plate fixation tolerated more torsion to failure and less torsional stiffness. Edwards et al[16] also reported superior biomechanical characteristics with proximal humeral plate constructs in both cantilevered varus bending and torsion after cyclical testing with surgical neck osteotomy cadaver fracture models. However, Lill et al[17] reported higher stiffness in intramedullary fixation toward axial load, as well as rotational and cantilever bending in varus. Fuchtmeier and colleagues also reported higher stiffness with intramedullary fixation compared with plate fixation,[18] as did Yoon et al[19] who reported that nail fixation of the proximal segment with a spiral blade is the stiffest construct, followed by nail fixation with screws, then 4.5 locking plate, and finally 3.5 locking plate fixation. Clavert et al[20] evaluated biomechanical construct of plate fixation or nail fixation with two proximal posterior screws in four-part fractures created on sawbones. These authors found that the proximal humerus nail demonstrated higher values for both stiffness and load to failure in this model compared with a locking plate construct.

Torsional and rotational fixation strength are necessary to allow for early range of motion and rehabilitation in the immediate postoperative period. Fixation is most at risk in patients with diminished bone mineral density, medial calcar cortical disruption, and varus head displacement.[6,7] Jung et al retrospectively evaluated 252 proximal humeral fractures treated with locked plates, aiming to identify the risk factors for postoperative loss of reduction. Multivariate regression analysis demonstrated that osteoporosis, a displaced varus fracture with less than 110° of neck shaft angle, medial comminution, and insufficient medial calcar fixation support were independent risk factors for reduction loss.[6] Krappinger et al[7] supported these conclusions that age, local bone mineral density, anatomic reduction, and medial calcar support significantly influence the success of fracture fixation. Ultimately, the prevention of varus head collapse may be the most critical component of any type of fixation device for achieving optimal outcomes.

In this regard, intramedullary fixation appears to hold some biomechanical advantage over plate fixation secondary to centralization of the implant. The intramedullary position of the implant allows for the unique advantage of an additional fixation point just below the humeral head subcortical bone, providing a “fifth point of fixation” that may help prevent varus displacement by supporting the superior portion of the head from tipping medially into varus. Intramedullary fixation has also been shown to provide medial calcar support and has been used for augmenting plate fixation with an intramedullary fibular strut allograft in osteoporotic patients with medial calcar comminution.[21] However, intramedullary allograft augmentation of plate fixation requires extensive dissection of the fracture site, potentially denuding local blood supply to the fragments. In addition, successful allograft healing in the proximal humeral intramedullary canal is potentially associated with complete filling of the proximal humeral canal with dense bone, making future arthroplasty procedures more difficult.[22] Both these issues are avoided with intramedullary nail fixation.

Surgical Technique

Optimal placement of the intramedullary implant along with adequate fracture reduction can be technically challenging, and most surgeons will improve with experience through an initial, and sometimes steep, learning curve. Although this implant can be used for almost all variations of proximal humeral fractures, the optimal use of this implant appears to be for two-part surgical neck fractures.

Open Technique

An open approach is the preferred method during the initial learning period for this procedure. The benefits of an open approach include direct visualization of the starting point through the rotator cuff muscle, nail insertion depth, and proximal locking screw position. This approach is most commonly performed via an incision using Langer's lines along the lateral acromion in the same fashion as the incision used for an open rotator cuff repair. A deltoid split is made in the raphe between the anterior and middle heads of the deltoid. To facilitate exposure in multipart fractures, the deltoid with coracoacromial ligament can be released off of the acromion and acromioclavicular joint anteriorly. Depending on the medial-lateral size of the acromion, or its projection, a more centered starting point can be challenging to achieve. If encountered, the humeral head can be manually pushed anteriorly to allow for improved acromial clearance of the humeral head as placement of the nail too anteriorly can lead to fracture malreduction. Typically, the ideal location for the insertion of the nail is just anterior to the acromioclavicular joint to avoid violation of the lateral cuff insertion and its tendionous component.

Percutaneous Technique

Percutaneous nail insertion is a valuable technique that preserves fracture biology and healing but requires precise and reproducible imaging and anatomic reduction before placement of fixation. Reduction typically is accomplished with the use of a cobb or joker placed through a small stab incision along the anterolateral proximal humerus just distal to the fracture localized with fluoroscopic guidance. The instrument is advanced into the fracture site, and it manipulates the head segment into an anatomic neck shaft angle and version, which then can be pinned if unstable. Tuberosity fractures can be reduced with K-wires or a ball spike pusher placed through stab incisions after confirming position with imaging (Figure 5, A–D).

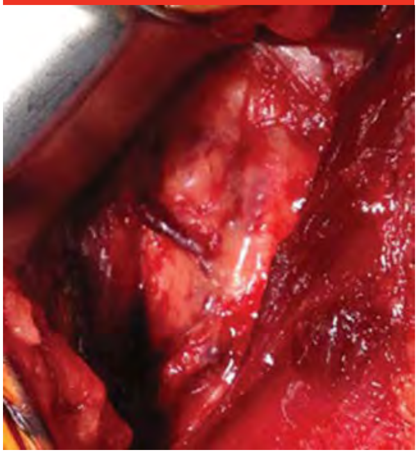
Fracture-specific Technique

Due to limitations in nail constructs, historical indications were limited to two-part fractures, fractures with extension into the humeral shaft, and impending pathologic fractures.[23] With the evolution of nail design and improved surgical technique, indications for nail placement have expanded to include three- to four-part fractures. Currently, we consider intramedullary fixation as our primary modality for fixation of most proximal humeral fractures that do not require prosthetic replacement.

Two-part Fractures

Two-part surgical neck fracture is a readily reliable fracture pattern that provides a reasonable starting point for surgeons interested in nail fixation (Figure 6, A–C). With characteristic anterior and medial displacement of the humeral shaft secondary to the deforming force of the pectoralis, reduction can commonly be attained with traction and gentle flexion of the humeral diaphysis. This reduction

Figure 3



Large arterial anastomosis between the deltoid branch of the thoracoacromial artery and the anterolateral anterior circumflex artery inserting into the anterolateral proximal humerus.

Figure 4

Robust healing along the lateral proximal humerus after nail placement.

Figure 5

Percutaneous fixation of a comminuted four-part fracture in a 52-year-old patient with high risk to proximal humeral blood supply. This patient has a history of calcific tendinitis. **A**, Preoperative radiograph. **B**, Reduction typically is initiated with the correction of head alignment using a cobb or joker placed through a lateral stab incision. **C**, The tuberosity can be corrected with a ball spike pusher. **D**, Nail placement is used to maximize fixation strength. **E**, Percutaneous placement requires multiple small stab incisions but preserves the fracture biology.

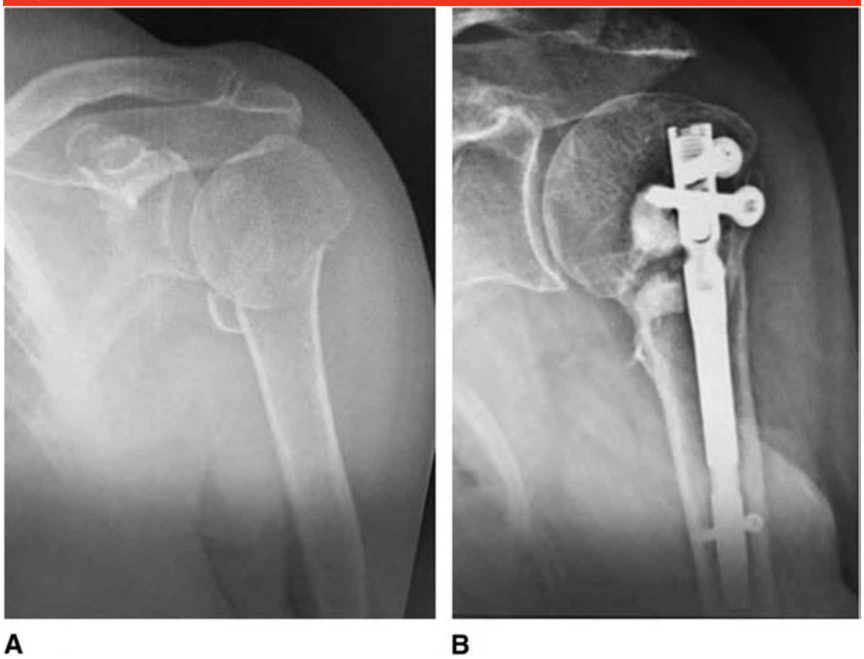
can sometimes be facilitated with nail placement, aligning the humeral head to the shaft with insertion, but places a premium on the starting point to avoid varus displacement of the head.

After nail insertion, compression at the fracture site is most commonly accomplished via hand-applied pressure at the elbow to compress the fracture site before distal screw fixation. Another option, requiring accurate nail depth, is by obtaining initial fixation in the distal fracture segment and back-slapping through the jig. Most nailing systems also have dynamic screw options that allow compression with axial load postoperatively.

Three- and Four-part Fractures

With the evolution of nail design, an increasing number of three- and four-part fractures can be managed with intramedullary fixation (Figure 7, A–C). After reducing the head, greater tuberosity reduction can be facilitated with either a K-wire insertion into the fracture fragment and used as a joystick or the use of a ball spike pusher placed on the teres tubercle to push the tuberosity anteriorly and under the head segment. The head is lifted up and then allowed to *rest* on the reduced tuberosity fracture segment, maintaining the reduction. Commonly, one or multiple K-wires are used to hold reduction during nail placement. An open approach allows for reduction of the tuberosities with suture.

Figure 6



Nail fixation in a 73-year-old patient with a two-part fracture and calcar comminution. This was placed percutaneously. **A**, Calcium phosphate graft was injected into the calcar region after nail placement to help resist varus collapse. This typically is used in patients with concern for bone quality who are at risk for varus displacement as the graft can be injected percutaneous and provides additional structural support to the calcar region. **B**, 2-year postoperative radiograph.

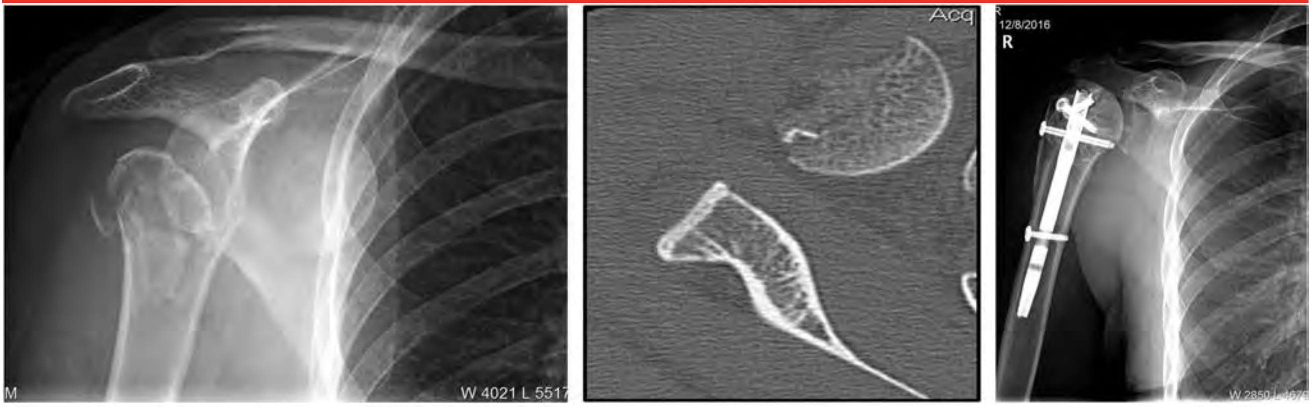
Authors' Preferred Technique

Our preference is positioning with the head of the bed raised 40° using a beach chair positioner. Fluoroscopy is brought in contralaterally, and preoperative radiographs are confirmed before draping. Reproducible imaging is critical for achieving anatomic fracture reduction and appropriate nail placement, especially using the percutaneous technique. We prefer using two primary radiographs intraoperatively maintaining the arm positioned in neutral rotation (gunslinger position) during the entire procedure. The first is a Grashey view taken with the C-arm tilted horizontally to match the semirecumbent orientation of the patient and orbiting the machine 30° to 45° to obtain a perpendicular view of the glenoid face. With the arm in neutral rotation, this image will reproduce the standard AP 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° to 45°. This view allows for the interpretation of the position of the tuberosities as the infraspinatus and teres minor tubercles of the greater tuberosity should be identifiable if reduced anatomically. From this view, the correct position of the guide pin in the anterior to posterior direction is determined as well as the optimal tuberosity screw position.

Standard reduction includes gentle arm traction with lifting of the humeral head using a cobb or joker through a lateral stab incision to correct valgus or varus angulation and rotational malalignment (Figure 8, A and B). Tuberosity reduction is facilitated by correcting the humeral head and manipulating the tuberosities with a ball spike pusher, bone hook, dental pick, or suture into an acceptable position in relation to the head. The tuberosities can be provisionally pinned before definitive screw fixation. Open reduction through windows can facilitate tuberosity reduction in more challenging three- and four-part fractures.

A starting point for guidewire placement is localized just anterior to the acromioclavicular joint and medial to the coracoacromial ligament. A straight antegrade nail is used with the desired entry point at the zenith of the humeral head on the Grashey view and centered in the AP direction on the Y-lateral view ensuring preservation of the rotator cuff tendon and footprint. After the starting cortical hole is reamed, the nail is then advanced over the guidewire. Proximal locking fixation is dependent on the degree of tuberosity comminution and the complexity of the fracture pattern. If possible, greater tuberosity screw fixation is directed at the infraspinatus and teres minor tubercles optimizing screw fixation where there is increased bone density enhancing fixation. This is most

Figure 7



A B C

Nail fixation in a 43-year-old patient with a four-part proximal humeral fracture dislocation including anatomic neck fracture gross displacement of the humeral head. **A** and **B**, Preoperative images. **C**, Radiograph at 6 years postoperative.

Figure 8

A B

A and **B**, Cobb reduction of humeral head displacement placed through a lateral stab incision at the level of the fracture. The C-arm is positioned on the opposite side of the surgical arm and is tilted to a degree that is perfectly perpendicular to the humerus to achieve accurate radiographs that are critical for decision on fracture reduction, nail height, and screw positioning.

reliably seen on the Y-lateral view as is lesser tuberosity screw fixation which is directed at the lesser tuberosity prominence. Identifying accurate nail depth should be verified on both AP and lateral imaging due to concavity of the head.

Postoperative course is dependent on fracture type and fixation strength but typically includes sling immobilization with early rehabilitation including passive forward elevation to 90° and external rotation to neutral. Sling immobilization is discontinued at 4 to 6 weeks, and active motion is initiated on tuberosity and surgical neck callus.

Clinical Outcomes

Clinical outcomes as reported in the literature consist mainly of case series reports and several higher quality, prospective, randomized trials comparing intramedullary nail and plate fixation. Differences in implant design type, surgical approach, and type of fractures treated make it challenging to draw definitive conclusions. A systematic review of outcomes performed by Wong et al[14] provides an informative overview on the established literature. These authors reported on 14 studies (10 retrospective and four prospective) with 448 patients who met inclusion data, which included reports on two-, three-, and four-part fracture management with intramedullary fixation. The authors found the overall mean Constant score after nail fixation to be 72.8, with an American Shoulder and Elbow Society (ASES) score of 84.3. Constant score for two- and three-part fractures was significantly higher than that for four-part fractures. Additionally, final postoperative range of motion was significantly better for two- and three-part fractures compared with four-part fractures. The most common complication reported was secondary loss of reduction in 24% of patients, followed by malunion at 21%. The revision surgery rate for two- or three-part fractures was 13.6% to 17.4%, compared with 63.2% for four-part fractures; however, this study only included a total of 19 patients with four-part fractures. The authors concluded that intramedullary fixation for two- and three-part proximal humeral fractures yields satisfactory clinical outcomes; however, nail fixation for four-part fractures could not be recommended without further clinical investigations.

Hatzidakis et al[24] reported on a series of 38 patients with two-part surgical neck fractures and a mean age of 65 years. The authors reported a 100% union rate, mean adjusted constant score of 97%, and all but one patient healed with a neck shaft angle over 125°. The authors concluded that patients with two-part surgical neck fractures managed with locked angular-stable intramedullary nailing via an articular entry point had reliable fracture healing, favorable clinical outcomes, and little residual shoulder pain.

Lin reported on a case series of 22 patients with displaced three-part proximal humeral fractures undergoing nailing. The author reported a 100% union rate but also had a 27% complication rate, including 2 patients with osteonecrosis.[25] Cuny et al[26] reported on a case series consisting of 67 patients, reporting a weighed constant score for two- and three-part fractures at 84% and 95%. Articular four-part fractures treated with intramedullary fixation had constant scores of 84% for valgus impacted but only 67% for complex disengaged fractures with an associated 67% complication rate. Ultimately, the authors recommended intramedullary fixation for patients with extra-articular or valgus-impacted articular fractures, but arthroplasty should be considered for displaced articular four-part fractures.

Kloub et al[27] retrospectively evaluated 125 patients who underwent intramedullary fixation for three- or four-part fractures at an average of 57 months postoperatively. This cohort included 14 fracture dislocations. The authors reported a final adjusted Constant score of 85% in three-part fractures and 73% in four-part fractures including 70% in four-part fracture dislocations. No nonunions were identified; however, 17 cases of humeral head necrosis were noted, with 82% of these occurring in the four-part fracture cohort. The authors concluded that nailing is appropriate for all proximal humeral fracture types; however, the quality of reduction has a strong influence on the incidence of postoperative necrosis, and if good reduction cannot be achieved, treatment strategy should be reassessed.

Clinical Comparison With Plate Outcomes

A number of clinical studies have compared outcomes after intramedullary or plate fixation for proximal humeral fractures. Notably, revision surgery rates for two- and three-part fractures treated with intramedullary fixation have been reported between 13.6% and 19.0%,[14,28] mostly for the removal of proximal screws, compared with revision surgery rates for plate fixation between 3 5% and 30%,[28,29] mostly for intra-articular screw penetration. The revision surgery rates for four-part fractures treated with intramedullary fixation have been reported between 11.0% and 63.2%,[14,29] compared with a revision surgery rate for plate fixation in four-part fractures at 30% to 33.3%.[29,30] Gracitelli et al[31] performed a meta-analysis and reported no significant differences in Constant scores between nail and plate fixation in 11 of 12 published reports. Zhu et al[32] prospectively evaluated 51 patients with two-part proximal humeral fractures randomized to either intramedullary or plate fixation. The authors reported that the plate group had significantly higher ASES scores and supraspinatus strength after 1 year; however, no differences were present between the groups after 3 years. Additionally, the complication rate after 1 year for plate fixation was reported at 31% compared with 4% for nail fixation. Gracitelli et al[28] recently reported on their findings from a prospective randomized controlled trial of 72 patients with two- and three-part proximal humeral fractures who underwent immediate plate fixation or intramedullary fixation. They found that radiographic and clinical outcomes were equal between the two groups including Disabilities of the Arm, Shoulder, and Hand (DASH) score, visual analog scale scores, range of motion, rotator cuff tear rate, and postsurgical neck shaft angle. However, over 12 months, the complication and revision surgery rates were significantly higher in the nail group.

Boudard et al[30] retrospectively evaluated 63 patients treated for three- or three-part proximal humeral fractures, reporting no difference between intramedullary fixation or plate fixation in regard to the quality of reduction or functional scores, although the plate group had three infection and the intramedullary group had none. Gadea et al[29] retrospectively looked at locked plating or intramedullary nailing in four-part proximal humeral fractures in 107 patients. The authors reported no significant difference between groups in terms of constant score, rate of poor outcomes, position of head healing, rate of anatomic tuberosity healing, and complication rate; however, the revision surgery rate was 30% in the plate group and 11% in the intramedullary nail group. The authors reported that the presence of a displaced medial hinge fracture pattern did significantly worse with nail fixation.

Ultimately, clinical outcomes after locked plate or intramedullary fixation for two- or three-part proximal humeral fractures do not appear to demonstrate any definitive differences to justify one fixation method over the other.[29,30,32] Plate fixation for less severe fractures may result in a lower revision surgery rate but must be considered against the cost of an open incision, increased surgical time, and soft-tissue trauma with an open approach. Four-part proximal humeral fractures continue to present a challenging fracture pattern to treat with any type of fixation. Currently, not sufficient outcome data are available on the treatment of four-part proximal humeral fractures to draw any definitive conclusions regarding the ideal treatment method; however, four-part fractures tend to have worse outcomes regardless of the fixation method.[14,26]

Summary

Indications for nail fixation in proximal humeral fractures have expanded given the evolution of nail design and the recognized preserved vascularity for healing at the fracture site. Meticulous attention to radiographic imaging is critical for accurate nail placement, avoiding the rotator cuff footprint, and tuberosity fixation. In general, published reports demonstrate nail fixation as having relatively equivalent outcomes to plate fixation, supporting its use as an alternative fixation technique for most two- and three-part proximal humeral fractures, with inconclusive data on the use with four-part fractures.

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