ARTICLE IN PRESS

J Shoulder Elbow Surg (2015) ■■, ■■–■■

ELSEVIER

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

Intramedullary nailing of the proximal humerus: evolution, technique, and results

Matthew F. Dilisio, MD[a,*], Robert J. Nowinski, DO[b], Armodios M. Hatzidakis, MD[c], Edward V. Fehringer, MD[d]

[a]*Creighton University Orthopaedics, CHI Health Alegent Creighton Clinic, Omaha, NE, USA*
[b]*OrthoNeuro, New Albany, OH, USA*
[c]*Western Orthopaedics, Denver, CO, USA*
[d]*Columbus Community Hospital Orthopaedics and Sports Medicine, Columbus, NE, USA*

Proximal humerus fractures are the third most common fracture in the elderly. Although most fractures can be treated conservatively with acceptable outcomes, certain fracture patterns are at high risk for progression to humeral malunions, nonunions, stiffness, and post-traumatic arthrosis. The goal of antegrade humeral nailing of proximal humerus fractures is to provide stability to a reduced fracture that allows early motion to optimize patient outcomes. Certain technical pearls are pivotal in managing these difficult fractures with nails; these include rotator cuff management, respect of the soft tissues, anatomic tuberosity position, blood supply maintenance, knowledge of the deforming forces on the proximal humerus, fracture reduction, and rehabilitation strategies. Modern proximal humeral nail designs and techniques assist the surgeon in adhering to these principles and have demonstrated promising outcomes. Humeral nail designs have undergone significant innovation during the past 40 years and now can provide stable fixation in the humeral shaft distally as well as improved stability in the head and tuberosity fragments, which were the common site of fixation failure with earlier generation implants. Compared with other fixation strategies, such as locking plate fixation, no compelling evidence exists to suggest one technique over another. The purpose of this review is to describe the history, results, new designs, and techniques that make modern intramedullary nailing of proximal humerus fractures a viable treatment option.

Level of evidence: Narrative Review

Keywords: Proximal humerus fracture; intramedullary nail; review; shoulder trauma

Proximal humerus fractures are the third most common fracture in the elderly. Whereas many fractures can be treated nonoperatively, some authors estimate that 15% to 64% of proximal humerus fractures are displaced and may warrant surgical treatment.[1] Conservative treatment of these fractures that results in humeral malunions, nonunions, stiffness, and post-traumatic arthrosis can be significantly disabling. In response, a variety of surgical techniques to treat these fractures have been developed, including plating, percutaneous pinning, suture or wire fixation, joint replacement, and humeral nailing. However, no single technique has demonstrated evidence-based superiority in the treatment of proximal

Institutional Review Board approval is not required for this review.

*Reprint requests: Matthew F. Dilisio, MD, Creighton University Orthopaedics, CHI Health Alegent Creighton Clinic, 601 North 30th Street, Suite 2300, Omaha, NE 68131, USA.

E-mail address: dilisiom@gmail.com (M.F. Dilisio).

1058-2746/$ - see front matter © 2015 Journal of Shoulder and Elbow Surgery Board of Trustees. Published by Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2015.11.016

humerus fractures.[18] In addition, several recent reports question the value of surgical treatment of these fractures as a whole[9,22] despite the widespread use of these various techniques.

Antegrade humeral nailing techniques and implants have undergone significant innovation during the last 40 years. The goal of nailing is to provide stability to a reduced fracture that allows early motion to rehabilitate the shoulder and to improve patient outcomes that may have otherwise been theoretically achieved with conservative management. Certain technical pearls are pivotal in managing these difficult fractures with nails; these include rotator cuff management, respect of the soft tissues, anatomic tuberosity position, blood supply maintenance, knowledge of the deforming forces on the proximal humerus, fracture reduction, and rehabilitation strategies. The purpose of this review is to describe the history, results, new designs, and techniques that make modern intramedullary nailing of proximal humerus fractures a viable treatment option.

History

"First-generation" nailing

The evolution of antegrade proximal humerus nailing began with the goal of achieving secure fixation of displaced proximal humerus fractures with a minimally invasive technique. The use of early intramedullary rods or nails, however, was not found to provide adequate fixation to neutralize the deforming forces in this type of fracture and often led to malunion or nonunion. The earliest intramedullary device attempted was Rush rod fixation. However, these pins were not sufficient to provide adequate fixation of displaced fragments and provided no rotational control. Proximal migration of the rod often led to acromial contact, requiring a second procedure for removal. The major issues with first-generation proximal humeral nails were the inability to secure unstable fracture fragments and lack of rotational control, often leading to fixation failure.

"Second-generation" nailing

To stabilize displaced fracture fragments better, antegrade proximal humerus nail designs evolved from experiences with locked lower extremity nails. Early proximal humeral locking nail designs included the Polarus nail (Acumed, Beaverton, OR, USA), the Telegraph nail (FH Orthopedics, Heimsbrunn, France), the Targon PH (Aesculap AG, Tuttlingen, Germany), and the Austofix PHN (North Plympton, SA, Australia). The original Polarus nail was an intramedullary locked, hollow, unreamed nail made of titanium alloy with specific features. These included a spiral array of locking screws, radiolucent targeting guide, axillary nerve window to avoid nerve injury, calibrated drills and drill guides, and cannulation to implant the rod percutaneously over a guidewire. Another unique feature of the Polarus nail was the proximal bend to allow easier lateral entry.

The major disadvantage of this generation of proximal humerus nails was inadequate security of the proximal interlocking screws. Although they were interlocking screws, they did not allow constructs that were fixed angular stable. As these screws engaged only the osteoporotic bone of the proximal humerus, fixation was often lost. Screw backout was common, requiring a secondary surgical procedure for removal.

"Third-generation" nailing

Third-generation nails evolved to solve the issue of proximal screw loosening and ultimate fixation failure. This led to the advent of more secure locking mechanisms for proximal screw fixation to allow fixed angular stable constructs (Table I). The Stryker T2 Proximal Humeral Nail (Stryker, Kalamazoo, MI, USA), for example, was designed to incorporate a number of features including a small diameter, left and right versions, end caps of different heights, and threaded proximal locking holes with a nylon bushing for improved holding strength. The Synthes Proximal Humeral Nail (Synthes, West Chester, PA, USA) offered a spiral blade for angular stable locking proximally, providing an increased surface area for fixation of the humeral head compared with screws with one plane of fixation. In this design, the proximal end cap was used to provide the angular stable locking mechanism for the blade. The Synthes MultiLoc Humeral Nailing System offers screw-in-screw technology for improved fixation in osteoporotic bone. The proximal locking screws target the posteromedial region with strong bone mineral density, potentially reducing the risk of varus collapse. The proximal ascending screw provides additional calcar fixation for medial support. The Tornier Aequalis Proximal Humeral Nail (Tornier, Bloomington, MN, USA) features a smaller core diameter with a shorter length to avoid engagement of the isthmus of the proximal humeral shaft, polyethylene bushings in the proximal holes to engage the proximal screws and to prevent screw backout, and more widely divergent proximal screws for "tuberosity-based" proximal fixation. Moreover, the nail is straight and was designed to be placed with a partial articular entry site.

Many features of the third generation of nail design address insertion and fixation. Modification of the proximal locking screws in some designs includes blunt screw tips to reduce the risk of secondary perforation, screw head suture holes to enable rotator cuff attachment, and countersunk screw heads to reduce acromial contact. The proximal bend in several offers insertion options laterally, just inside the greater tuberosity, or centrally, through the articular surface at the top of the humeral head. Central insertion improves fixation through interference between the subchondral bone at the entry point and the proximal end of the nail. Strategic proximal locking holes enable locking of the lesser tuberosity, the greater tuberosity, and the humeral head. Threaded proximal locking

Table I Modern commercially available antegrade humeral nail designs

Telegraph	T2 Humeral Nail	Targon H/PH (EU only)	Trigen	MultiLoc	Centro Nail (international only)	Polarus
Short: 150 mm Long: 210, 230, 250, 270 mm	140, 160, 180 mm 190-320 × 10-mm increments	Short: 150 mm Long: 200, 220, 235, 250, 265, 280 mm	Short: 160 mm (straight and proximal bend) Long: 180-280 × 20-mm increments	Short: 160 mm Long: 180-315 × 15-mm increments	Short: 150 mm Long: 185-320 × 15-mm increments	Short: 150 mm Long: 200-280 mm
Short: 7, 8, 9 mm (10 mm on request) Long: 7 and 8 mm	7, 8, and 9 mm	Short: 8 mm Long: 7 mm	Short: 7 mm Long: 7, 7.5, 8.5 mm	Short: 8 and 9.5 mm Long: 7 and 8.5 mm	7, 8, and 9 mm	8 mm
Stainless steel 316RSV	Ti ELI	Titanium alloy (Ti6Al4V)	Titanium	Titanium 6%, aluminum 7%, niobium alloy (TAN)	Titanium	Titanium
One intermediary positioner works as a stabilizer for distal targeting	2.2 mm cannulation, 6° proximal bend and 4° distal bend	4° proximal bend (H); 2 midshaft holes (PH)	4° proximal bend; recommends shaft reaming for long nails	Divergent distal screws (25°)	15° proximal bend	Tapered nail profile, spiral proximal screw array
A metal attachment is attached to the jig with a screw and slot combination; technique recommends fluoroscope guidance	No distal jig targeting; technique recommends a limited open approach to avoid nerve damage	No distal jig targeting; no drill sleeve for freehand approach	No distal jig targeting	No distal jig targeting; perfect circle technique described in surgical technique	A metal attachment is attached to the jig with a screw and slot combination; technique recommends fluoroscope guidance	Polarus Plus Cane distal targeting device is used to target distal screw holes

holes allow increased holding strength in the nail, analogous to locking plate and screw fixation. These angular stable screws in intramedullary nails can provide firm anchoring for suture augmentation of the tuberosity fragments. Washers can be used in conjunction with the screws for fixing fragmented tuberosities, allowing compression of the surrounding bone against the nail. Nails are typically shorter to allow distal screw guides that do not require freehand drilling with radiographic control. Most have longer nail options for fracture that extends into the humeral shaft. Finally, distal locking configuration for the shorter versions can allow static or dynamic locking modes.

Preoperative assessment

Preoperative imaging

Before consideration of surgical repair of a proximal humerus fracture with an angular stable short humeral nail, standardized radiographs must be performed. These include true anteroposterior, axillary, and scapular Y views. Whereas motion may occur at the fracture site during the process of obtaining the radiographs, they provide baselines with which to compare and a standard against which one may compare alignment with nontraumatized humeri. Standard true anteroposterior views allow one to assess coronal alignment. Axillary views allow one to assess flexion-extension at the fracture site and, in particular, the lesser tuberosity and its possible involvement. Moreover, glenohumeral relationships are easily visualized on an axillary view. The scapular Y view allows one to assess anteroposterior alignment of the shaft with respect to the humeral head with the arm at the side, the most common position of immobilization. Although computed tomography scans may help differentiate complex cases and can be used on a case-by-case basis, plain radiographic images are the mainstay for proximal humerus fracture diagnosis and treatment.[5]

Classification and indications

Great variability exists with respect to surgical considerations as operative indications vary on the basis of patient and fracture variables. Traditionally, the Neer classification has been and remains the standard in the basic description of proximal humerus fractures, defining the “parts” of the humerus as the head, greater tuberosity, lesser tuberosity, and humeral shaft; 1 cm of displacement and 45° of angulation define the separate parts, and many surgeons continue to use this classification to frame their indications to support operative intervention in otherwise active patients with anything other than a 1-part fracture. Other classification systems have been developed as alternative classifications or modifications of Neer’s classification in an attempt to refine preferred operative indications.[9,15] However, the interobserver reliability results regarding proximal humeral fracture classification have generally been poor,[5,24] and surgical treatment decisions and the agreement between surgeons are even less clear. The complexities inherent in interobserver reliability classification problems and agreement on operative indications are far beyond the scope of this manuscript.

Surgical technique

Surgical setup

As with any procedure, surgeons have biases regarding the operating room setup for proximal humeral fracture treatment in open fashion. We have found that one may use a “lazy lateral” patient position with C-arm imagers approaching from the contralateral side of the table when short humeral nails are used for these fractures. Some prefer a beach chair position with C-arm approaching from the contralateral side of the table or from the head of the bed, facilitating true anteroposterior imaging for coronal alignment and medial-lateral nail position. With shoulder rotation, one may assess fracture alignment and nail position in the anteroposterior plane. Dynamic fluoroscopy can often be useful to confirm fracture reduction and optimal screw placement without an intra-articular breach.

Surgical approach

Our goal with approaching a proximal humerus fracture with a short humeral nail is to enter the humeral head at the lateral articular margin. This differs from the traditional approach of splitting the supraspinatus tendon laterally at its footprint. Rather, we prefer to sacrifice a bit of superior lateral humeral head articular cartilage in an effort to avoid complicating or potentiating rotator cuff disease and tears and to avoid potential sources of residual shoulder pain after fracture treatment (Fig. 1, *A*). With a more medial starting point, the supraspinatus muscle is more likely to be violated rather than the tendon and therefore has a greater potential to heal. Rotator cuff muscle violation occurs with every shoulder arthroscopy, and it seems most likely that placing nails the size of cannulas through muscle makes practical sense.

In an effort to achieve the more medial starting point, one may perform a standard deltoid-splitting approach at the raphe between the anterior and middle thirds of the deltoid. Frequently, depending on the medial-lateral size of the acromion or its projection, a more medial insertion site can be difficult to initiate and achieve. With slight shoulder extension, the more medial starting point can be easily accessed anterolateral to the acromion without sacrificing the coracoacromial ligament. In addition, other authors have identified Neviaser’s portal both in the laboratory[17] and clinically[8] as an entry route to better navigate the more medial site without damaging tendon structures. These approaches may be used in percutaneous fashion for nail instrumentation with or without

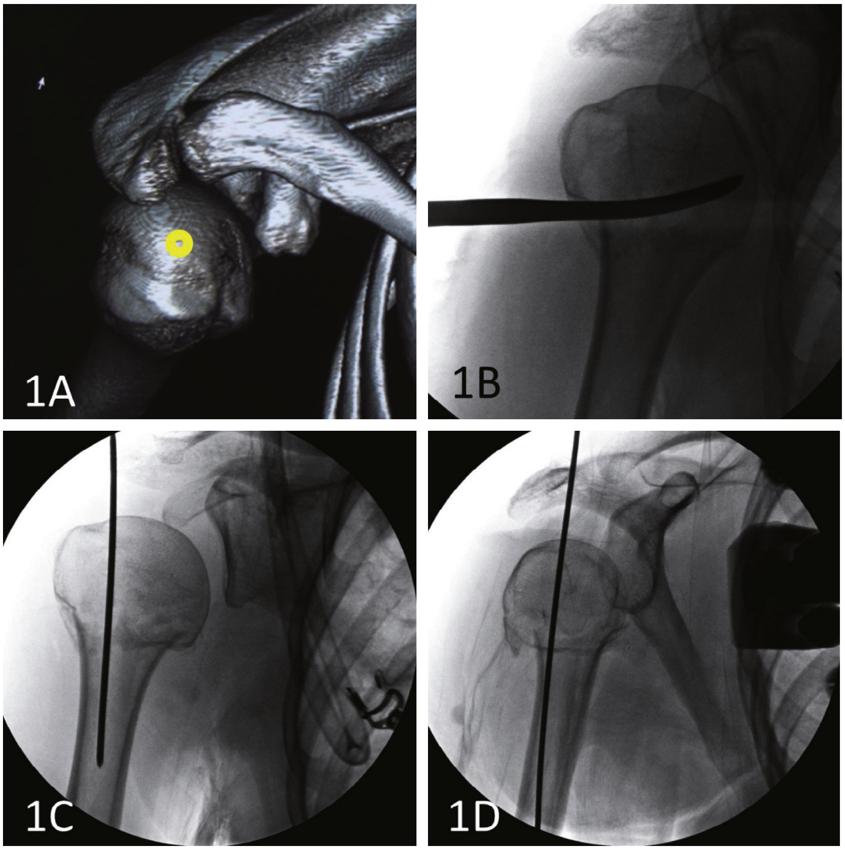

Figure 1 Straight humeral nails use a more medial starting point that sacrifices part of the superior humeral head articular surface, but the supraspinatus muscle is more likely to be violated rather than the tendon (**A**). A percutaneous reduction tool may be used through a separate small incision to help "lift" the humeral head out of its typical varus position (**B**). The optimal guide pin starting point should be confirmed on both anteroposterior and lateral radiographs before proceeding to ream for the nail (**C, D**).

accessory reduction incisions. Regardless of the approach, the surgeon must remain cognizant of the course of the axillary nerve. Whereas axillary nerve anatomy is relatively predictable,[26] it remains at risk during placement of the proximal interlocking screws.

Reduction

For some simpler reductions, such as 2-part surgical neck fractures, the nail itself may be placed through the head and then through the shaft, using the nail itself for the reduction. In this situation, optimizing the starting point of the nail in the proximal fragment is essential to avoid a varus malreduction. If it is performed through a percutaneous approach, a percutaneous reduction tool may be used through a separate small incision to help "lift" the humeral head out of its typical varus posture (Fig. 1, *B*). In an open approach, provisional K-wire fixation may be used, placing the wires in planes that will not interfere with eventual nail passage. For more complex fracture patterns, various tools and reduction techniques exist, including sutures placed in cuff tendons to facilitate "pulling" the head out of varus and a shoulder hook to accomplish the same; the same tools used in the percutaneous reduction can be used as well. By reducing the fracture from "above," it allows one better control of the tuberosities as opposed to operating "around the corner" as frequently occurs with plate application through an anterior approach.

If the fracture is exposed, reduction sutures can be used. In this situation, the surgeon can see where the fragments should be placed, but it can be difficult to maintain a reduction with a clamp or a K-wire, given the sometimes eggshell-like anatomy of the proximal humerus cortical bone. Drill holes are placed at corresponding positions along the fracture. With this approach, they can "key in," and a figure-of-8 suture can be placed through the fracture itself. This configuration prevents over-reduction and can facilitate easier nail preparation and placement. Regardless of the techniques used, an optimal guide pin starting point should be confirmed on both anteroposterior and lateral radiographs before proceeding to ream for the nail (Fig. 1, *C, D*). By better neutralizing the pectoralis major and deltoid and with their load-sharing properties, these nails may also allow more predictable head-shaft reductions. Moreover, they will likely create less trauma and therefore less postoperative surgical stiffness and hardware problems (Fig. 2).

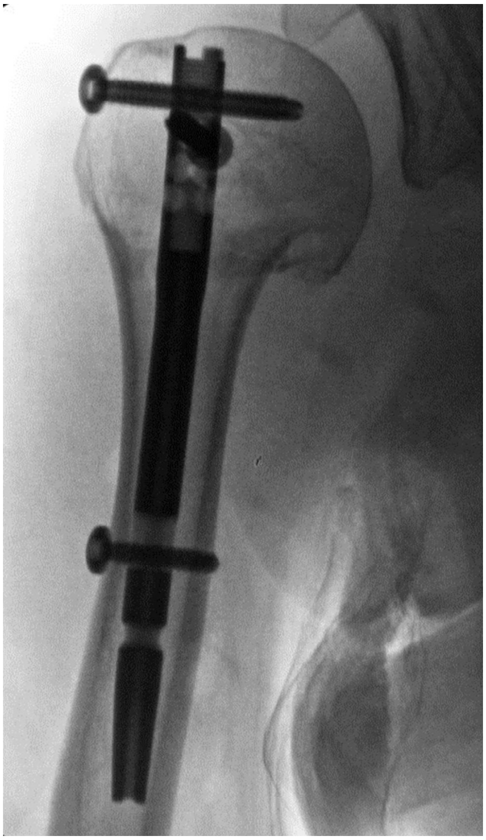

Figure 2 Final anteroposterior radiograph of the definitive nail demonstrates that light over-reduction of the humeral neck fracture is achieved with excellent reconstitution of the head-neck relationship. It is essential to avoid varus positioning or distraction of the fracture.

Nail height

Subacromial nail height can be deceiving as well. One must be constantly cognizant of the trajectory of the x-ray beam, shoulder rotation and its potential change through the procedure, and patient position. Changes in any of these can significantly change subacromial nail height.

Nail height in the humeral head can also affect the proximity of humeral head interlocking screws. Particularly with lateral-medial screws, one must always be cognizant of the axillary nerve. Knife blades should be used for skin only, with blunt dissection being performed through deltoid muscle to bone. From the lateral edge of the acromion, the average distance to the axillary nerve or its branches is 58 mm (38-70 mm).[26] More deeply placed nails carry a higher risk of nerve damage with lateral-medial interlocking screws. Oblique screws into the head also place the nerve and its branches at risk. Posterolateral screws have little risk of nerve damage, nor do distal locking screws for short nails.

Inferomedial screws

Calcar support with lateral to medial screws may be necessary for fractures with a varus posture in the main fracture line, as has been demonstrated in plate fixation studies.[13] It is unclear if this principle also applies to intramedullary nails. However, in some angular stable short-nail clinical studies, neck-shaft angle maintenance has been impressive.[14] Beyond calcar screws, additional sutures through rotator cuff tendons and then around interlocking screw heads can be used to further stabilize the fracture. Screws placed outside the nail may be used as well.

Results

In 2002, Cuny et al reported on the use of the Telegraph nail for proximal humerus fractures. As opposed to previous nail designs and techniques, this was straight, and the authors recommended an anterolateral approach through the medial and well-vascularized part of the cuff. These authors also reported the results of the first 64 nails inserted during the first year (1998-1999). Outcomes were "favorable," including those with 3- and 4-part fractures.[7]

Srám et al described benefits of the Targon PH long nail (Aesculap) that combined the long nail fixation with angle-stable screws proximally in their clinical follow-up study in 2007.[25] Füchtmeier et al followed this with a 2008 report of 36 patients treated with a Sirus nail using fixed-angle screws inserted in a locking technique for dislocated 2- and 3-part fractures. Outcomes were evaluated using the Constant score; 75% good to very good outcomes were achieved with an average of 79.2 at an average 12.1 months postoperatively.[12]

In 2009, Popescu et al described the use of the T2 proximal humerus nail. Mean Constant score in their 28 fractures, 7 of which involved the shaft, was 65.7, and the mean age-adjusted score was 76.1.[21] A U.S. report in 2009 on acute displaced proximal humerus fracture treated with a proximal locked antegrade humeral nail (Polarus) led the authors to conclude that proximal locked antegrade intramedullary nailing used in the treatment of displaced proximal humerus fractures resulted in predictable union and good alignment and function.[23] Zhu et al specified in their 2010 *Journal of Shoulder and Elbow Surgery* study that their 22 operative cases were in patients with 2-part surgical neck fractures treated with a locking proximal humerus nail. Mean active forward elevation was 147°, with all uniting by 8 weeks. All patients were satisfied.[27]

In 2009, Blum et al introduced and stressed the term *angle-stable intramedullary nailing* of proximal humerus fractures in their report of 151 proximal humerus fractures treated in this fashion to distinguish it from standard interlocking. Their patients had median Constant scores of 75.3 in the injured shoulder and 89.9 in the uninjured shoulder.[4] Konrad et al found similar outcomes between their 211 long nail and proximal humerus nail patients for displaced and unstable 3-part proximal humerus fractures.[18] Related to that, Hatzidakis et al reported on their clinical results after angular stable locked short intramedullary nailing of 2-part surgical neck fractures with a medial starting point. Although it was not novel with respect to the starting point, the study was confined to 1 type of fracture with an angular stable device. All of their fractures healed primarily with a mean follow-up Constant score of 71, a mean forward elevation of 132°, and all but 1 healing with a neck-shaft angle ≥125°. Mean Constant pain score was 13 (possible range, 0-15 points, with 15 points representing no pain).[14]

Hessmann et al confirmed good clinical results with the use of the MultiLoc nail that has short and long nail options with angular stable fixation in the humeral head. For their 2- to 4-part fractures, mean Constant score at follow-up was 66.[16] Freynik et al reported on angular stable devices for internal fixation of proximal humerus fractures with a mean postoperative Constant score of 67.4, noting the best clinical results with a postoperative head-shaft angle between 141° and 150°.[11]

However, not all reported results of modern humeral nailing techniques have been successful. Nolan et al reported on the use of the Polarus nail in treating 12 patients with 2-part and 6 patients with 3-part proximal humerus fractures. Using this short nail, this study reported a high complication rate; 9 of 18 shoulders had final neck-shaft angles <120° as the neck-shaft angle collapsed into varus by an average of 11°. The mean Constant and American Shoulder and Elbow Surgeons scores were 61 and 67, respectively; forward elevation averaged 118°. Patients had 5 of 8 positive rotator cuff signs. Seven patients underwent reoperations for loss of fixation or prominent hardware, and 1 required revision to a hemiarthroplasty.[20]

These studies illustrate that many variables affect the ultimate patient outcome in operative treatment of proximal humerus fractures. As outlined in the following, a host of complications can occur with intramedullary nailing of these fractures. However, with appropriate selection of patients and proper operative technique, the literature seems to support the efficacy of modern antegrade nailing for proximal humerus fractures.

Complications

The complications of antegrade nailing of proximal humerus fractures are similar to those of other common treatment modalities. Given the variety and evolution of nail design and techniques, it is difficult to precisely define published complication rates. Lanting et al performed a systematic review of 2155 patients in 66 studies treated for proximal humerus fractures with a variety of methods.[19] In compiling their data across all fracture types, there was an 11.9% complication rate for humeral nailing. There was a 5% incidence of nonunion or malunion and a 3.2% incidence of implant loosening or nail migration. The rate of osteonecrosis was 4.5%, but it was as high as 19.2% in 3- and 4-part fractures. Shoulder pain is a well-described complication of antegrade humeral nailing for humeral shaft fractures often attributed to iatrogenic rotator cuff injury.[3,6] However, there are so many causes of shoulder pain after proximal humerus fractures that it is difficult to attribute postoperative shoulder pain to the nail itself. Nerve injury has been described after humeral nailing and is usually attributed to the approach or locking screws, but it is rare. Stiffness is also a common complication after humeral fracture fixation and is a universal risk following these fractures regardless of the treatment method.

Conclusion

Improvements in implant design and proximal humeral nailing techniques continue to evolve. The basic principles involve fracture reduction to restore anatomic relationships, stability as required by the nature and the location of the fracture, preservation of blood supply, and early mobilization. Newer generation proximal humeral nail design and technique adhere to these principles and may lead to improved outcomes in the treatment of these problematic fractures. There are clearly patients who benefit significantly from proximal humeral nailing for displaced traumatic fractures, but uniform surgical indications are yet to be defined.

Surgical pearls

- The patient should be positioned to allow full shoulder motion to access the humerus before the procedure, and the ability to obtain adequate fluoroscopic imaging should be confirmed before preparation and draping.
- Reduction of the fracture is essential, and distraction at the fracture site must be avoided to minimize the nonunion risk.
- Iatrogenic shoulder pain is a well-described complication of antegrade humeral nailing[3,6] that is hypothesized to be due to rotator cuff damage during nail preparation and insertion. Obtaining access more medially through the supraspinatus muscle belly and obtaining a nail entry point at the superior articular surface are key to a good outcome.
- Anatomic reduction and stable fixation of the tuberosities are the most important factors in achieving a successful functional outcome, a widely accepted shoulder fracture surgery principle.[2,10] Rotator cuff tendons, which are often more robust than tuberosities in osteopenic fractures, should be incorporated into the fixation construct.
- Meticulous soft tissue management is vital to maintain the delicate blood supply to the humeral head from the tuberosities. Extensive stripping should be avoided, and indirect reduction techniques are encouraged.

- Whereas a variety of initial fracture patterns exist, the major deforming forces acting on proximal humerus fractures are predictable. These include posterior displacement of the greater tuberosity and varus alignment of the head by the posterosuperior rotator cuff, apex anterior head-neck alignment due to the proximal pull of the deltoid, and medial translation of the shaft by the pectoralis major. Augmentation of the nail, often with lateral and anterior tension bands that have been described with first-generation intramedullary techniques, can help counteract these forces and further stabilize the fixation construct.
- Reduction of the fracture before nail insertion is preferable, but it can be difficult to hold with traditional clamps and K-wires. Reduction sutures can be useful to obtain a direct reduction.
- Fixation should be stable enough to allow early range of motion and to minimize the risk of postoperative stiffness.
- Evidence-based, universal surgical indications for proximal humerus fractures are yet to be defined.

Disclaimer

Armodios M. Hatzidakis and Edward V. Fehringer receive royalties for the design of a humeral nail from Tornier that is related to the subject of this article. All 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.

References

1. Aaron D, Shatsky J, Paredes JC, Jiang C, Parsons BO, Flatow EL. Proximal humeral fractures: internal fixation. Instr Course Lect 2013;62:143-54.
2. Badman B, Frankle M, Keating C, Henderson L, Brooks J, Mighell M. Results of proximal humeral locked plating with supplemental suture fixation of rotator cuff. J Shoulder Elbow Surg 2011;20:616-24. http://dx.doi.org/10.1016/j.jse.2010.08.030
3. Baltov A, Mihail R, Dian E. Complications after interlocking intramedullary nailing of humeral shaft fractures. Injury 2014;45(Suppl 1):S9-15. http://dx.doi.org/10.1016/j.injury.2013.10.044
4. Blum J, Hansen M, Rommens PM. Angle-stable intramedullary nailing of proximal humerus fractures with the PHN (proximal humeral nail). Oper Orthop Traumatol 2009;21:296-311. http://dx.doi.org/10.1007/s00064-009-1806-4
5. Bruinsma WE, Guitton TG, Warner JJ, Ring D, Science of Variation Group. Interobserver reliability of classification and characterization of proximal humeral fractures: a comparison of two and three-dimensional CT. J Bone Joint Surg Am 2013;95:1600-4. http://dx.doi.org/10.2106/JBJS.L.00586
6. Chapman JR, Henley MB, Agel J, Benca PJ. Randomized prospective study of humeral shaft fracture fixation: intramedullary nails versus plates. J Orthop Trauma 2000;14:162-6.
7. Cuny C, Pfeffer F, Irrazi M, Chammas M, Empereur F, Berrichi A, et al. A new locking nail for proximal humerus fractures: the Telegraph nail, technique and preliminary results. Rev Chir Orthop Reparatrice Appar Mot 2002;88:62-7.
8. Dilisio MF, Fitzgerald RE, Miller ET. Extended Neviaser portal approach to antegrade humeral nailing. Orthopedics 2013;36:e244-8. http://dx.doi.org/10.3928/01477447-20130122-30
9. Edelson G, Safuri H, Salami J, Vigder F, Militianu D. Natural history of complex fractures of the proximal humerus using a three-dimensional classification system. J Shoulder Elbow Surg 2008;17:399-409. http://dx.doi.org/10.1016/j.jse.2007.08.014
10. Frankle MA, Mighell MA. Techniques and principles of tuberosity fixation for proximal humeral fractures treated with hemiarthroplasty. J Shoulder Elbow Surg 2004;13:239-47. http://dx.doi.org/10.1016/S1058-2746(02)00041-1
11. Freynik F, Freynik S, Zenker W, Pflugmacher R. Angular and sliding stable internal fixation of proximal humerus fractures using the "Varion" intramedullary nail. Z Orthop Unfall 2013;151:343-9. http://dx.doi.org/10.1055/s-0033-1350626
12. Füchtmeier B, Bröckner S, Hente R, Maghsudi M, Nerlich M, Prantl L. The treatment of dislocated humeral head fractures with a new proximal intramedullary nail system. Int Orthop 2008;32:759-65. http://dx.doi.org/10.1007/s00264-007-0390-1
13. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma 2007;21:185-91. http://dx.doi.org/10.1097/BOT.0b013e3180333094
14. Hatzidakis AM, Shevlin MJ, Fenton D, Everett D, Nowinski RJ, Fehringer EV. Angular-stable locked intramedullary nailing of two part surgical neck fractures of the proximal humerus. A multicenter retrospective observational study. J Bone Joint Surg Am 2011;93:2172-9. http://dx.doi.org/10.2106/JBJS.J.00754
15. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 2004;13:427-33. http://dx.doi.org/10.1016/j.jse.2004.01.034
16. Hessmann MH, Nijs S, Mittlmeier T, Kloub M, Segers MJ, Winkelbach V, et al. Internal fixation of fractures of the proximal humerus with the MultiLoc nail. Oper Orthop Traumatol 2012;24:418-31. http://dx.doi.org/10.1007/s00064-011-0085-z
17. Knierim AE, Bollinger AJ, Wirth MA, Fehringer EV. Short, locked humeral nailing via Neviaser's portal: an anatomic study. J Orthop Trauma 2013;27:63-7. http://dx.doi.org/10.1097/BOT.0b013e31825194ad
18. Konrad G, Audigé L, Lambert S, Hertel R, Südkamp NP. Similar outcomes for nail versus plate fixation of three-part proximal humeral fractures. Clin Orthop Relat Res 2012;470:602-9. http://dx.doi.org/10.1007/s11999-011-2056-y
19. Lanting B, MacDermid J, Drosdowech D, Faber KJ. Proximal humeral fractures: a systematic review of treatment modalities. J Shoulder Elbow Surg 2008;17:42-54. http://dx.doi.org/10.1016/j.jse.2007.03.016
20. Nolan BM, Kippe MA, Wiater JM, Nowinski GP. Surgical treatment of displaced proximal humerus fractures with a short intramedullary nail. J Shoulder Elbow Surg 2011;20:1241-7. http://dx.doi.org/10.1016/j.jse.2010.12.010
21. Popescu D, Fernandez-Valencia JA, Rios M, Cuñé J, Domingo A, Prat S. Internal fixation of proximal humerus fractures using the T2-proximal humeral nail. Arch Orthop Trauma Surg 2009;129:1239-44. http://dx.doi.org/10.1007/s00402-008-0789-1
22. Rangan A, Handoll H, Brealey S, Jefferson L, Keding A, Martin BC, et al. Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. JAMA 2015;313:1037-47. http://dx.doi.org/10.1001/jama.2015.1629
23. Sforzo CR, Wright TW. Treatment of acute proximal humerus fractures with a Polarus nail. J Surg Orthop Adv 2009;18:28-34.
24. Sidor ML, Zuckerman JD, Lyon T, Koval K, Cuomo F, Schoenberg N. The Neer classification system for proximal humeral fractures. An

assessment of interobserver reliability and intraobserver reproducibility. J Bone Joint Surg Am 1993;75:1745-50.
25. Srám J, Lukás R, Krivohlávek M, Taller S. [Application of the Targon PH long nail in storey fractures and metaphyseal fractures of the proximal humerus]. Rozhl Chir 2007;86:254-62.
26. Sung CM, Roh GS, Sohn HJ, Park HB. Prediction of the location of the anterior branch of the axillary nerve, using correlations with physical factors: a cadaveric study. J Shoulder Elbow Surg 2013;22:e9-16. http://dx.doi.org/10.1016/j.jse.2013.01.021
27. Zhu Y, Lu Y, Wang M, Jiang C. Treatment of proximal humeral fracture with a proximal humeral nail. J Shoulder Elbow Surg 2010;19:297-302. http://dx.doi.org/10.1016/j.jse.2009.05.013