Four-part proximal humerus fractures: evaluation and treatment

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Proximal humerus fractures represent 4% to 5% of all fractures and are the most common fractures of the shoulder girdle. Retrospective epidemiologic reviews have demonstrated that proximal humerus fractures accounted for 53% of all significant shoulder girdle injuries [1]. Most of these fractures are the result of a fall, and the female-to-male ratio is 2:1. Furthermore, increasing age has been shown to correlate with increasing fracture risk in women, suggesting an association with osteoporosis. Fractures of the humerus also represent the third most common fracture in the elderly (with only hip fractures and Colles' fractures being more common), and the prevalence of proximal humeral fractures in the elderly has been increasing in recent decades, although the underlying cause for this trend is not clear [2].

Clinical Presentation

The shoulder girdle is often extremely swollen after proximal humeral fracture, with ecchymosis often tracking down the arm and into the chest. Because most patients who have proximal humeral fractures are elderly, assessment for concomitant injuries is paramount. Head injuries from the fall, cardiac or neurologic reasons for the fall, and other fractures are often first diagnosed at the initial evaluation for the shoulder injury.

Electromyographic evaluation has demonstrated that approximately two thirds (67%) of all patients who have proximal humeral fractures suffer acute neurologic injury from the violence of the injury. Most commonly, this involves either the axillary nerve (58%) or the suprascapular nerve (48%). Appreciation and documentation of this finding is important for prognostic evaluation and appropriate management of the injury.
RADIOGRAPHIC EVALUATION

Initial radiographic evaluation consists of the classic Neer trauma series with orthogonal views (anteroposterior, scapular “Y,” or axillary views). Because of the anatomy of the proximal humerus, it may be difficult to appreciate fracture lines and fragment displacement. If plain radiographs do not offer adequate visualization, a CT scan with reconstructions may be necessary.

Classification

Neer’s four-part classification system of proximal humerus fractures has endured by virtue of its simplicity. It allows for a conceptual understanding of the fracture pattern by dividing the fracture into separate parts. However, interobserver reliability and intraobserver reproducibility has been reported to be only poor to fair. Recently, a “comprehensive binary” description of fractures, based on Codman’s original concept of fracture planes rather than fracture parts, has been described [3]. These fracture planes run along the physeal lines of the proximal humerus. The system results in 12 possible fracture patterns: 6 patterns resulting in two fracture fragments, 5 patterns resulting in three fracture fragments, and 1 pattern resulting in four fracture fragments. This system has demonstrated improved interobserver reliability and better intraobserver reproducibility. The focus of this article is the evaluation and treatment of fractures of the proximal humerus in which four fracture fragments are involved.

DECISION-MAKING ALGORITHM

Most proximal humerus fractures not involving four fracture segments are managed conservatively. However, after defining the fracture as one in which four fracture segments are involved, one must first assess the viability of the humeral head. Hertel [3] prospectively evaluated 100 intracapsular fractures of the proximal humerus for perfusion intraoperatively, by observation of backflow through a centrally placed bonehole in the humeral head and by intraoperative laser Doppler. When combined with preoperative radiographs, ischemia of the humeral head correlated with posteromedial metaphyseal extension of less than 8 mm and disruption of the medial hinge, defined as displacement of the humeral shaft, of more than 2 mm. These two preoperative findings, in combination with an anatomic neck fracture, resulted in a 97% positive predictive value for humeral head ischemia. It is the authors’ recommendation that four-part anatomic neck fractures with posteromedial metaphyseal extension of less than 8 mm and a medial hinge disruption of greater than 2 mm be treated with arthroplasty. On rare occasions, the medial hinge may be intact and indicate potential head viability, leading to management with osteosynthesis.
SURGICAL TECHNIQUES

Osteosynthesis techniques

When the humeral head is deemed viable and fracture fixation is attempted, many methods of fracture fixation are available, each with inherent advantages and disadvantages. Percutaneous fixation can be performed with minimal soft tissue stripping and devascularization (fig. 1). The largest reported peer-reviewed series on 27 three- and four-part proximal humerus fractures treated with percutaneous pin fixation demonstrated good to very good results in all three-part fractures at average 24-month follow-up [4]. The patients who had four-part fractures did not do as well, with 2 of the 18 patients eventually requiring revision to a prosthesis, 1 patient because of avascular necrosis and another for displacement.

When percutaneous techniques are not possible because of inadequate reduction or poor bone quality, proximal humeral plating allows for potentially greater control of, and ability to manipulate, individual fracture fragments into anatomic alignment (fig. 2). This direct exposure comes at the cost of soft tissue stripping, which may lead to complications, and in osteoporotic bone, adequate fixation may be difficult. Recent advances in plate designs, such as proximal humeral locking plates, have renewed interest in this treatment option, and cadaveric studies demonstrate improved resistance to torsion in locking plate constructs when compared with fixed angle blade plates [5]. These differences were particularly pronounced in osteoporotic specimens.

Intramedullary nails designed for proximal humeral fixation remain enticing but current designs still demonstrate higher postoperative dissatisfaction rates with rotator cuff pain and dysfunction. Hence, the authors do not advocate current intramedullary nailing techniques.

Fig. 1: (A) Preoperative anteroposterior radiograph of a proximal humerus fracture. (B) Postoperative anteroposterior radiograph of proximal humerus fracture treated with closed reduction and percutaneous pinning. (From Krishnan S., Sumant G., Pennington S.D. et al. Shoulder arthroplasty for fracture: restoration of the "gothic arch". Techniques in Shoulder & Elbow Surgery 2005;6(2):57–66; with permission.)
Shoulder arthroplasty for fracture

Primary hemiarthroplasty for fractures of the proximal humerus can result in good patient satisfaction and pain relief when osteosynthesis is not possible (fig. 3). A recent retrospective review of 66 patients who underwent hemiarthroplasty for proximal humerus fracture demonstrated that 93% were pain free and satisfied with their results [6]. Other studies have also demonstrated successful pain relief but poorer functional outcomes with hemiarthroplasty, when compared with replacement arthroplasty performed for osteoarthritis.

Recent work has highlighted the importance of intraoperatively restoring anatomic humeral height, humeral version, and tuberosity reconstruction to improve outcomes after arthroplasty for shoulder fracture. The importance of anatomic repositioning of the tuberosities when performing hemiarthroplasty for proximal humeral fracture was demonstrated in a recent cadaveric study [7]. In these cadaveric shoulder specimens, four-part proximal humerus fractures were created and repaired with a shoulder hemiarthroplasty in which the tuberosities were intentionally positioned either anatomically or nonanatomically. The biomechanical effects of this tuberosity positioning demonstrated that anatomic repositioning of the tuberosities around a shoulder hemiarthroplasty produced external rotation kinematics identical to the native shoulder. When the tuberosities were malpositioned, however, an eightfold increase in torque was required to achieve the same degree of external rotation.
In these studies, radiographic evidence of final tuberosity malpositioning correlated with poor functional results. Malpositioning of the prosthesis itself in turn correlated with tuberosity malposition. Boileau has pointed out the "unhappy triad" in which a prosthesis not only has excessive height but also is in excessive retroversion, and the greater tuberosity has been positioned too low. This combination was associated with poor functional results, persistent pain, and stiffness in all cases. It is clear from these studies that careful attention to the recreation of proximal humeral anatomy is critical in shoulder fracture arthroplasty.

The "Gothic arch" reconstruction

The "Gothic arch" is the authors' term for the architectural anatomy of the proximal shoulder girdle. The arch is easily seen on a normal radiograph by tracing the medial border of the proximal humeral calcar to the articular surface and joining this with the lateral border of the scapula to the articular surface; joining these lines forms the classical vaulted or Gothic arch shape seen in medieval period renaissance architecture (fig. 4). Restoration of this Gothic arch provides a very reproducible technique for recreating proper humeral height and improving the potential for anatomic tuberosity reconstruction.

Preoperative radiographs are paramount in reproducible shoulder fracture arthroplasty and are used to determine the distance from the fracture line at the medial calcar to the desired height of the humeral head. By measuring the...
Fig. 4: Gothic arch of a normal shoulder girdle. (1) Outline of the medial border of the proximal humeral shaft (medial calcare) to the base of the humeral articular surface. (2) Outline of the lateral border of the scapula to the base of the glenoid articular surface. (3) Joining these lines creates a classical vaulted arch or Gothic arch shape. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the "Gothic arch". Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.)

Fig. 5: (A) N 1/4 entire length of normal humerus along perpendicular from medial epicondyle to top of humeral head. Use scaled ruler on radiograph to calculate radiographic magnification and obtain actual number. (B) F 1/4 length of injured humerus along perpendicular from medial epicondyle to fracture at superior edge of medial calcare. Use scaled ruler on radiograph to calculate radiographic magnification and obtain actual number. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the "Gothic arch". Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.) (C) N — F = H, H is the fracture to top of head height.

Calculations to Restore Gothic Arch

<table>
<thead>
<tr>
<th>Normal side</th>
<th>Fracture side</th>
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<tbody>
<tr>
<td>Ruler</td>
<td>Ruler</td>
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<tr>
<td>X-ray 11.2 cm</td>
<td>X-ray 12.1 cm</td>
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<tr>
<td>Actual 10.0 cm</td>
<td>Actual 10.0 cm</td>
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<tr>
<td>Magnif. 1.12 cm</td>
<td>Magnif. 1.21 cm</td>
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Humeral length (N)

<table>
<thead>
<tr>
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<th>Fracture side</th>
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<tbody>
<tr>
<td>X-ray 36.0 cm</td>
<td>X-ray 32.8 cm</td>
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<tr>
<td>Actual 31.3 cm</td>
<td>Actual 29.9 cm</td>
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</tbody>
</table>

Step 1. Fx to top of head: N - F = H
Actual N (31.3 cm) Minus Actual F (26.9 cm) Equals H (4.4 cm)

Step 2. Greater tuberosity length (G)

<table>
<thead>
<tr>
<th>Normal side</th>
<th>Fracture side</th>
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<tr>
<td>X-ray 5.5 cm</td>
<td>X-ray 4.5 cm</td>
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| Actual 4.5 cm        | (This number should be within 3-5 mm of fracture to top of head "H")
injury films and the contralateral humerus, an accurate assessment of humeral height can be made (fig. 5). The authors obtain full-length scaled radiographs of the injured and the contralateral humeri with a ruler of defined length. These radiographs can even be done in the operating room immediately before surgery and should not be overlooked (fig. 6). Although surgeons in the past have subjectively “eyeballed” appropriate prosthetic position, this simple preparation allows an easy, reproducible, and accurate restoration of proximal humeral anatomy.

Fig. 6: (A) Scaled radiograph of normal humerus. (B) Scaled radiograph of injured humerus. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the “gothic arch”. Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.)

In addition, the authors also measure the length of the greater tuberosity fragment to ensure that humeral prosthetic height will allow for anatomic tuberosity reconstruction. This measurement is compared with the intraoperative length of the greater tuberosity fragment, which is perhaps the most important measurement because the greater tuberosity should sit 3 to 5 mm below the prosthetic head.

Restoration of the Gothic arch

The patient is placed in a modified beach-chair position, with the scapula supported. A 2.5- to 3-in deltopectoral approach is used. The authors have found that a well-placed incision and a mobile soft tissue window permits the procedure to be performed easily through this limited incision (fig. 7). With adequate exposure, the fracture is visualized. Typically, the fracture line can be located with a blunt elevator or osteotome between the tuberosities, just posterior to the bicipital groove. Four horizontal mattress nonabsorbable sutures are placed around the greater

Fig. 7: Limited 3-in modified deltopectoral incision used for shoulder fracture arthroplasty. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the “gothic arch”. Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.)
tuberosity at the bone–tendon junction (two in the infraspinatus and two in the teres minor). Two temporary stay sutures are placed around the lesser tuberosity at the subscapularis/bone tendon junction. The tuberosities are gently retracted apart. The head fragment is removed and measured with a caliper. If the humeral head falls in between sizes, the smaller size is selected. Structural cancellous bone graft is procured from this articular fragment.

The medullary canal is prepared using cylindric reamers and fracture-specific trial implants (Aequalis Fracture Prosthesis, Tornier, St. Ismier, France) of increasing diameter by hand. Once the appropriate trial implant and head size are determined, retroversion is selected by facing the prosthetic head toward the glenoid with the forearm in neutral rotation at the side (approximately 20° of retroversion relative to the transepicondylar axis of the elbow).

Fig. 8: Medial calcar (arrows) of the proximal humerus is the portion of the humeral shaft just below the inferior limit of the anatomic neck. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the “Gothic arch”. Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.)

The dedicated fracture-specific prosthetic stem of the appropriate diameter is opened and the preselected trial head is placed on this definitive implant with the eccentric head offset rotated into the most lateral position, which allows for the least amount of medial overhang of the humeral head during the all-important restoration of the Gothic arch.

This surgical technique differs from previously described techniques that reference the prosthetic humeral reconstruction off the lateral portion of the humerus and humeral metaphysis. In most proximal humeral fractures, the medial calcar of the proximal humerus is intact (this calcar is the proximal medial humeral shaft just inferior to the anatomic neck) (fig. 8). In the few cases where the medial calcar is fractured, this fragment is often large and can be rigidly fixed with simple wire or heavy suture fixation. By referencing the reconstruction off the medial calcar, the Gothic arch can be recreated objectively in a methodic fashion (fig. 9).

Using the preoperative radiographic calculations previously described, the appropriate mark is placed on the prosthetic implant and the implant is placed into the humeral shaft with the appropriately selected trial head. The lateral half of the Gothic arch (medial calcar of the humerus up to the inferior margin
of the anatomic neck) should be unbroken (fig. 10). If the arch is not “visualized,” it will be for one of the following reasons:

- The prosthetic height is incorrect (usually too high).
- The medial calcar is fractured and has not been restored.
- The head size is either too large or has not been rotated into the most lateral offset position.

**Fig. 9:** (A) Greater tuberosity length (G) is measured and corrected for radiographic magnification using scale on radiograph. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the “Gothic arch”. Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.) (B) This number should be within 3 to 5 mm of the fracture to top of head height (H) that was marked on the prosthetic implant.

**Fig. 10:** (A) Gothic arch restoration with trial head on actual implant. Implant has been placed to predetermined mark and confirmed with ruler. (B) Final Gothic arch restoration. (From Krishnan S, Sumant G, Pennington SD, et al. Shoulder arthroplasty for fracture: restoration of the “Gothic arch”. Techniques in Shoulder & Elbow Surgery 2005;6(2):57-66; with permission.)
After establishing the arch, two drill holes are placed in the proximal humeral shaft before final prosthetic cementation. Two nonabsorbable sutures are placed in these holes in a horizontal mattress fashion to be used as tension-band sutures for final tuberosity osteosynthesis. The stem is cemented, using a standard third-generation technique, to the predetermined depth and rotation, in slight valgus. Three structural cancellous bone graft wedges that were previously obtained from the fractured humeral head are then placed as follows:

1) In the “window” of the fracture-specific prosthesis
2) Under the greater tuberosity at the lateral fin of the prosthesis
3) Under the medial edge of the prosthetic head between the head and neck of the implant.

Tuberosity osteosynthesis is performed as described elsewhere, and the biceps is tenodesed within the intertubercular groove/rotator interval to soft tissue (fig. 11) [8, 9]. The shoulder is placed through a full range of motion, to ensu-

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Fig. 11: (A) Six-suture configuration for anatomic tuberosity osteosynthesis. (B) Greater tuberosity fixation over lateral bone graft. (C) Lesser tuberosity fixation over medial bone graft. (D) Final tuberosity osteosynthesis with tension-band sutures passed through anterosuperior and posterosuperior cuff.
there no micromotion of the tuberosity fragments. Passive intraoperative range of motion should be at least 160° of elevation, 40° of external rotation, and 70° of internal rotation. Postoperative radiographs should demonstrate anatomic reconstruction of the proximal humerus (fig. 12).

Postoperatively, patients are placed into a SmartSling orthosis (Innovation Sports, Ossur, California) for 6 weeks. Immediate supine passive motion is begun the day after surgery, with motion limits dictated by the intraoperative evaluation following tuberosity osteosynthesis. Active motion is allowed at 7 weeks after surgery. Resistance exercises begin 10 weeks after surgery.

CLINICAL RESULTS
AFTER SHOULDER
ARTHROPLASTY FOR
FRACTURE

Using this approach, the authors have retrospectively reviewed 130 consecutive patients who had proximal humerus fractures who underwent the Gothic arch technique for fracture arthroplasty at minimum 2-year follow-up. Mean active anterior elevation was 129° (range 50–165), mean American Shoulder and Elbow Society (ASES) score was 74 (range 10–100), and 114 (88%) greater tuberosities healed anatomically. Pain scores averaged 1.2 (0 1/4 no pain; 10 1/4 worst pain). Satisfaction averaged 9.1 (0 1/4 unsatisfied; 10 1/4 completely satisfied). For patients with active anterior elevation (AAE) greater than 120° (106 cases), mean age was
62 years, mean AAE was 146°, mean ASES score was 86, and 94% of tuberosities healed. Those with AAE less than 120° (24 cases) had mean age of 82 years, mean AAE of 95°, mean ASES score of 46, and 61% of tuberosities healed (P<.03). For patients who had fracture-specific prosthesis (65 cases), mean AAE was 140°, mean ASES score was 82, and 92% of tuberosities healed (P <.05) [10, 11].

SUMMARY

Four-part proximal humerus fractures represent a difficult entity in the management of upper extremity trauma. Most of these fractures are not amenable to operative fixation; thus, surgical address is necessarily one of fracture arthroplasty. Timely reestablishment of the Gothic arch using a fracture-specific prosthesis leads reliably to anatomic tuberosity osteosynthesis. Hence, shoulder arthroplasty for fracture should be considered an augmented osteosynthesis, with precise prosthetic implantation supplementing anatomic tuberosity reconstruction. Further investigations are ongoing regarding the use of specific fracture implants and biologic substrates in an attempt to improve further the rate of tuberosity healing in the older patient population after this operation.

REFERENCES