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Open reduction and internal fixation of the proximal humerus with femoral head allograft augmentation “the French fry technique”

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Fractures of the proximal humerus account for 4%-8% of injuries to the appendicular skeleton. Most are stable, minimally displaced osteoporotic fractures in the elderly, and are the result of low-energy falls. A large majority of these patients regain adequate shoulder function without operative intervention. Surgery is considered in approximately 20% of patients because they require improved shoulder function for their activities of daily living or because of the significant deformity of their fracture and the need to restore functional alignment, length, and rotation in active, higher demand individuals. However, fixation of these fractures can pose a challenge due to poor bone quality and displacing forces of the rotator cuff. This is especially true in 3-part and 4-part fractures. These factors lead to the high failure rates seen with early attempts at osteosynthesis. In the last 2 decades, locking plate technology has been an innovation in treating these complex fractures. Despite the improvements in torsional strength and rigidity, outcome studies on locking plate technology demonstrate equivocal results with complication rates as high as 20%-30% and a revision rate of 10%. Specifically, these complications include avascular necrosis, varus collapse, intra-articular screw penetration, and postoperative stiffness. Varus collapse occurs when the weak osteoporotic bone fails around the implant. In turn, fibular strut endosteal augmentation was introduced to provide additional support and decrease implant failure rates in displaced fractures with varus coronal malalignment and significant metaphyseal bone loss. Although clinically successful and biomechanically superior to plate-only constructs, a few concerns remain. In turn, we introduce a novel technique of creating individual cancellous femoral head allograft struts or “French fries” that provides structural support for the humeral head but does not have the potential problems of a cortical fibular strut.

Fractures of the proximal humerus account for 4%-8% of all fractures and are the third most common type of injury in patients aged > 65 years.[2,4,23,37] The rate of proximal humerus fractures has been steadily increasing in North America over the past 30 years at a rate of approximately 13% per year.[14,21,24,31] This may be attributed to the aging population and the associated increase in incidence of osteoporosis.[15,20] Although proximal humerus fractures are frequently encountered in orthopedic practice, the majority (up to 80%) are nondisplaced or stable and can be treated nonoperatively with good functional outcomes.[10,16,18]

The treatment of displaced fractures, however, remains controversial. In their level I study, Handoll et al have suggested that at 5 years, displaced surgical neck fractures in older individuals managed nonoperatively may do as well as those treated surgically.[13] Similarly, operative treatment is rarely indicated in the very elderly (aged > 85 years), those with cognitive impairment, a nonfunctional limb, or severe medical comorbidity.[11] Based on poor historical outcomes with expectant management,[1,5,17,37] surgical treatment of younger patients remains the optimal choice. Unfortunately, operative intervention can be challenging; bone fragments are often of poor quality and are subject to the deforming forces of the rotator cuff. These factors have led to higher failure rates seen with early attempts at osteosynthesis.[1] Suboptimal surgical outcomes have led to many alternative surgical strategies with mixed results. The optimal treatment for proximal humerus fractures is yet to be elucidated.[5,15,17,32]

Institutional review board approval was not required for this technical note.

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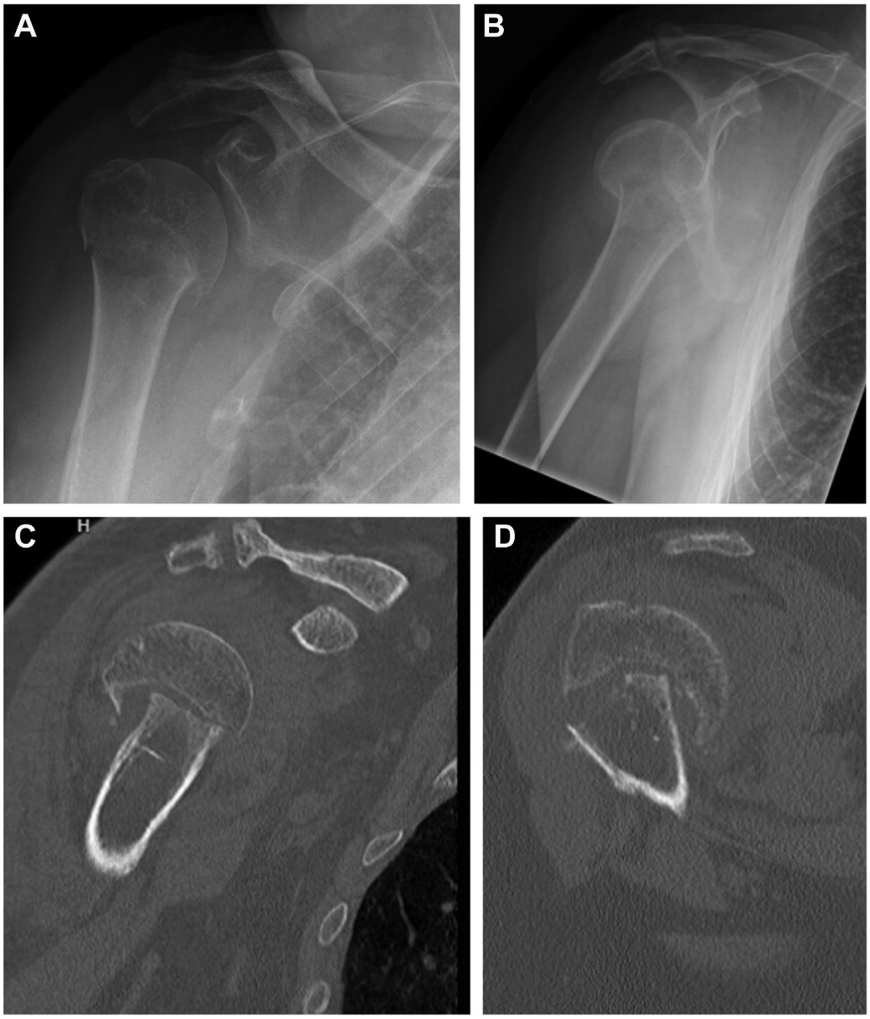

Figure 1 Example of a 58-year-old patient who sustained a mechanical fall onto his shoulder. Initial radiographs (A anteroposterior and B lateral) show a well-reduced, non-comminuted 2-part proximal humerus fracture with an intact medial hinge. Nonoperative management ensued; the patient was made nonweight-bearing to the affected extremity and placed in a Velpeau sling. A CT scan 6 weeks post injury (C sagittal view and D coronal view) shows varus collapse of the 2-part fracture with considerable loss of cancellous metaphyseal bone of the humeral head. *CT*, computed tomography.

In the past 2 decades, locking plate fixation has been an innovation in treating these complex fractures. Each screw acts as a miniature blade plate, angular stable scaffolding for osteoporotic bone.[15] Locking plates have better rigidity and torsional stability in comparison with blade plates or intramedullary nail fixation.[1,36] Despite the improvements in torsional strength with locked plates, numerous publications reported poor initial results, with complication rates as high as 20%-30% and a reoperation rate of 10%.[38,40] Specifically, these complications included avascular necrosis, varus collapse, intra-articular screw penetration, and nonunion.[1,11] Varus collapse is the most common failure pattern following fracture fixation of the proximal humerus,[6,7,40] and the risk is increased with substantial humeral head bone loss (Fig. 1).[6]

Bone allografts have been successfully used to structurally augment unstable proximal humerus fractures[6,30] and have predominantly been used for the surgical management of nonunions and fracture reconstructions; they are available as formulations ranging from osteobiologics (ie, calcium phosphate or sulfate cement) and cancellous chips to large structural grafts.[6,31,34,37] The structural graft most reported to date is fibular strut allograft. The use of fibular graft to augment locked plate fixation has been shown to increase overall construct stiffness and maximal load to failure[33] while providing medial calcar support; this, in turn, decreases the risk of varus humeral head collapse and secondary intra-articular screw penetration.[9] Many biomechanical and clinical studies have demonstrated that the combined use of intramedullary fibular strut allograft with locked plating can provide improved outcomes for complicated proximal humerus fractures.[25,26,28,31,33,39] Despite its clinical and biomechanical success, concerns remain.

Femoral head allograft augmentation in the proximal humerus was first described by Euler et al in the fixation of unstable, varus displaced 2-part proximal humerus fractures with good results.[6] In that study, a thawed fresh frozen femoral head allograft was fashioned into a mushroom-shaped cancellous allograft which was then impacted into the humeral shaft. The cancellous allograft provided intrinsic stability and promoted fracture healing; their cohort of "high risk" patients all showed solid union without secondary varus displacement at 2 years following fracture fixation. They concluded that using a cancellous femoral head allograft may

Figure 2 The patient in the beach-chair position with the bony landmarks of the shoulder marked: clavicle, acromion, scapular spine, acromioclavicular joint, and coracoid. The planned skin incision for the deltopectoral interval is also marked starting 1 cm lateral to the coracoid and extending distally 12-14 cm toward the deltoid tuberosity.

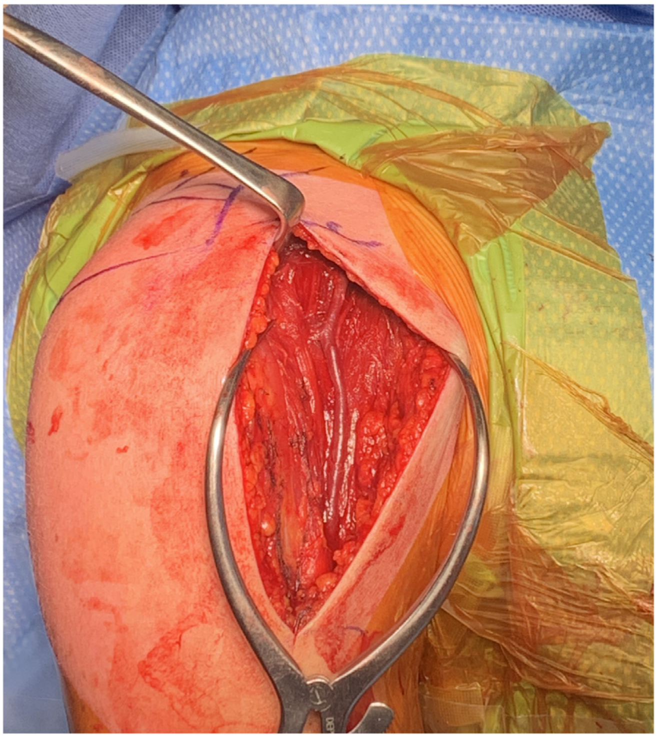

Figure 3 Exposure of the cephalic vein and the deltopectoral interval.

be a viable and reliable alternative to prevent early varus failure and nonunion.

In this article, we present a novel technique of using cancellous femoral head allograft fashioned into longitudinal cancellous struts or “French fries” to reconstruct the humeral metaphysis during fixation of proximal humerus fractures.

Indications

The ideal fracture pattern for use of allograft augmentation in the proximal humerus is in a patient with significant metaphyseal comminution compromising the medial calcar.[3] In 3-part and 4-part valgus impacted fractures, there is usually a substantial defect in the metaphysis after reduction.

Structural allograft may also be used as a ‘strut’ to improve the stability of fractures in which the humeral head is displaced into varus, or if there is instability due to loss of the posteromedial calcar.[6,8] It may also serve as a space-filler in anterior and posterior fracture-dislocations, where there is a humeral head impaction fracture resulting in a defect.[29] Patients with overall poor bone quality, such as in osteoporosis, can be considered for allograft augmentation use as well.

In those patients with fracture patterns that maintain relative alignment outside of varus (neutral or valgus) and ample bone stock in the humeral head and metaphysis, allograft augmentation may not be required.

Surgical technique

Positioning

Patients are typically placed under general anesthesia for the procedure, with the use of a regional interscalene nerve block on the affected extremity. The patient is placed in the beach-chair position, with the head of the bed elevated 45°-60° relative to the horizontal and the shoulder off the edge of the table to allow full range of motion (ROM) of the extremity during the operation. The cervical spine and head are secured appropriately in a neutral position. The bed is rotated 45° so that the operative arm faces the main operating space. Once the patient has been positioned, the large fluoroscan is brought over the fractured extremity from the head of the table with the monitor across from the patient. Prior to sterile draping, confirm that adequate fluoroscopic images, including anterior posterior and axillary views, can be obtained during the procedure. The patient is prepped and draped in the usual sterile manner and the axilla is cordoned off with Ioban and the affected arm placed into a pneumatic arm holder throughout the operation.

Approach

The bony landmarks of the shoulder are marked on the skin including the clavicle, acromion, spine of the scapula, acromioclavicular joint, and coracoid (Fig. 2).

A standard deltopectoral approach is used to access the proximal humerus. An incision is made starting 1 cm lateral to the coracoid and extending distally 12-14 cm toward the deltoid tuberosity (Fig. 2). Dissection is performed to identify the cephalic vein, located in the internervous plane between the deltoid (axillary nerve) and pectoralis major (medial and lateral pectoral nerves) (Fig. 3).

The cephalic vein is typically mobilized medially, taking care to identify and cauterize any lateral vascular tributaries. Dissection is carried down to the clavipectoral fascia. The pectoralis major tendon is identified and preserved. The arm is then abducted to 45° and the subacromial and subdeltoid space is developed bluntly with a Cobb elevator. Once subdeltoid adhesions have been sufficiently released, a blunt Hohmann retractor is placed inferior to the coracoacromial ligament and superior to the humeral head to retract the deltoid laterally. If the fracture has not disrupted the

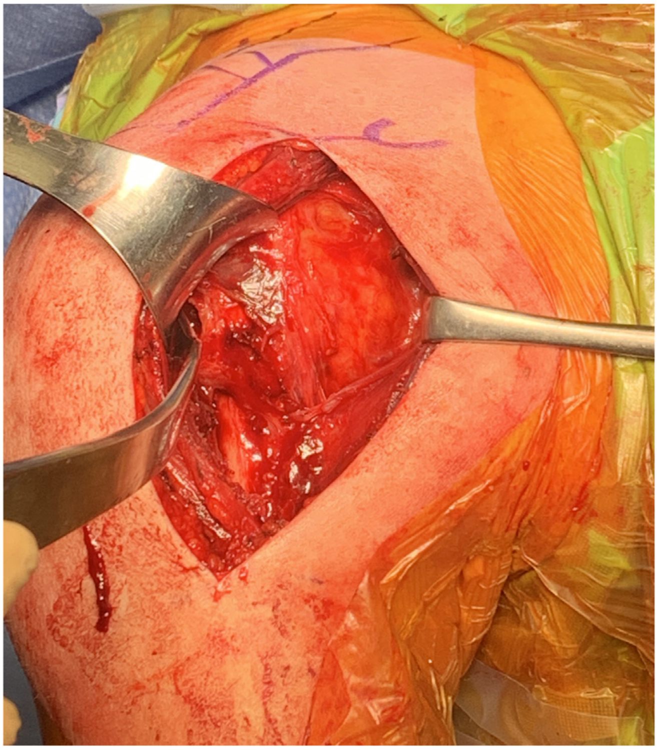

Figure 4 Exposure of the subscapularis musculotendinous junction. The cephalic vein has been mobilized medially and a blunt Hohmann placed into the subdeltoid space after blunt dissection to assist with lateral deltoid retraction. A right-angled retractor is used to medially retract the conjoint tendon.

clavipectoral fascia, this can be incised lateral to the muscular border of the conjoint tendon. A right-angled retractor is used to retract the conjoint tendon medially to expose the underlying subscapularis tendon. An extensive fracture hematoma is frequently encountered. This blood is evacuated and important neurovascular structures, particularly the axillary and musculocutaneous nerves, are identified once at the fracture site (Fig. 4).

The biceps tendon is identified in the bicipital groove passing deep to the pectoralis major tendon, and the sheath overlying the tendon is unroofed. This tendon is essential in orienting the anatomy of the proximal humerus as it runs in the bicipital groove between the greater and lesser tuberosities. This is particularly evident in highly comminuted fractures or 4-part fractures, where bony anatomy can be significantly distorted but the dense cortical bone of the biciptal groove is typically intact. The biceps tendon is isolated using a Lauer clamp, and the tendon is tenodesed to the upper border of pectoralis major using heavy nonabsorbable suture in situ to tension the tenodesis anatomically (Fig. 5).

The biceps tendon is then sharply tenotomized 1 cm superior to the tenodesis site and is followed proximally into the glenohumeral joint. The biceps sheath and rotator interval are released with Metzenbaum scissors to facilitate identification of the greater and lesser tuberosity fragments and the articular surface. Once the long head of the biceps is used to help orient the proximal humeral anatomy, the tendon is divided intra-articularly at its origin on the supraglenoid tubercle using Metzenbaum scissors.

The rotator cuff is then generously tagged using number 2 high-strength sutures placed through the bone-tendon junction of the subscapularis, supraspinatus, infraspinatus, and teres minor. These sutures are essential to assist with fracture reduction (ie, levering the humeral head out of varus and retroversion), and capture of the

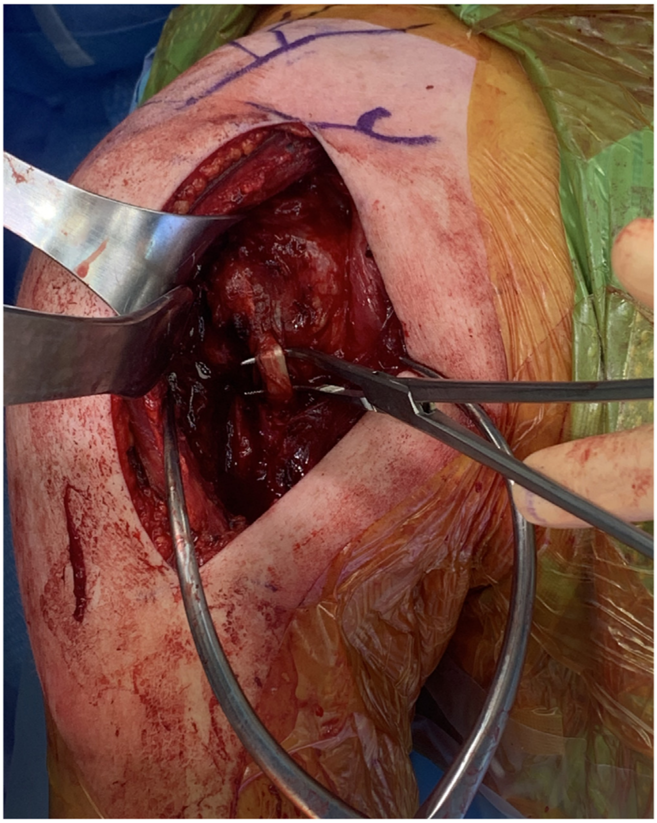

Figure 5 Isolate the biceps tendon in the bicipital groove using a Lauer clamp. The subpectoral aspect of the tendon is then tenodesed at an anatomic tension to the pectoralis major tendon using heavy nonabsorbable suture.

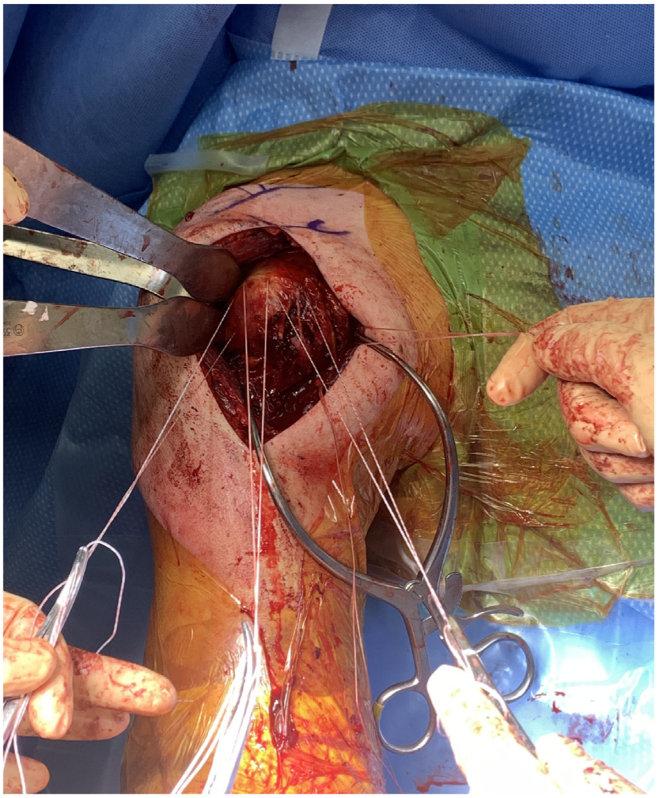

Figure 6 Tagging of the rotator cuff using number 2 high strength sutures placed through the enthesis of the subscapularis, supraspinatus, infraspinatus, and teres minor. These sutures assist with fracture reduction, and reinforcement of the fracture fixation to the locking plate.

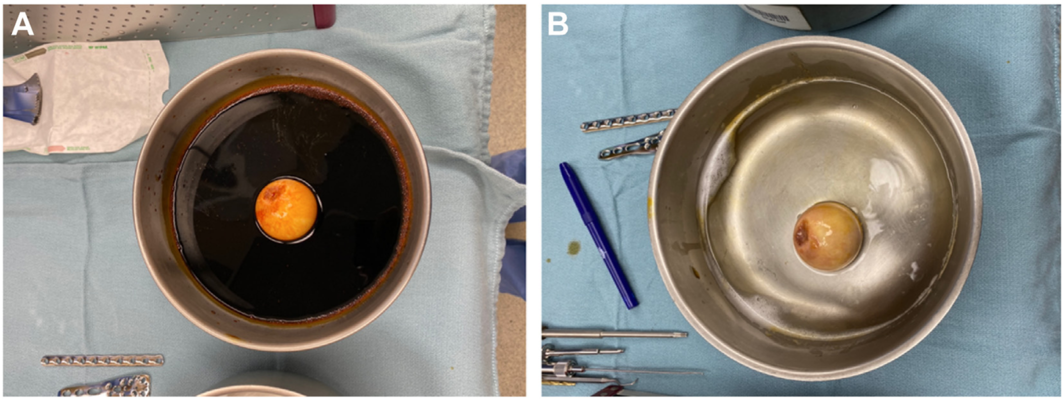

Figure 7 Thawing of the frozen femoral head allograft. At the start of the case, the allograft head is sequentially placed in equal parts betadine, peroxide, and normal saline (A) followed by a soak containing saline, 2g IV Ancef, and bacitracin (B). This allows sufficient time for the allograft to thaw while the humeral canal is exposed and prepared for implantation.

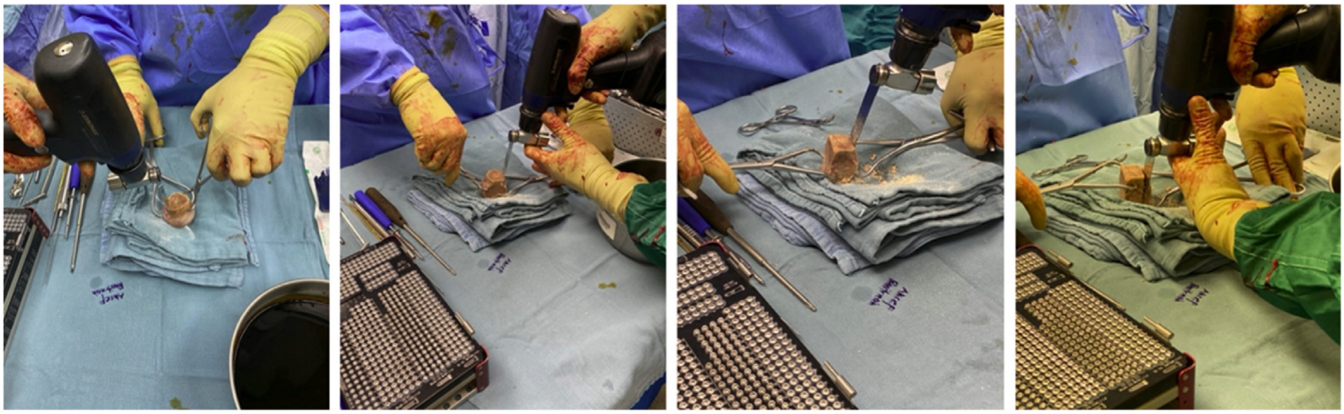

Figure 8 Preparation of the femoral head allograft. Cortical bone is removed using an oscillating saw, and allograft is fashioned into a rectangle.

tuberosities to prevent escape as they will be secured to the plate to counter the deforming forces of the rotator cuff (Fig. 6).

The arm is extended to deliver the humeral shaft. The metaphyseal canal is then débrided of any intervening hematoma and fibrinous tissue via sequential curetting; this prepares the canal for bone graft implantation. The shaft is then displaced posterior to deliver the humeral head. Similarly, the head is débrided of any intervening hematoma and fibrinous tissue.

Allograft preparation

A frozen femoral head allograft is placed in betadine and peroxide followed by a soak containing saline, 2g IV Ancef, and bacitracin (Fig. 7).

Once thawed, the allograft is prepared on the back table. Cortical bone is removed using an oscillating saw, and the allograft fashioned into rectangular slats ~5-8 mm in width (Fig. 8).

This rectangular graft is divided longitudinally using an oscillating saw into 2 or 3 thinner rectangular pieces ~5-8 mm in width. Sequential longitudinal cuts of each rectangular pane are then performed using an oscillating saw to create allograft “French fries” (Figs. 9 and 10).

The individual allograft pieces are then press-fit into the humeral canal and will act as structural metaphyseal support for the humeral head (Fig. 11). The individual allograft pieces can also be fashioned into a spike at one end with a rongeur to customize and wedge into the canal. Because the allograft pieces are press-fit into the canal and has interference fit, there is little possibility for subsidence or pistoning of the graft, which can occur with fibular graft.[37,38]

Reduction

The humeral head is reduced onto the shaft with traction on the prior placed rotator cuff sutures, as well as abduction of the arm. The bicipital groove can serve as a good reduction gauge as the floor of the groove is dense cortical bone and often well preserved. The image intensifier is then used to confirm appropriate alignment and positioning of the fragments, making sure that both neck-shaft angle and medial calcar alignment have been restored (Fig. 12).

Multiple 1.6 mm K-wires are placed in cross-pin fashion to provisionally hold reduction; care is taken to place these K-wires out of the intended plating zone.

Fixation

After fracture reduction, a proximal humeral locking plate is positioned lateral to the bicipital groove and 15-20 mm distal to the tip of the greater tuberosity depending on the size of the humeral head. The plate position is anterolateral and not directly lateral as the humeral head is retroverted. The deltoid insertion may need to be partially elevated to allow application of the plate, which

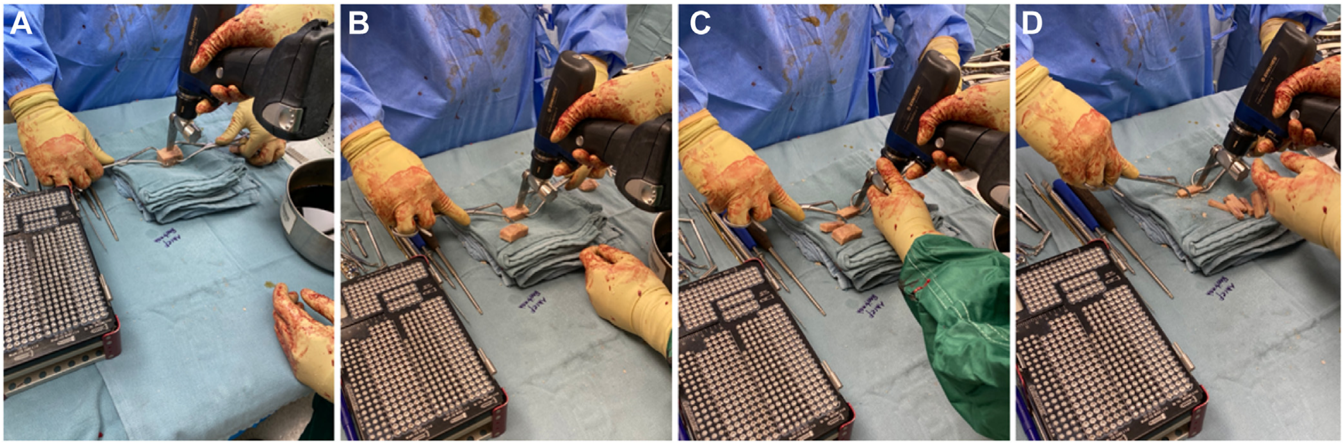

Figure 9 Creation of cancellous femoral head allograft "French fries." The rectangular allograft is divided longitudinally into 3 thinner rectangular panes using an oscillating saw (A, B, C). Sequential longitudinal cuts of each thin rectangular pane are then performed using an oscillating saw creating allograft "French fries" (D).

Figure 10 Prepared femoral head allograft "French fries" for immediate use. Otherwise, soak in Ancef solution until insertion to prevent desiccation.

typically rests between the deltoid tuberosity and pectoralis major insertion on the humerus.

Plate length is determined by fracture type as well as extension into the metadiaphysis. Typically, 4-6 cortices distal to the fracture are needed for adequate fixation in proximal humerus fractures. A plate with 3 holes in the shaft usually suffices. It is critical that the plate height is determined by the optimal positioning of the inferior calcar screw. If necessary, the plate can be further contoured with the use of large plate benders to match the patient's anatomic neck shaft angle more appropriately. The rotator cuff sutures are passed through the corresponding holes in the periphery of the plate appropriately spaced. The plate is parachuted down to the humeral head proximally but is held off the humeral shaft distally. The plate is positioned on the humerus and provisionally held using 2 1.6 mm K-wires through the proximal-most peripheral holes. Plate position/height is then assessed, and adequacy of fracture reduction confirmed with fluoroscopic imaging (Fig. 13).

One 4.0 mm cancellous screw is then placed through the superior-most portion of the plate to compress the plate to the bone. Next, 1-3 proximal unicortical locked screws are placed above the fracture depending on how proximal the fracture line exits laterally, measuring 10 mm shorter than measured. Inserting shorter screws in the superior head is recommended because these fractures may subside during the healing process risking screw penetration (Fig. 14).

The plate is then reduced to the humeral shaft distally to leverage the humeral head out of varus (Fig. 15). A minimum of 2-3 bicortical screws are then drilled and inserted into the shaft end of the plate. To maximize construct stability, place as many, unicortical locked screws into the humeral head as the plate will allow, typically 5-7 screws. The safe zone for these screws is typically up to 45-50 mm in length. Longer screws may cause intra-articular penetration, particularly posterosuperiorly.

The calcar screws are of particular significance to allow for adequate fixation of the fracture and to prevent varus collapse. These are typically placed under fluoroscopic guidance and are the longer screws in the humeral head (Fig. 16).

Supplementation fixation of the lesser and greater tuberosities using 2.7 mm limited contact dynamic compression plate or one-third tubular plates placed anteriorly and posteriorly, respectively, may be considered to increase construct stability where needed as the standard proximal humeral plate is position anterolateral, just lateral to the bicipital groove and may often not capture or buttress the greater tuberosity fracture which is posterior in more complex 4-part fracture patterns (Fig. 17).

When all the screws have been placed through the plate, fluoroscopic shots are scrutinized to ensure adequate reduction, correct

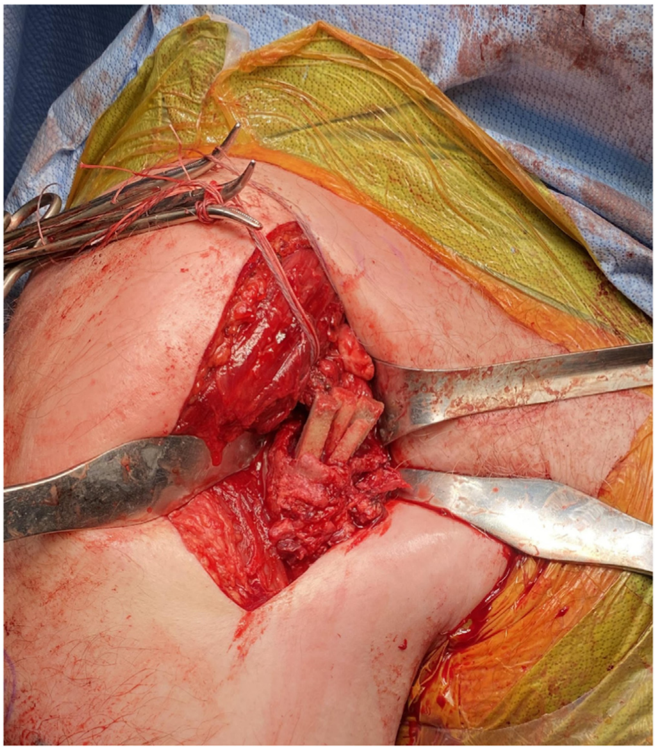

Figure 11 Individual allograft pieces are press-fit into the humeral canal and act to serve as structural metaphyseal support for the humeral head.

Figure 12 Intraoperative fluoroscopic anteroposterior image demonstrating appropriate reduction of the humeral head onto the humeral shaft. Note the restoration of the metaphysis and humeral head height by the allograft “French fries.”

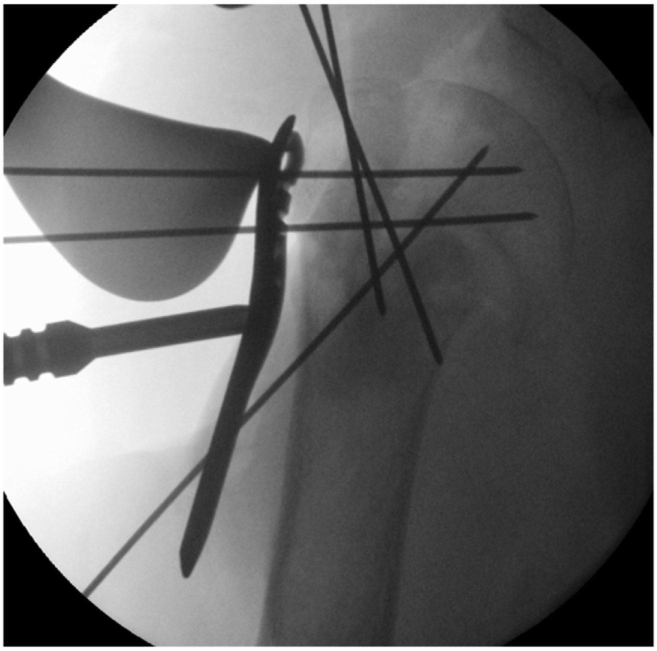

Figure 13 Intraoperative fluoroscopic anteroposterior image demonstrating provisional fixation of the fracture reduction and the proximal humeral locking plate using multiple 1.6 mm K-wires. Note the plate is held off the bone distally in an abduction position to allow for proximal fixation first and proper seating of the plate to the head.

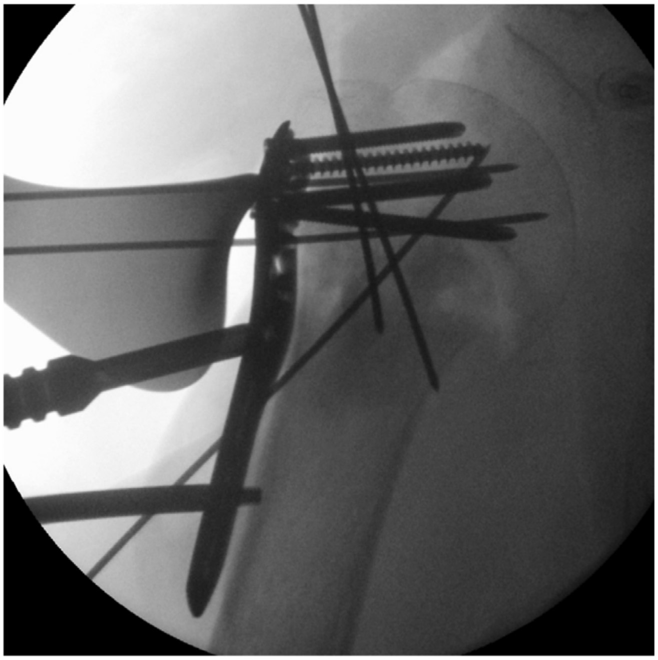

Figure 14 Intraoperative fluoroscopic anteroposterior image demonstrating proximal fixation of the proximal humeral locking plate to the humeral head with 1 cancellous screw and 3 unicortical locked screws.

implant placement, and recreation of the native neck-shaft angle. Extremes of rotation are performed under live fluoroscopy to rule out intra-articular screw penetration. The rotator cuff sutures are then tied down through the plate. This allows tensile forces of the rotator cuff to be neutralized to further increase the stability of the fracture reduction.

With the fixation complete, the shoulder is taken through a full, passive ROM to evaluate the stability of the final construct. The wound is then irrigated and closed in layers, and a regular Velpeau sling is applied. Standard orthogonal X-rays are taken in the recovery room.

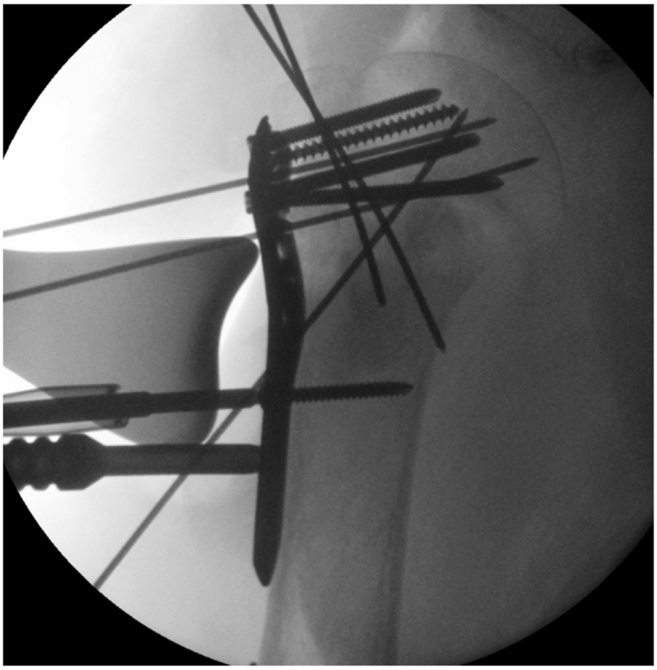

Figure 15 Intraoperative fluoroscopic anteroposterior image demonstrating distal reduction of the plate to the humeral shaft using a bicortical nonlocked screw after initial proximal fixation. This sequential proximal to distal fixation of the locking plate to the bone serves to reduce the humeral head out of varus and restore the anatomic neck-shaft angle.

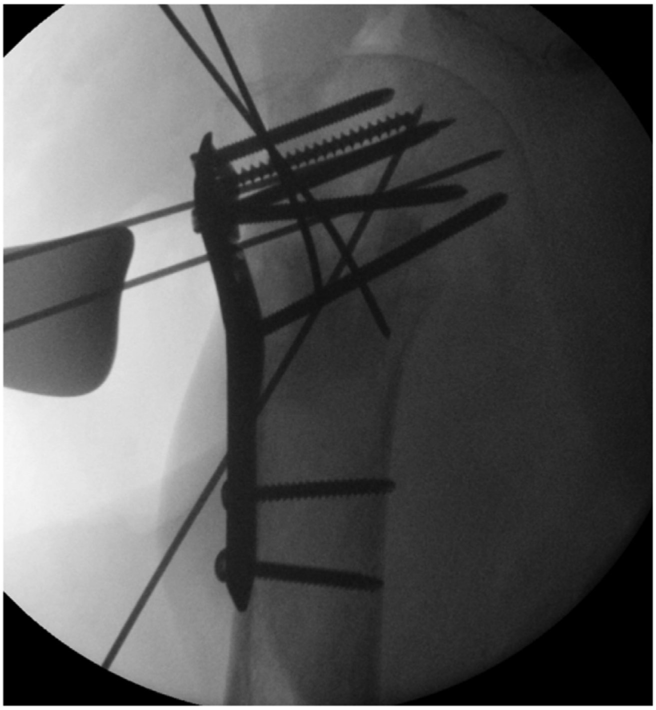

Figure 16 Intraoperative fluoroscopic anteroposterior image demonstrating calcar screw placement.

Postoperative management

Postoperatively, the arm is placed in a Velpeau sling. Young patients are discharged the next day, and those with significant medical comorbidities may require skilled nursing facility or rehab placement. Passive and active-assisted ROM exercises may start on the first postoperative day to 90° of forward elevation and abduction with external rotation to 45° to help avoid shoulder stiffness. It is imperative to educate the patient on scapular stabilization as active exercises and strengthening can start immediately postsurgery to prevent scapular dyskinesis. Active ROM of the elbow, forearm, wrist, and hand are also encouraged immediately after surgery.

At approximately 4-6 weeks postoperatively, the sling is weaned. Weight-bearing on the arm is limited for 6 weeks. Full active, active-assisted, and passive ROM are permitted, and formal physical therapy can be initiated at this time. Strengthening is not initiated until approximately 10-12 weeks postoperatively, when radiographic evidence of bony consolidation is confirmed, and the patient has achieved sufficient coordination of the extremity.

True anterior posterior (Grashey), axillary, and scapular Y radiographs of the shoulder are obtained at routine 6-week and 12-week follow-ups, as well as 6 and 12 months postoperatively.

Discussion

Fractures of the proximal humerus account for 4%-8% of injuries to the appendicular skeleton.[2,4,23,37] Most are stable, minimally displaced osteoporotic fractures in the elderly, and are the result of low-energy falls.[10,16,18] Most of these patients regain a functional shoulder without operative intervention. Surgery is considered in approximately 20% of patients[27] because they require improved shoulder function for their activities of daily living or because of the significant deformity of their fracture and the need to restore functional alignment, length, and rotation in active, higher demand individuals. However, fixation of these fractures can pose a challenge due to poor bone quality and displacing forces of the rotator cuff. This is especially true in 3-part and 4-part fractures. These factors lead to the high failure rates seen with early attempts at osteosynthesis.[1]

In the last 2 decades, locking plate technology has been an innovation in treating these complex fractures. Each screw acts as an angular stable construct, providing support for osteoporotic bone.[12] Locking plates are more rigid and have improved torsional stability compared to blade plates or intramedullary nail fixation.[1,36] Current plates have polyaxial locking holes and suture eyelets that have improved implant fixation.[1,22]

Despite the improvements in torsional strength and rigidity, outcome studies on locking plate technology demonstrate equivocal results with complication rates as high as 20%-30% and a revision rate of 10%.[38,40] Specifically, these complications include avascular necrosis, varus collapse, intra-articular screw penetration, and postoperative stiffness. Varus collapse occurs when the weak osteoporotic bone fails around the implant. This has been noted to occur at a rate of 3%-12% and the risk may be even higher with substantial bone loss of the head fragment;[12,40] movements within the fracture during the initial phase after injury as well as the continuous subsidence and impression of the shaft into the head may lead to extensive destruction of the cancellous bony structure of the head. In turn, fibular strut endosteal augmentation was introduced to provide additional support and decrease implant failure rates in displaced fractures with varus coronal malalignment and significant metaphyseal bone loss.[26,28]

The use of fibular strut allograft as an adjunct to locked plating has been shown to increase construct stiffness and maximal load to failure.[33] Its purpose is to provide medial calcar support to prevent varus collapse and eventual intra-articular screw penetration. The clinical results of fibular strut allograft use as a supplement to locked plating are promising.[3,25,26,39] Overall, proximal humerus fractures with preoperative displacement, varus coronal malalignment, and/or medial cortical comminution are indicated for fibular

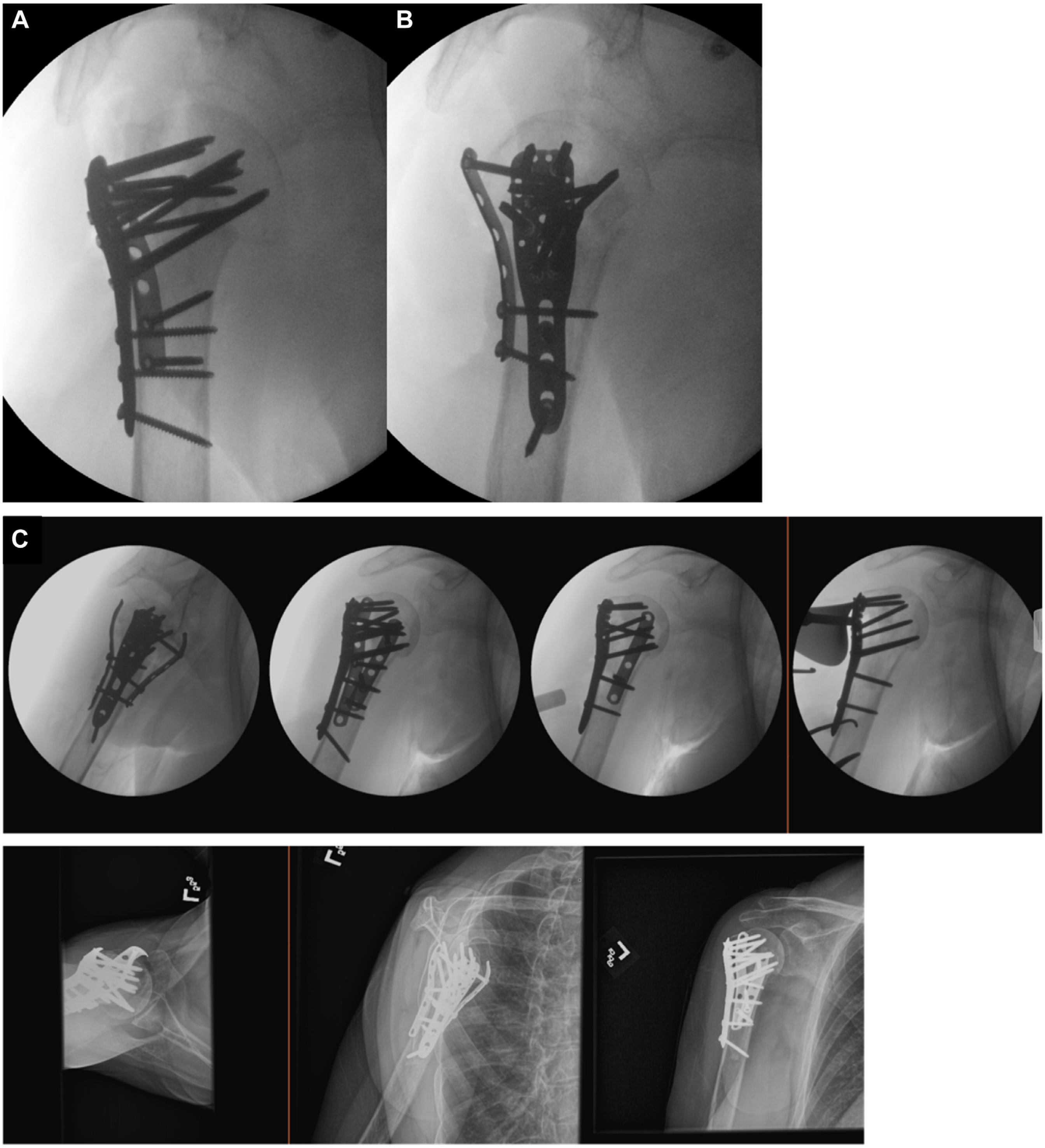

Figure 17 Intraoperative fluoroscopic anteroposterior (A) and lateral (B) images demonstrating complete fixation of the proximal humeral locking plate to the bone, as well as supplemental fixation using a one-third tubular plate placed posteriorly against the greater tuberosity in buttress fashion. Note the recreation of the metaphysis and the native neck-shaft angle. (C) Another example of supplemental fixation with 2 additional plates.

strut allograft augmentation. This technique consists of reaming the humeral shaft to create an acceptable recipient site and sizing the fibular graft to fit the medullary canal of the humerus. Once in place, the graft provides a strut on which the head fragment and the tuberosities can be reduced. Although clinically successful and biomechanically superior to plate-only constructs, a few concerns remain.

One such concern is keeping a fibular graft in routine supply at most hospitals. Often surgeons may need to request grafts in advance, which obviate their use in a trauma case. Furthermore, revision after fibular strut augmentation poses a unique and technically challenging problem because most shoulder replacement systems have stemmed humeral implants. Currently, there is a paucity in literature about removal of a fibular strut allograft for conversion from locked plate and screws to shoulder arthroplasty.[19,35] Arthroplasty revision, already a complicated procedure, becomes even more complex with the need to remove 5-9 cm of ingrown endosteal bone from a shell of osteoporotic cortical bone. Because of these concerns, we introduced a novel technique of creating individual cancellous femoral head allograft struts or “French fries” that provides structural support for the humeral head but does not have the potential problems of a cortical fibular strut. Furthermore, because multiple allograft pieces are press-fit into the canal, there is little possibility for subsidence or pistoning of the graft, which can occur with a single fibular graft.[19,35]

Disadvantages of this technique are the creation of the individual cancellous allograft “French fries” can be time-consuming. However, in our experience, it is less time-consuming when compared to endosteal fibular allograft augmentation. Furthermore, while there is a theoretical risk of disease transmission from the allograft, with the advent of stricter screening processes, the literature suggests that is minimal, and, by using a freeze-dried product, the concern is further mitigated. Another potential complication that could occur during press-fitting of the individual allograft “French fries” is fracturing the humerus via a stress-riser effect of the graft in the distal shaft; however, this has not occurred in our practice.

Conclusion

The authors describe a novel technique of using individual cancellous femoral strut allograft or “French fries” as an endosteal pedestal, in lieu of a fibular allograft, to reconstruct the humeral metaphysis during locking plate fixation of proximal humerus fractures. The potential benefits of this technique are 2-fold. Because the allograft pieces are press-fit into the canal, there is less possibility for subsidence or pistoning of the graft, which can occur with a fibular graft.[19,35] Furthermore, it limits the amount of allograft bone needed to seat into the medullary canal. This creates the potential for an easier reconstruction or arthroplasty revision options in the future as it avoids the need to remove ingrown endosteal bone from a shell of outer osteoporotic cortical bone.

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Supplementary Data

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