The Combined Olecranon Osteotomy, Lateral Paratricipital Sparing, Deltoid Insertion Splitting Approach for Concomitant Distal Intra-articular and Humeral Shaft Fractures

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Abstract: Fractures of the distal humerus involving the articular surface can be challenging. The complexity of these fracture patterns increases when the distal fracture is associated with a concomitant humeral shaft fracture with significant proximal extension. The combined exposure technique described here allows for consistent and controlled posterior humeral exposure proximally from the traverse of the axillary nerve to the distal trochlear tip. It is especially useful for complex segmental fracture patterns where distal intra-articular involvement is present and a single approach is desired.

Key Words: humerus, combined fracture patterns, extensile humeral exposure, intra-articular fracture patterns

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INTRODUCTION

Fractures of the distal humerus involving the articular surface can be quite challenging as a single entity. Complications such as instability, bone loss, articular incongruity, stiffness, nonunion, or malunion are common.[1–3] When considered with a concomitant humeral shaft fracture or a distal fracture with significant proximal extension, the complexity of these fracture patterns increases dramatically. The need for adequate exposure is paramount for proper fracture reduction and fixation while simultaneously allowing for preservation of the neurovascular structures that often lie in proximity to the fracture and dissection.[4] Numerous approaches to the humerus have been described, each stemming from one of the traditional posterior (triceps splitting, sparing/reflecting, osteotomy) or anterior approaches (deltopectoral, anterior, anterolateral, lateral).[3,4,5–12] The combined olecranon osteotomy, lateral paratricipital sparing, deltoid insertion splitting technique (COLD) described herein adds to the physician's options for a single approach for complex humeral fractures requiring extensile exposure. This technique is particularly well suited for situations in which a large amount of the humerus must be exposed in addition to providing adequate exposure for fixation of the distal humeral intra-articular involvement through a posterior approach. When employed in this manner, more than 94% of the posterior aspect of the humerus can be exposed with this combined exposure technique.[7]

SURGICAL TECHNIQUE

Technical points emphasized by this single-incision technique include the concept of distal lateral triceps subfascial exposure for radial nerve protection; preservation of the anterior deltoid insertion band with its contiguous pectoralis major fibers, distal to proximal splitting of the posterior deltoid raphe to allow retraction medial and lateral to the posterior and middle deltoid, respectively; protection of the origin of the lateral head of the triceps; and protection of the superolateral cutaneous innervation of the skin overlying the deltoid.

After administration of general endotracheal anesthesia, the patient is placed in the lateral decubitus position on a bean bag with an axillary roll at nipple level. The operative arm is placed in 90 degrees of forward elevation and internal rotation, allowing the elbow to flex with gravity assistance over an adjustable, right-angle-well leg holder from a standard fracture table. The well leg holder must be placed so as not to apply pressure over the volar distal humerus, thus avoiding inadvertent fracture fixation of the distal fragment in extension. The axilla and arm are shaved and sterilely prepared anteriorly from the neck to the ipsilateral nipple and posteriorly from the scapular spine to the axilla, allowing for maximal proximal landmark identification intraoperatively. Landmarks identified with a marking pen include, proximally, the posterolateral border of the acromion, the scapular spine, the posterior border of the deltoid, and its insertion on the lateral humeral shaft. Distally, the medial and lateral epicondyles are identified, as is the subcutaneous border of the olecranon tip and ulnar shaft. A large "M" is written medially over the ulnar nerve to prevent location confusion. A long

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posterior incision is first marked starting 5 cm distal to the posterolateral border of the acromion heading in line with the lateral head of the triceps towards the tip of the olecranon
F1,2 (Figs. 1 and 2). In approaching the olecranon, the incision marking curves laterally to the tip and follows the subcutaneous border of the ulna distally for approximately 7 cm. A sterile tourniquet over sterile cast padding is then placed as far proximally on the brachium as possible in anticipation of ulnar nerve exposure with subsequent mobilization or transposition. The arm is exsanguinated, the tourniquet raised to 100 mm Hg above the patient's systolic pressure, and the incision is started from the proximal limit of the tourniquet in a distal direction. Full-thickness fasciocutaneous flaps are developed via sharp dissection through the subcutaneous tissue and through the posterior brachial fascia. Violation of the investing epimysial fascia of the triceps surae must be avoided to diminish bleeding once the tourniquet is released. Undermining medially allows for a standard ulnar nerve transposition or mobilization to be performed through a single incision. The ulnar nerve is first found proximally as it enters the posterior compartment of the arm. Mobilization is done by

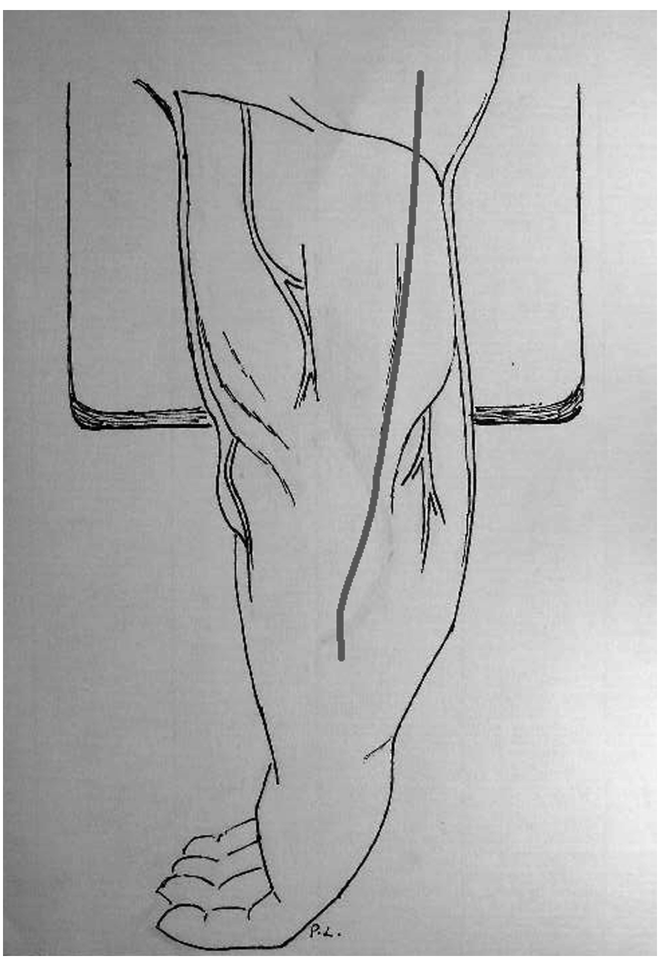

FIGURE 1. Posterior lateral skin incision for the COLD approach with the patient in the lateral decubitus position and the affected arm placed over a buttress (right arm depicted).

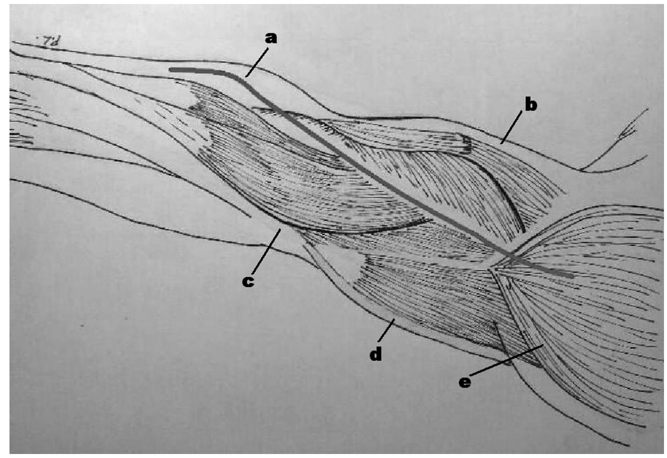

FIGURE 2. The COLD approach with dermis removed and muscle planes identified. Incision path (a), triceps surae (b), brachioradialis (c), biceps brachi (d), and deltoid (e) (right arm depicted and viewed from superior).

excising a portion of the medial intermuscular septum and releasing the arcade of Struthers, Osborn's ligament, and the fascia between the two heads of the flexor carpi ulnaris (FCU) while protecting the first motor branch of the ulnar nerve.

Attention is then turned to the olecranon osteotomy portion of the procedure. Submuscular dissection along the medial and lateral borders of the olecranon allows for olecranon articular surface visualization in anticipation of an apex distal chevron osteotomy. Soft tissue is elevated distally along the ulnar subcutaneous border for plate placement. The osteotomy site is outlined with a bovie cautery, where the transverse bisector of the osteotomy corresponds to the bare area of the olecranon articular surface.[13] A pre-bent, six-hole, locking, one-thirds tubular plate (Synthes USA) is placed over the proximal olecranon and secured with a small lobster claw. Using a 2.0 drill bit, an oblique, extra-articular "money screw" is drilled through the second hole from proximal posterior to distal anterior exiting at the coronoid process. The plate is removed and placed on the back table for later osteotomy fixation. Using the microsagittal saw, the osteotomy is cut to the level of the subchondral bone and completed with a narrow osteotome to prevent articular injury and facilitate osteotomy congruence with reduction.[10,13]

The tourniquet is released and hemostasis is obtained. Release of the tourniquet at this juncture allows for immediate local hemostasis. A towel clamp secures the proximal olecranon tip and allows for tissue tension while elevation of the extensor mass is performed both medially and laterally
(Figs. 3 and 4). The medial and lateral epicondyles serve as F3,4
landmarks for the medial and lateral intermuscular septae, respectively. Dissection proceeds in a proximal direction along the medial border of the triceps, staying posterior to the intermuscular septum to allow for retraction of the osteotomy extensor mass unit. Avoidance of the concentrated nutrient foramina zone of the medial aspect of the distal middle third of the humeral shaft is warranted to avoid, as Carroll[14] suggests, an increased risk of nonunion. The medial dissection is carried as far proximally as needed to establish adequate

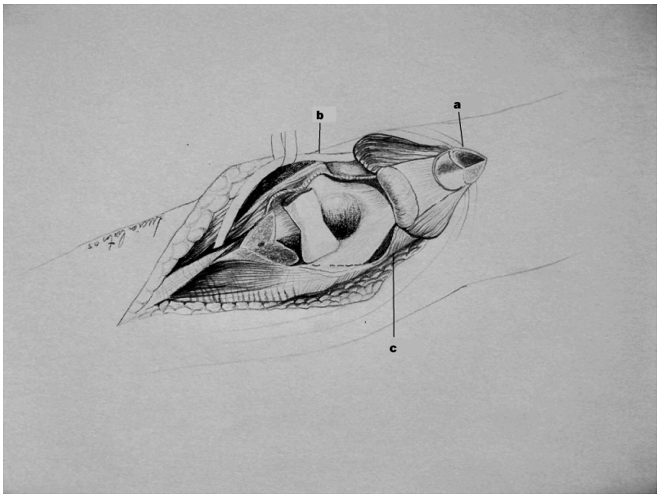

FIGURE 3. Initial dissection proceeds with an ulnar nerve transposition and then a distal chevron olecranon osteotomy, allowing complete posterior distal humeral articular surface exposure. Reflected olecranon osteotomy (a), ulnar nerve (b), and lateral intermuscular septum (c). Right arm depicted and viewed from superior to the patient's head.

exposure, with a maximum limit of 21 cm from the medial epicondyle. This corresponds to the proximal medial crossing zone of the radial nerve.

Dissection of the lateral side follows a similar technique, except that its proximal extent will continue past the humeral crossing of the radial nerve and profunda brachial vessels up to the level of the posterior branch of the axillary nerve with its subdeltoid position. The distal dissection is done subfascially, thus preserving the lateral intermuscular septum while providing a protective sleeve for the radial nerve proper, as described by Mills et al.[12] Dissection continues from the laterally released anconeus insertion on the olecranon, with its origin preserved, and heads proximally along the posterior margin of the lateral intermuscular septum. It is important to note that the posterior antebrachial cutaneous nerve, a branch from the radial nerve, is in danger with this exposure because of its superficial location overlying the lateral aspect of the medial head of the triceps muscle en route to the forearm.[4,6,7] Once this nerve is encountered, it can be traced proximally to the radial nerve trifurcation in anticipation of radial nerve mobilization. Mobilization of the triceps extensor mass off of the fracture fragments and periosteum allows for communication between the medial and lateral dissections. Visualization of the entire distal posterior humeral shaft and articular surface may now be appreciated.

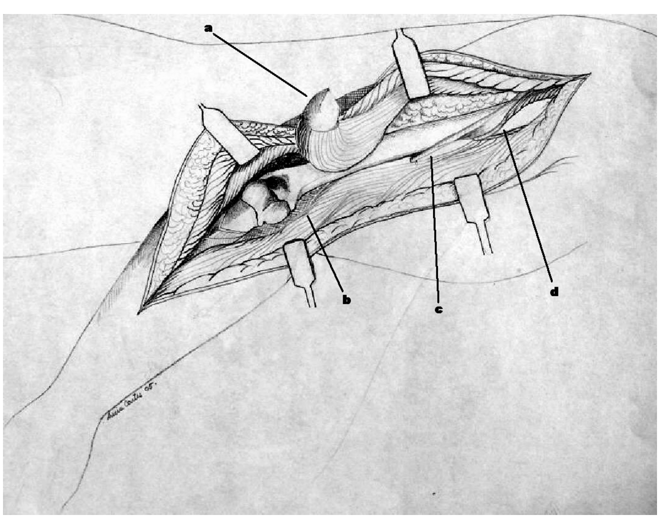

FIGURE 4. The COLD approach seen from above (bird's eye view) with the patient in the lateral decubitus position (right arm depicted). The olecranon osteotomy component (a) is reflected proximally while dissection proceeds along the lateral intermuscular septum (b). The radial nerve (c) is seen obliquely crossing the humerus distal to the deltoid insertion split (d).

The incision is continued proximally as needed following the previously marked path. Full-thickness flaps are developed to the level of the fascia of the lateral aspect of the lateral head of the triceps and proximally to the raphe separating the posterior and middle deltoid. Manipulation of the retracted distal extensor mass and careful lateral dissection with tenotomy scissors allows for identification of the radial nerve and the profunda brachial artery as they traverse the humeral diaphysis in the spiral groove. Their oblique path en route to the anterior compartment of the arm via the lateral intermuscular septum defines the most proximal extent of the deep medial head of the triceps. The neurovascular bundle is mobilized and protected. Once proximal to the nerve, sharp dissection to bone is performed, heading in a proximal direction and staying lateral to the lateral head of the triceps. The most posterosuperior aspect of the brachialis muscle, which lies just superior to the traversing radial nerve and profunda brachial artery, needs to be sharply incised en route to the deltoid insertion. The target zone is the raphe between the middle and posterior heads of the deltoid with their distinct terminal nerve branches from the axillary nerve.[8,15–18] The deltoid insertion is a tortuous, V-shaped amalgamation of muscle fibers, making blunt dissection of this area nearly impossible. Sharp dissection through the deltoid along the raphe can be continued for a maximum of 3 cm to bypass its adherent insertion. Sharp subperiosteal elevation of the posterior deltoid insertion can then be performed to the proximal border of the lateral head of the triceps. If additional proximal humeral exposure is needed, careful blunt dissection can be performed while staying directly on bone. It is important to note that the axillary nerve and posterior humeral circumflex artery typically run 5 cm distal to the posterolateral acromial border along the undersurface of the deltoid muscle after emerging from the quadrangular space.[8] These and the cutaneous nerves to the lateral brachium must be preserved. Exposure of the humerus now consists of complete distal exposure of the posterior humerus to the proximal origin of the lateral head of the triceps, which corresponds to exposure of more than 94% of the posterior humerus.[7] Proximal open reduction and internal fixation can now be performed with a plate placed deep to the posterior insertion of the deltoid and radial nerve along the posterolateral border of the humerus. Additionally, the distal articular surface and shaft can be repaired with lag screws and an orthogonal plate construct of the medial and posterolateral columns.[2,10] Closure consists of repair of the olecranon osteotomy, loose reapproximation of the triceps interface with the lateral intermuscular septum, and ulnar nerve transposition with a fascial sling[19] followed by reapproximation of the posterior brachial fascia, subcutaneous tissue, and skin.

CASE REPORT

A 38-year-old right hand–dominant male was admitted to the regional trauma center after crashing his motorcycle. On presentation, his initial injuries included a laceration over the right olecranon (Gustilo grade II) with intra-articular communication and gross deformity of the ipsilateral arm. All peripheral nerves were intact and his radial pulse was palpable and strong. Radiographs of the right upper extremity revealed a transverse upper-middle-third diaphyseal fracture of the humerus with a concomitant distal intra-articular fracture with supracondylar extension, OTA/AO C1 (Figs. 5A and B). F5 Operative clearance was obtained and the patient was taken to the operating suite for an initial debridement. The arm was immobilized in a plaster splint. After 48 hours, he returned to the operative suite for a second debridement and definitive open reduction and internal fixation. The patient's original laceration was incorporated into the planned incision for the COLD approach. The procedure plan included repeat irrigation and debridement followed by ulnar nerve transposition, olecranon osteotomy, proximal humeral shaft exposure, and, finally, reduction and fixation of the fracture elements. Humeral shaft reduction and fixation was performed before the definitive open reduction and internal fixation of the distal articular surface to provide stability and to protect the radial nerve. Stable internal fixation of the humeral shaft was achieved with an eight-hole 4.5 LCDC plate placed along the lateral humerus deep to the radial nerve and profunda brachial vessels. The distal articular surface was rigidly fixed with a 90/90 construct of periarticular plates and lag screws along the medial and posterolateral columns. The osteotomy site was repaired and the lateral triceps fascia was reapproximated, followed by the brachial fascia, subcutaneous tissues, and skin (Figs. 6 and 7). F6, 7 Postoperatively, the patient was immobilized in a bulky dressing and side-slat splint to limit incision irritation. The patient's nerve and vascular examination were completely normal postoperatively, and he returned to his country of origin on postoperative day 4. No further follow-up was available.

DISCUSSION

The proximal humeral diaphysis is cylindrical in shape until the level of the spiral groove, where it takes on a triangular configuration with anterolateral, anteromedial, and posterior surfaces.[9] The nature of this morphology has led to the description of various operative approaches with their inherent plate placement zones. These operative techniques are variants of the two most commonly described approaches: the anterior approach and the posterior approach.[10] The COLD approach uses the distal articular exposure gained through an olecranon osteotomy, a lateral subfascial, paratricipital, intermuscular septum-sparing approach for midhumeral diaphyseal visualization[12] and a posterior deltoid insertion split for proximal humeral access. The limits of exposure are the trochlea distally to the level of the axillary nerve and posterior humeral circumflex artery proximally.

The deltoid insertion has been described as a V-shaped tendinous confluence consisting of a broad posterior band, a middle band, and a narrow, separate, anterior band.[8]

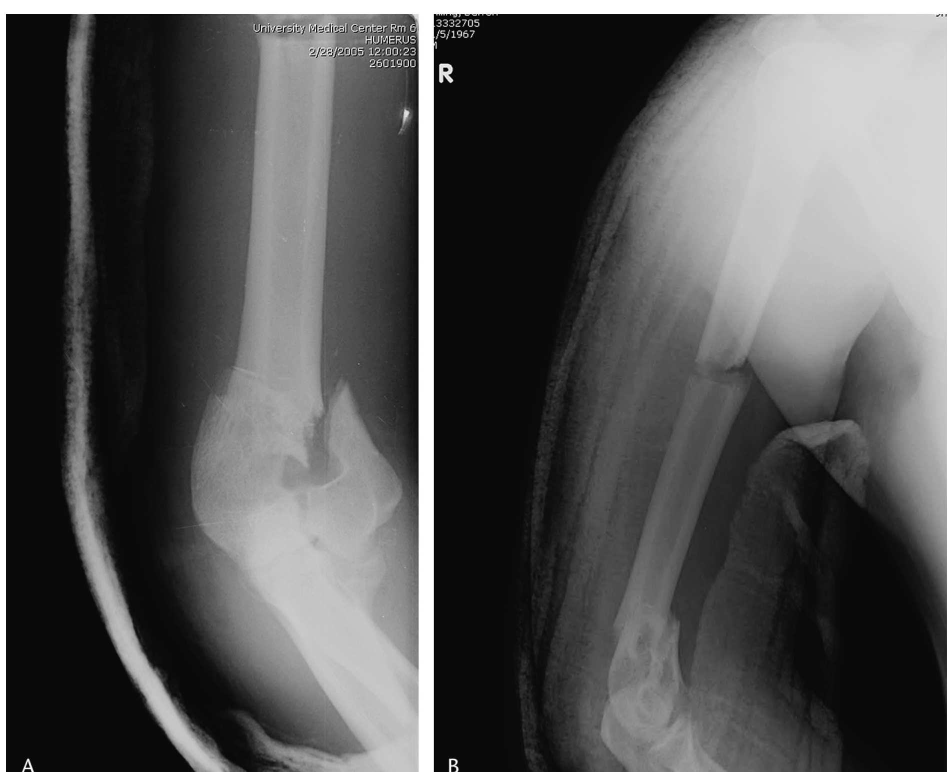

FIGURE 5. AP (A) and lateral radiograph (B) showing a distal intra-articular humeral fracture (OTA/AO C1) with a concomitant transverse humeral shaft fracture.

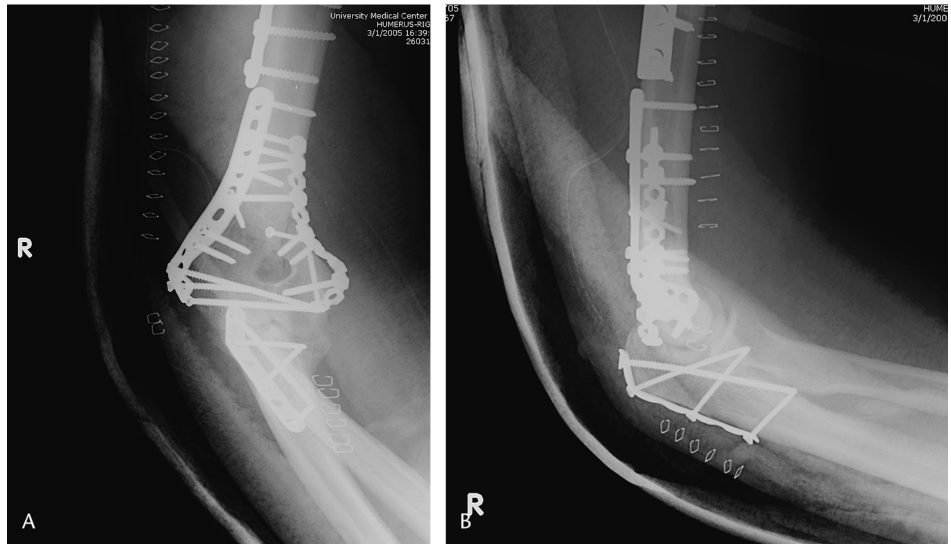

FIGURE 6. AP (A) and lateral (B) radiographs of the fracture depicted in Figure 5 after open reduction and internal fixation with the COLD approach.

Delineation of these deltoid fiber groups are based on their origins from the scapular spine, lateral acromion, and anterior acromion with clavicle, respectively. The anterior band insertion is separated from the pectoralis major insertion by as little as 2 mm. In a cadaveric study of 36 deltoid insertions, Klepps et al[8] showed that the anterior band of the deltoid contributed only to one fifth (0.44 cm) of the entire deltoid insertion. He surmised that slight subperiosteal elevation of the anterior deltoid insertion would lead to a complete compromise of its function. Studies have confirmed that the anterior deltoid is essential for shoulder abduction and forward elevation,[20] making the contribution by Klepps et al[8] that much more significant. In a study of 134 deltoids from 67 fresh cadavers, Kontakis et al[17] showed that the axillary nerve was located a mean distance of 2.6 cm superior to the longitudinal equidistant point between the deltoid's origin and insertion. They concluded that the shorter the deltoid length, the greater the risk of axillary nerve injury. In the same study, the radial nerve was shown to lie between 2.2 and 2.6 cm distal to the posterior deltoid insertion point. With the new combined exposure technique described here, the interval between the posterior and middle deltoid fiber groups is developed. This prevents anterior deltoid disruption and allows for decreased traction on the axillary nerve, as would be seen in a pure posterior deltoid retraction technique such as the one described by Mekhail.[9] Mekhail's description encompasses a proximal extensile approach that uses the posterior border of the deltoid as a dissection plane. This has the inherent risk of injury to the superior lateral brachial cutaneous nerve and a traction neuropraxia of the axillary nerve because of overly aggressive anterior deltoid retraction to obtain adequate proximal humeral exposure. The closest distance from the deltoid insertion to the axillary nerve has been described as 4 cm.[8] The deltoid insertion is far less than 4 cm in length, and therefore, the posterior aspect can be sharply released subperiosteally, allowing for continued blunt dissection proximally to safely approach the axillary nerve.

Ball et al[15] in 19 fresh-frozen human cadaveric specimens, specifically studied the posterior branch of the axillary nerve as it related to deltoid innervation and surgical dissection. The posterior branch was noted to separate from the anterior circumflex branch directly anterior to the origin of the long head of the triceps, after which it divided into the superolateral brachial cutaneous nerve and the nerve to teres minor. Entrance of the nerve into the teres minor was on the muscle's inferior border. The cutaneous nerve in all specimens became superficial by passing around the medial border of the posterior deltoid. In 15 of the 19 specimens, a branch from the posterior branch of the axillary nerve supplied the posterior deltoid. The branch, on average, entered the muscle 29 mm medial to the raphe between the posterior and lateral portions of the deltoid. Ball et al[15] suggested that postoperatively, cutaneous innervation of the skin overlying the posterior lateral deltoid could be used as a marker for teres minor muscle innervation preservation. It is important to note that all specimens in this study had an anterior branch contribution to the posterior deltoid, thus making it the more consistent innervation supply.

Approximately 75% of patients will have dual innervation to the posterior deltoid. Similar to the posterior nerve branch, the anterior nerve branch entrance into the posterior deltoid occurs approximately 2 cm from the longitudinal equidistant point of the muscle.[15] In our described technique, the deltoid insertion is split proximally along the raphe between the posterior and lateral heads, with subperiosteal elevation of the posterior insertion band in a posterior direction. With this splitting, less traction is placed on the motor and sensory contributions of the posterior branch of the axillary nerve because of medial and lateral retraction of the respective muscle components. It is important to note that the more condensed and narrow anterior band is preserved with this combined exposure technique.

Gerwin et al[7] eloquently defined the course of the radial nerve with respect to the posterior aspect of the arm by performing an anatomic study on 10 cadaveric specimens. Three operative approaches were used, and the routes of the radial nerve and amounts of humerus exposed were recorded. The radial nerve was found to obliquely cross the posterior aspect of the humerus 20.7 cm proximal to the medial epicondyle (on average) and 14.2 cm proximal to the lateral epicondyle (on average). Additionally, it was noted in all specimens that during the posterior course of the nerve there were several nerve branches to the lateral head of the triceps but no branches to the medial head. Trifurcation of the nerve occurred at the lateral border of the humerus and included a branch to the medial head, the lower lateral brachial cutaneous nerve, and the radial nerve proper as it continued distally piercing the lateral intermuscular septum. Local nerve branching has been shown to influence nerve mobility and postoperative morbidity.[7,21] The COLD approach exploits the radial nerve's trifurcation zone and therefore decreases the morbidity associated with radial nerve branch mobilization from a purely posterior approach. Humeral exposure ranged from 55% with a posterior triceps-splitting technique to 94% with a modified posterior approach in which the medial and lateral heads of the triceps were elevated.[7,11] In our technique, the addition of the olecranon osteotomy distally increases the amount of exposure gained to more than the 94% obtained by Gerwin et al[7] while proximally protecting the origin of the lateral head of the triceps (Fig. 8).

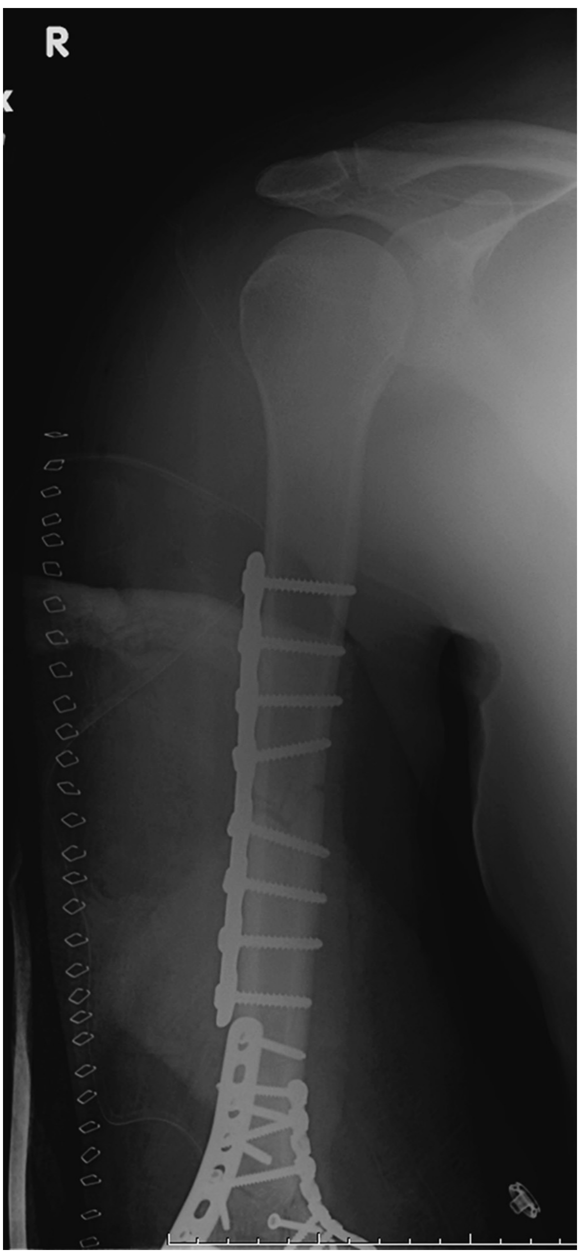

FIGURE 7. AP radiograph of the concomitant humeral shaft fracture fixation.

The authors have used this approach in six patients in whom extensile proximal to distal humeral exposure was required. Except for one patient, all fractures and osteotomies have healed without incident. In the one case of a nonunion, the patient presented with a Gustilo II/III humerus fracture and subsequently developed a postoperative infection while being followed at another institution. At last report, the patient had had all of his hardware removed and antibiotic laden cement beads placed in anticipation of future open reduction and internal fixation. Other complications encountered have included one ulnar neuropraxia and one lateral antebrachial cutaneous neuropraxia, of which both have resolved without further complication. Subjectively, elbow stiffness remains a problem postoperatively, but this appears to be more related to the severity of the presenting injury than to the specific approach itself.

Disadvantages of this technique and all extensile posterior humeral exposures include an increased risk of infection, devascularization of fracture fragments, and the need for radial nerve mobilization with possible nerve-traction trauma during the procedure. Infection risk can be minimized by strict adherence to sterile technique, adequate debridement of devitalized tissue, and a course of perioperative antibiotics. Fracture nonunion is always a concern with severe injuries, and, therefore, the least amount of periosteal stripping of

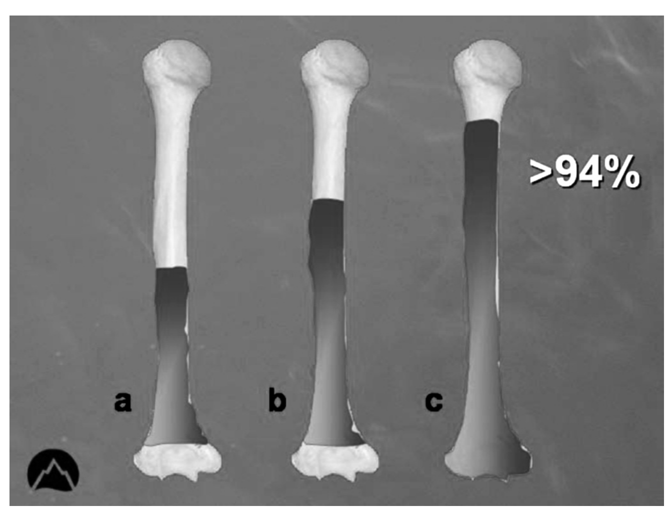

FIGURE 8. Schematic of the posterior humerus showing the area of exposure obtained when using the triceps splitting (a), the triceps-sparing radial nerve mobilizing (b), and the COLD approach (c). The latter achieves greater than 94% of posterior humeral exposure.

fracture fragments should be performed. Postoperative friction on the radial nerve from the underlying plate has been previously described.[6,7,9,21] In criticism of our plate construct for the representative case presented here, the authors recognize that the distal humeral construct does not overlap with the shaft fixation. Studies of the lower extremity, particularly the femur, have shown that overlapped constructs tolerate the highest loads and strains before failure.[22] The humerus does not see the same loads as the lower extremity, so one might argue that plate overlap is unnecessary. That being said, it should be known that all subsequent procedures using this technique adhered to the plate-overlap theory.

In summary, the COLD approach allows for substantial humeral exposure. Articular fragments can be directly visualized and addressed while simultaneously fixing more proximal fracture components, all through a single exposure. By using a distal lateral head of the triceps submuscular dissection plane, the lateral intermuscular septum is preserved and the distal radial nerve is protected. Mobilization of the radial nerve at its lateral humeral crossover allows for less morbidity because of fewer take-off branches being disturbed. The dense anterior band of the deltoid insertion is maintained, reducing postoperative deltoid dysfunction. The radial nerve is protected proximally with the lateral head of the triceps, and the axillary nerve is preserved with cautious proximal splitting of the raphe between the posterior and lateral deltoid components. The COLD approach is a useful alternative exposure when confronted with a complex humeral fracture pattern requiring both proximal and distal posterior humeral access.

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