Surgical Exposures of the Humerus

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The neurovascular and muscular anatomy about the humerus precludes the use of a truly "safe" fully extensile approach. Working around a spiraling radial nerve at the posterior midshaft requires either a transmuscular dissection or a triceps-avoiding paramuscular technique. To gain maximal exposure, the radial nerve must be mobilized at the spiral groove. For exposure of only the proximal humeral shaft, many surgeons prefer the anterolateral approach because it uses the internervous plane between the axillary and deltoid nerves proximally and the radial and musculocutaneous nerves distally. Proximally, the deltopectoral approach to the shoulder continues to be the most widely used. However, the lateral deltoid-splitting approach is a viable, less invasive approach for both rotator cuff repair and fixation of valgus-impacted proximal humeral fractures. Distally, intra-articular exposure is dependent on triceps mobilization, either by olecranon osteotomy or triceps release; this exposure can be coupled with either a triceps-splitting or a paratricipital approach for proximal extension.

Surgical approaches to the humerus are designed to circumnavigate the complicated neural anatomy of the shoulder and brachium. These approaches are frequently used for the spectrum of upper extremity procedures, from fracture fixation to arthroplasty. The humerus can be divided into three zones: proximal humerus, humeral shaft, and distal humerus. There are indications, advantages, and disadvantages to the classic surgical exposures to the humerus as well as to some of the most recently developed more extensile exposures. Of paramount importance is the neurovascular anatomy of the brachium (Table 1). Proximally, the circumflex humeral vessels and the axillary nerve divide the humerus at the surgical neck. Distally, the radial and ulnar nerves travel in circuitous paths, crossing intermuscular septae. Techniques for avoiding injury to these structures while providing ample visualization are compiled from the literature and from our experience.

Patient positioning varies based on both the involved region of the humerus and the desired exposure. For the proximal humerus, the patient may be positioned in the beach chair, lateral, supine, or prone position. Dorsal approaches to the midshaft and distal humerus include the lateral decubitus or prone position with the arm over a post, or the supine position with the arm resting across the patient's chest on a bolster. The supine position with the arm on a hand table may be used for anterior approaches to the midshaft and distal humerus.

Table 1

Surgical Exposures of the Humerus

Location	Procedure	Clinical Example	Surgical Approach	Concerns and Limitations
Proximal	Total shoulder arthroplasty	Conventional or reverse prosthesis	Deltopectoral	Axillary nerve, anterior humeral circumflex artery
	ORIF of the proximal humerus	Three- or four-part fractures requiring open reduction	Deltopectoral	Axillary nerve, deltoid insertion, anterior humeral circumflex artery
		Valgus-impacted or isolated greater tuberosity fractures	Deltoid split	Axillary nerve, deltoid detachment
	Rotator cuff tear	Supra-/infraspinatus tear	Deltoid split	Axillary nerve, deltoid detachment
		Subscapularis tear	Deltopectoral	Axillary nerve, musculocutaneous nerve, anterior humeral circumflex artery
Middle	ORIF of humeral fracture	Proximal to mid third fracture	Anterolateral	Divides the brachialis, lateral antebrachial cutaneous, and radial nerves
		All diaphyseal fractures	Lateral paratricipital	Radial nerve, posterior antebrachial cutaneous nerve
		Distal third fracture	Triceps split	Radial nerve, less extensile proximally
Distal	ORIF of intercondylar fracture	Simple fracture requiring bicolumnar fixation	Medial and lateral paratricipital	Ulnar and radial nerves, poor intra-articular visualization
		Intra-articular fracture without anterior comminution	Medial triceps reflection	Ulnar nerve, tendon-to-bone healing
		Intra-articular fracture with anterior comminution	Olecranon osteotomy	Ulnar and radial nerves, olecranon nonunion
	Elbow arthroplasty	Implant or interposition arthroplasty	Medial triceps reflection	Ulnar nerve, tendon-to-bone healing
Extensile	ORIF of segmental humeral fracture	Diaphyseal and distal intra-articular fracture	Lateral paratricipital with lateral reflection	Radial and axillary nerves, tendon-to-bone healing, anconeus
		Proximal humeral fracture with proximal to mid third shaft	Deltopectoral with anterolateral	Radial, axillary, and lateral antebrachial cutaneous nerves

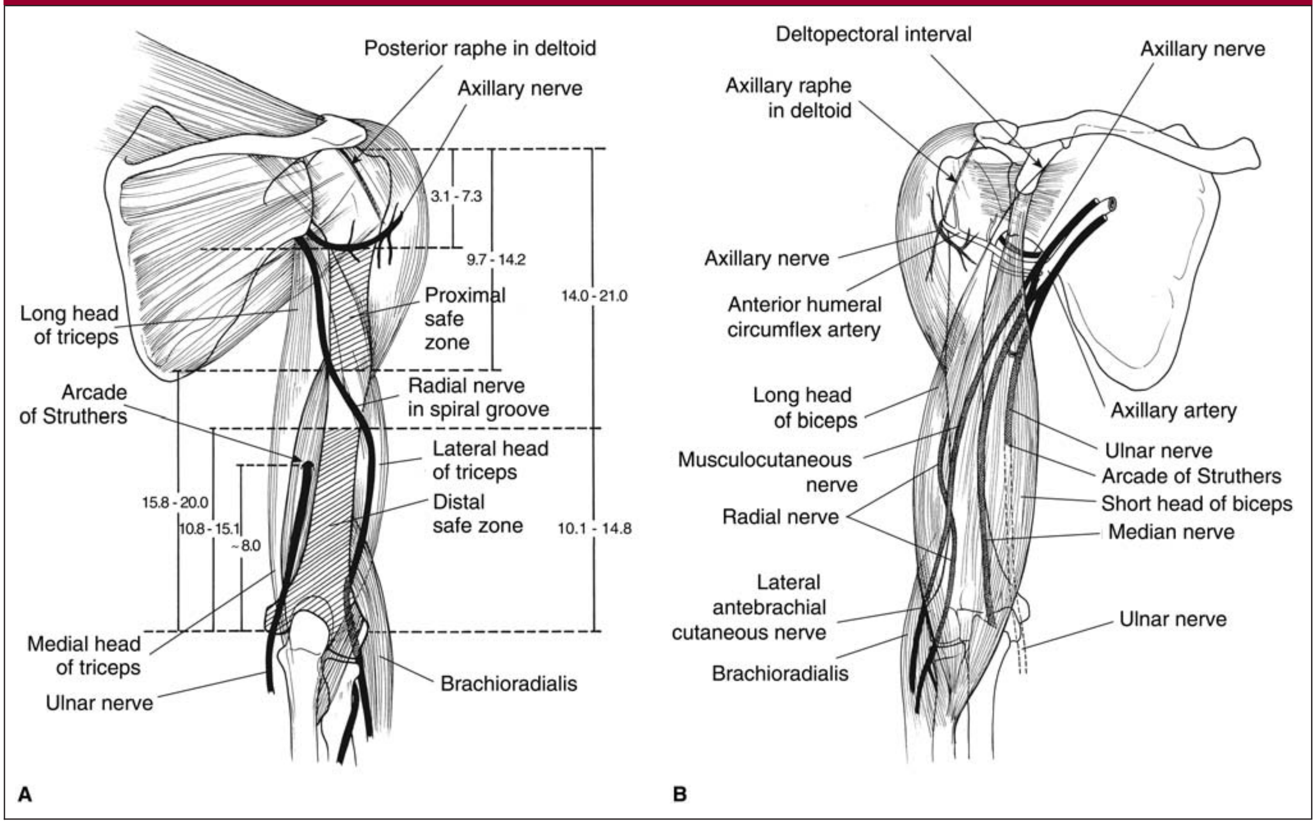
ORIF = open reduction and internal fixation

Anatomy

The axillary nerve is a continuation of the posterior cord. The nerve travels anterior to the subscapularis, wraps around the surgical neck of the humerus, and passes through the quadrangular space to innervate the teres minor and deltoid muscles (Figure 1). The nerve lies between 4.3 and 7.4 cm from the lateral edge of the acromion.[1] After entering the posterior third of the deltoid, the nerve travels along the deep deltoid fascia to innervate the middle and anterior thirds of the deltoid sequentially. The nerve to each head of the deltoid does not branch until it crosses each raphe.

The radial nerve is the other terminal branch of the posterior cord. This nerve begins anteromedially and travels along the subscapularis to join with the deep brachial artery

Figure 1



A, Posterior view of the neural anatomy of the brachium with reference measurements (in cm) from prominent anatomic landmarks. The area between the axillary nerve and the spiral groove is the proximal safe zone of the posterior humerus. The distal safe zone is distal to the spiral groove. **B,** Anterior view of the shoulder. Note the relationship of the axillary nerve and the anterior circumflex humeral artery to the inferior margin of the subscapularis muscle. During the deltopectoral approach, the "three sisters" (anterior humeral circumflex artery and its two venous communicantes) are often ligated separately to minimize blood loss and gain adequate exposure of the humeral metaphysis.

at the triangular interval. Beginning 97 to 142 mm from the lateral acromion, the nerve and artery then travel along the spiral groove, separating the medial and lateral heads of the triceps. The nerve exits the spiral groove 101 to 148 mm proximal to the lateral epicondyle.[2] As the nerve passes into the anterior brachium through the lateral intermuscular septum, the nerve is, on average, 10 cm from the distal articular surface of the elbow but never closer than 7.5 cm.[3] Distally, the radial nerve travels deep between the brachialis and brachioradialis muscles before bifurcating at the level of the radiocapitellar joint. Hence, the radial nerve originates anteromedially, courses posteriorly along the humerus, and emerges anterolaterally in the distal brachium.

The ulnar nerve arises from the medial cord and travels anterior to the medial intermuscular septum (Figure 1, B). At the arcade of Struthers, approximately 8 cm from the medial epicondyle, the nerve crosses into the posterior compartment[4] (Figure 1, A). It then courses posterior to the intermuscular septum and the medial epicondyle to enter the cubital tunnel. The ulnar nerve gives off an articular branch to the elbow joint that can be sacrificed during surgical exposure. Distally, the nerve passes into the anterior forearm between the two heads of the flexor carpi ulnaris.

Although rarely encountered in surgical exposures to the humerus, the brachial artery and median nerve warrant mention. The median nerve receives contributions from the medial and lateral cords and travels just medial to the brachial artery along the anterior surface of the medial intermuscular septum. At the elbow, the median nerve and the brachial artery can be found between the pronator teres muscle and the biceps tendon.

The deltoid enshrouds the proximal humerus and is divided into three heads by two fibrous raphes. The anterior, middle, and posterior heads originate from the distal clavicle, lateral acromion, and scapular spine, respectively. These three heads converge into a broad, 4-cm–wide tendinous insertion along the lateral humerus, approximately 9 to 13 cm distal to the lateral acromion. The anterior head originates from both the anterior acromion and the clavicle and forms a discrete insertion, constituting approximately one fifth the width of the deltoid insertion. Therefore, partial anterior deltoid release of more than one fifth of the insertion, frequently performed during plate fixation, completely detaches the anterior head of the deltoid.[5] The clinical sequelae of anterior deltoid detachment is unknown.

In the brachium, the most often encountered muscles are the triceps and the brachialis. The long head of the triceps originates from the inferior glenoid tubercle, the lateral head from the humeral shaft superolateral to the spiral groove, and the medial head inferomedial to the spiral groove. The lateral and long heads are superficial, with a visible, often palpable, cleft proximally, terminating in a common tendon. The medial head is deep and is accessible by dividing the long and lateral heads of the triceps. Innervation is provided by branches of the radial nerve. The radial nerve then passes through the lateral intermuscular septum to innervate the lateral third of the brachialis. The medial two thirds of the brachialis muscle and the remainder of the anterior compartment are innervated by the musculocutaneous nerve.

Proximal Humerus

Anterior Approach

The deltopectoral approach is the workhorse exposure for the proximal humerus. This approach develops the internervous plane between the deltoid (axillary nerve) and the pectoralis major (medial and lateral pectoral nerves). The cephalic vein is the landmark for this interval. The deltopectoral approach is useful for open reduction and internal fixation of a proximal humeral fracture, shoulder arthroplasty, anterior capsular shift, and subscapularis repair. We prefer this approach for shoulder arthroplasty and for plate-and-screw fixation of proximal humeral fractures because it affords greater visualization than does the lateral approach.

The axillary nerve should be palpated as it passes inferior to the subscapularis and the inferior capsule, and it should be protected throughout the procedure. External rotation of the shoulder during subscapularis release moves the dissection away from the axillary nerve and decreases tension on the nerve. Dissection medial to the conjoined tendon should be avoided because it places the musculocutaneous nerve at risk. Care should be taken to isolate and ligate the anterior humeral circumflex artery, along with, if necessary, its two venous communicantes at the distal margin of the subscapularis tendon during the exposure (Figure 1, B). To maintain the blood supply to the humeral head, surgical dissection should not extend to the inferior margin of the subscapularis. A cuff of muscle must be maintained to protect the anterior humeral circumflex vessels. Likewise, by releasing the subscapularis medial to its tendinous insertion, the arcuate artery is not sacrificed at the point at which it enters the humeral head along the lateral border of the bicipital groove.[6,7]

When a greater exposure of the lateral humeral shaft is needed, less than one fifth of the anterior deltoid insertion can be released.[5] Distal extension may be accomplished via the anterolateral approach to the humerus.

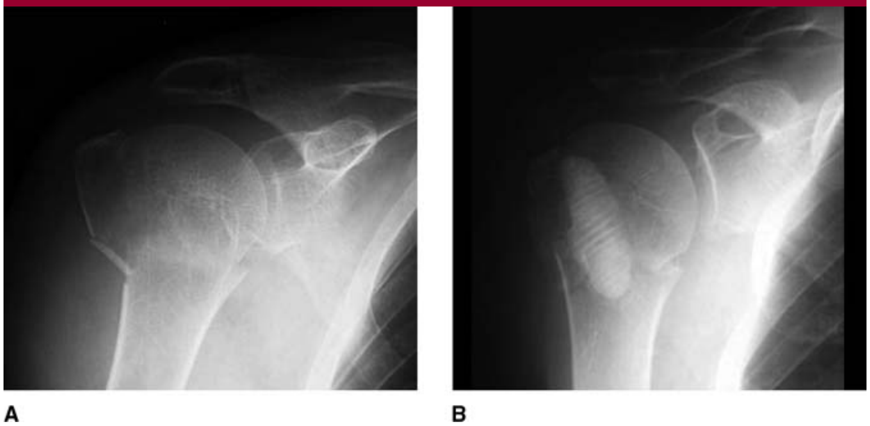
Lateral Approach

The second most common approach to the proximal humerus involves splitting the deltoid muscle. A split can be performed most easily through either raphe. The anterior raphe allows better access to the supraspinatus insertion and is optimal for antegrade humeral nailing. We prefer this approach for the fixation of two-part greater tuberosity fractures or other proximal humeral fractures amenable to treatment with a combination of suture fixation and/or intramedullary devices. We also use this approach to manage valgus impacted three- and four-part fractures (Figure 2). The more posterior rotator cuff tear can be accessed via the posterior raphe. A stay suture is placed in the distal-most apex of the split to prevent unwanted propagation and, thus, injury to the axillary nerve. For greater visualization, a portion of the deltoid can be released from the anterolateral acromion. At the time of closure, the crescentic deltoid origin should be repaired to the lateral acromion through small bone tunnels made with a towel clamp.

The deltopectoral and deltoid-splitting approaches may be combined to provide an extensile approach to the proximal humerus without risking denervation of the deltoid itself. This dual approach is helpful for concurrent subscapularis and posterosuperior rotator cuff tears as well as for anterior shoulder stabilization procedures with associated rotator cuff tears.[8]

Traditionally, the deltoid-splitting approach has been limited by the course of the axillary nerve to within 5 cm distal to the acromion. A recently described technique exploits the fact that the axillary nerve does not branch to innervate each deltoid head before crossing each raphe.[9] Extending the deltoid split through the raphe after protecting the main axillary trunk allows a more distal exposure of the proximal humerus without denervating the anterior deltoid[9] (Figure 3). This approach provides sufficient visualization to perform plate-and-screw fixation of proximal humeral fractures, with the plate placed deep to the isolated and protected axillary nerve and circumflex arteries.

Figure 2



A, Anteroposterior radiograph demonstrating a valgus impacted three-part proximal humeral fracture managed with a lateral deltoid-splitting approach without detachment of the deltoid or mobilization of the axillary nerve. **B,** Anteroposterior radiograph. The humeral head was disimpacted, and the valgus angulation was corrected. An Interpore coral spacer (Interpore Cross International, Irvine, CA) was used to fill the cancellous void. The greater tuberosity was then sutured to the humeral shaft via heavy nonabsorbable braided sutures threaded through drill holes.

Posterior Approach

Posterior approaches to the proximal humerus are less commonly performed because of the difficulty of the exposure and the infrequency of indications. The most common indications are posterior glenohumeral instability and tumor surgery. The patient is usually placed in either a beach chair or lateral position, with the arm draped free to allow unrestricted mobility of the glenohumeral joint. To allow release of the posterior deltoid origin from the scapular spine, the incision is made at a 45° angle to the scapular spine, halfway between the spine and the humerus (Figure 4). The teres minor is then retracted with the deltoid, along with their common neurovascular pedicle, the axillary nerve, and the posterior humeral circumflex artery. The plane between the infraspinatus and teres minor can be difficult to identify. It is best seen closer to the tendinous insertion at the level of the joint with the shoulder held in internal rotation. Sweeping the fascia off the two muscle bellies of the infraspinatus and the one muscle belly of the teres minor often reveals a fat stripe between the infraspinatus and teres minor. Occasionally, the tubercle of the teres minor can be found at the superior margin of the teres minor insertion.

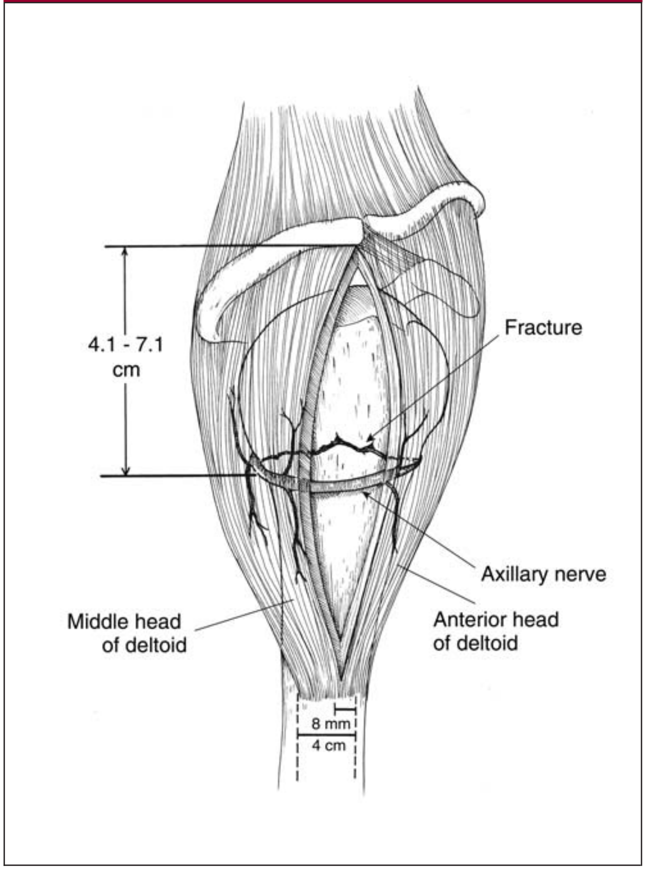
Exposure of the posterior glenohumeral joint capsule can be achieved by retracting the suprascapular nerve–innervated infraspinatus muscle superiorly. When further capsular exposure is needed superiorly, the infraspinatus tendon may be released 1 cm from its insertion onto the greater tuberosity and reflected medially. This additional exposure allows greater mobilization of the infraspinatus, potentially placing undue tension on the suprascapular nerve as it enters the infraspinatus muscle just distal to the spinoglenoid notch of the scapula.[10] One limitation of this approach is the lengthy deltoid detachment required. The posterior approach is also limited in that it cannot be extended distally. Thus, it is not recommended for addressing pathologic conditions distal to the anatomic neck of the humerus.

For exposure of the proximal humerus just distal to the surgical neck, the lateral head of the triceps can be reflected medially off the humerus to approximately 10 cm from the posterior aspects of the acromion.[2] At the midline of the posterior humerus, a safe zone exists proximal to the spiral groove between the axillary and radial nerves. With the deltoid retracted laterally, the proximal humeral shaft can be exposed.[11] This approach can be extended distally to expose the entire humeral diaphysis by continuing to reflect the triceps medially and elevating the radial nerve from the spiral groove. This approach allows for placement of plate-and-screw constructs spanning the length of the diaphysis. It is particularly useful for long oblique or spiral shaft fractures with proximal extension. Alternatively, the dissection can be continued along the lateral margin of the radial nerve as it spirals around the humerus, across the lateral intermuscular septum, and between the lateral and middle third of the brachialis muscle.[12]

Humeral Shaft

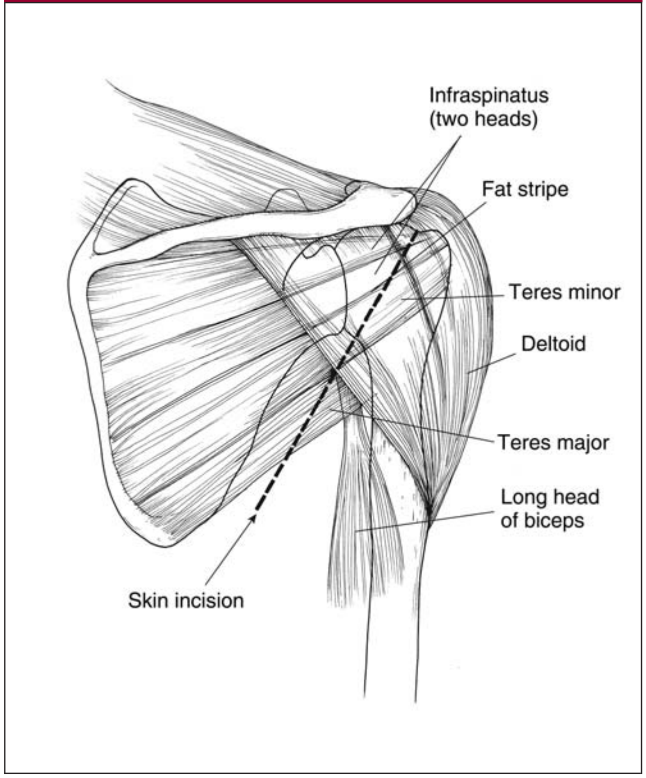
The spiral groove divides the humerus nearly in half and prevents so-called safe extensile exposure along the entire length of the humerus. Selection of surgical approach to the humeral shaft depends on fracture location and surgeon preference. Most commonly, an anterolateral approach is used for proximal and middle third shaft fractures. Distal extension is difficult because the lateral antebrachial cutaneous and radial nerves converge on the anterolateral aspect of the elbow. The posterior approach can be used for fractures along the entire diaphysis and can be extended distally for intra-articular fractures. Many surgeons shun this technique, however, because it can require dissection and mobilization of the radial nerve and deep brachial artery at the midshaft. Among the various trauma surgeons, there is no consensus on which ap-

Figure 3



Lateral view of the shoulder demonstrating an extended deltoid-splitting approach with mobilization of the axillary nerve. The axillary nerve enters each head of the deltoid as a single trunk, allowing for separation of the anterior and middle heads of the muscle along the anterior raphe without denervation of the anterior head.

Figure 4



Posterior view of the shoulder demonstrating the approach via the internervous plane between the suprascapular nerve (infraspinatus muscle) and the axillary nerve (teres minor and deltoid muscles). With the shoulder held in internal rotation, a fat stripe can usually be found between the two muscles at the level of the joint. The skin incision is oriented 45° from the scapular spine, allowing access to the scapular spine for detachment of the posterior deltoid origin while providing adequate visualization of the joint.

proach is preferable for each segment.

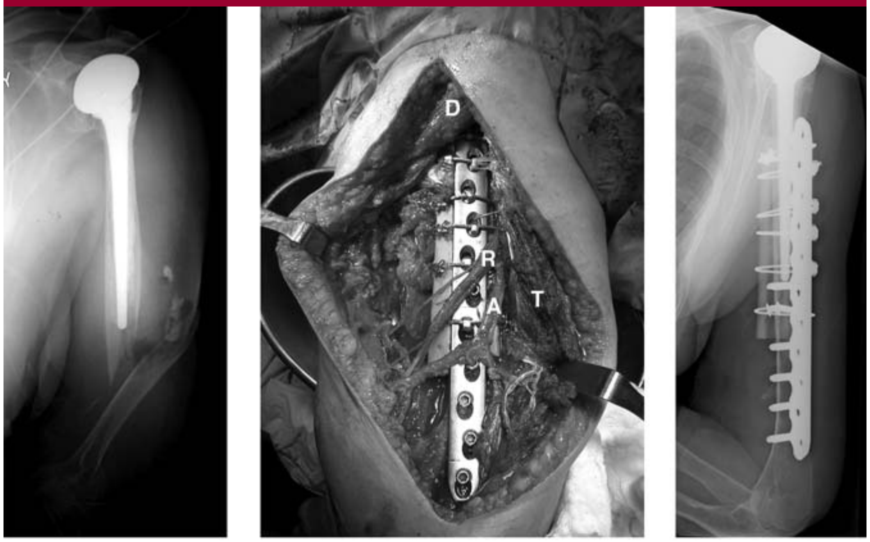
Anterolateral Approach

The anterolateral approach is a distal continuation of the deltopectoral approach. Proximally, the internervous plane between the deltoid and biceps muscles is used. Distally in the brachium, there is no true internervous plane because the brachialis receives dual innervation from the radial and musculocutaneous nerves. The anterolateral approach, therefore, splits the brachialis muscle along the middle and lateral thirds of the muscle belly. The lateral portion of the brachialis protects the radial nerve from retractors placed within the split. Care must be taken distally not to injure the lateral antebrachial cutaneous nerve as it exits between the biceps and brachialis muscles. The radial nerve is likewise at risk from distal extension and must be identified between the brachialis and brachioradialis.

Posterior Approaches

Posterior approaches involve either mobilizing the triceps from lateral to medial (paratricipital) or splitting the muscle belly along its fibers. The paratricipital approaches offer several advantages over triceps-splitting approaches. Some surgeons advocate using these approaches without a tourniquet because the approaches exploit relatively bloodless planes.[13,14] Avoiding injury to the triceps muscle itself also may limit intramuscular adhesions and scar formation and may, at least in theory, help lessen elbow contracture and improve postoperative triceps function. By staying outside the muscle, there is less risk of denervating a portion of the triceps or the anconeus. Moreover, extending the exposure proximally and distally can be

Figure 5



A B C

A, Anterposterior view of a periprosthetic mid diaphyseal humeral shaft fracture. **B,** A lateral paratricipital approach was used to gain access to the entire humeral shaft. The deltoid (D) limits exposure proximally, and the triceps (T) is reflected medially. A fixed-angle plate with proximal cables was used to secure the fracture and contain the two fibular strut grafts. The radial nerve (R) and profunda brachii artery (A) can be seen overlying the plate. **C,** Six months postoperatively, the fracture is healed, with maintenance of reduction and incorporation of the fibular grafts. An anterolateral approach was not selected for this fracture because it limits distal plate placement and does not allow direct visualization or mobilization of the radial nerve for placement of circumferential cables. Blind cable placement from an anterior exposure at the level of the spiral groove is not recommended.

accomplished more easily, particularly on the lateral side, by mobilizing the radial nerve and elevating the triceps off the humerus.

The lateral paratricipital approach uses the tissue plane between the lateral head of the triceps and the lateral intermuscular septum (Figure 5). The critical aspect of this approach is identification of the radial nerve as it exits the spiral groove approximately 14 cm proximal to the lateral epicondyle and pierces the intermuscular septum 10 cm from the articular surface.[3,15] The nerve is isolated and mobilized from the spiral groove, taking care to preserve the posterior antebrachial cutaneous nerve. The posterior antebrachial cutaneous nerve emerges from the radial nerve as the radial nerve exits the spiral groove, and it travels along the posterior aspect of the lateral intermuscular septum. It is important not to confuse the posterior antebrachial cutaneous nerve, which can be rather large, with muscular branches to the triceps.

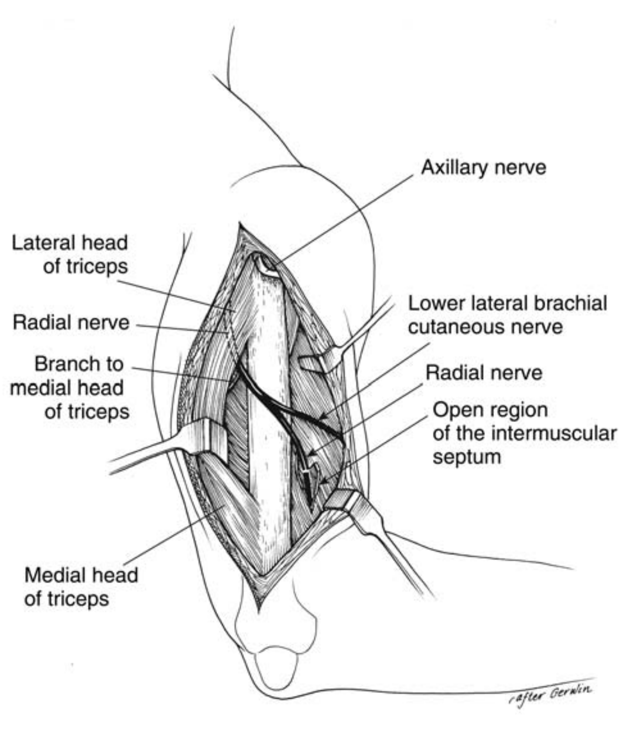
Once the radial nerve and its branches are identified and protected, the triceps is elevated subperiosteally and reflected medially. The approach may be extended proximally between the posterior deltoid and the lateral head of the triceps; it is limited by the axillary nerve. Approximately 94% of the humeral diaphysis can be exposed with this approach[15] (Figure 6). Distally, the approach can be combined with olecranon osteotomy, triceps reflection off the olecranon, or a modified Kocher approach. Another advantage of this technique is that it can be performed without a tourniquet because it exploits a relatively bloodless plane. Complete visualization of the radial nerve on both sides of the intermuscular septum also is possible with this approach.

The triceps-splitting approach separates the long head of the triceps from the lateral head superficially to reveal the medial head as it originates from the distal-medial aspect of the spiral groove. The interval between the two superficial heads is easier to locate proximally, before the formation of a common tendon, and is best identified by palpation. The radial nerve, which may lie directly on bone or may be separated from the humerus by several millimeters of the medial head of the triceps muscle, can be mobilized to allow a plate to be slid beneath it. Without mobilization of the radial nerve, only the distal 55% of the humeral shaft can be exposed. With mobilization of the radial nerve, the distal 76% of the humeral shaft is accessible.[15] Distally, plating is limited not by the exposure but by encroachment of the plate across the olecranon fossa. Proximally, the triceps becomes difficult to split, thus limiting an extensile exposure (Figure 7). A tourniquet may be used for the initial exposure; significant bleeding may be encountered on release of the tourniquet.

Distal Humerus

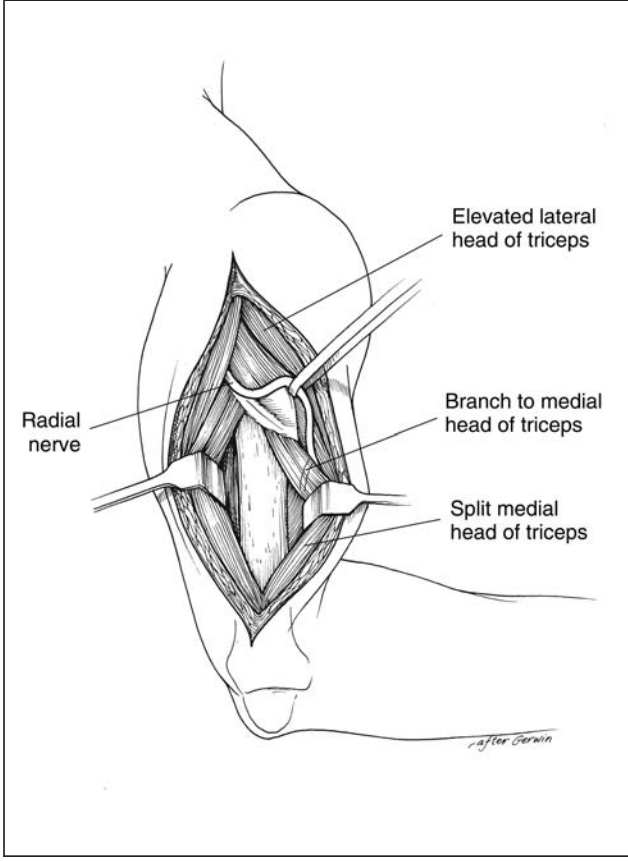
Approaches to the distal humerus allow exposure distal to the spiral groove, with a "safe zone" of 10 cm from the elbow joint.[2] Unlike the knee, where the patella and its attached extensor mechanism can be mobilized for visualization of the joint surfaces, the olecranon and triceps tendon are fixed, thus limiting direct visualization of the elbow joint. Multiple exposures to the distal humerus have been described to address this limitation. These exposures can be divided into two categories: procedures that detach the extensor mechanism and those that mobilize it. In general, detachment

Figure 6



The lateral triceps slide approach. Releasing the medial intermuscular septum facilitates subperiosteal mobilization of the medial and lateral heads of the triceps in a medial direction. When only limited exposure is necessary, either the proximal portion of the approach (before the spiral groove) or the distal portion of the approach (distal to the spiral groove) can be performed without the need to mobilize the radial nerve. Extended distally, an intra-articular exposure similar to the medial triceps slide can be achieved. (Adapted with permission from Gerwin M, Hotchkiss RN, Weiland AJ: Alternative operative exposures of the posterior aspect of the humeral diaphysis: With reference to the radial nerve. *J Bone Joint Surg Am* 1996;78:1690-1695.)

Figure 7



The posterior triceps-splitting approach provides access to the distal 76% of the humeral diaphysis once the radial nerve is mobilized. With this approach, the long and lateral heads of the triceps are separated, after which intramuscular division of the medial head of the triceps is performed. Proximal extension is limited by the lateral head of the triceps. (Adapted with permission from Gerwin M, Hotchkiss RN, Weiland AJ: Alternative operative exposures of the posterior aspect of the humeral diaphysis: With reference to the radial nerve. *J Bone Joint Surg Am* 1996;78:1690-1695.)

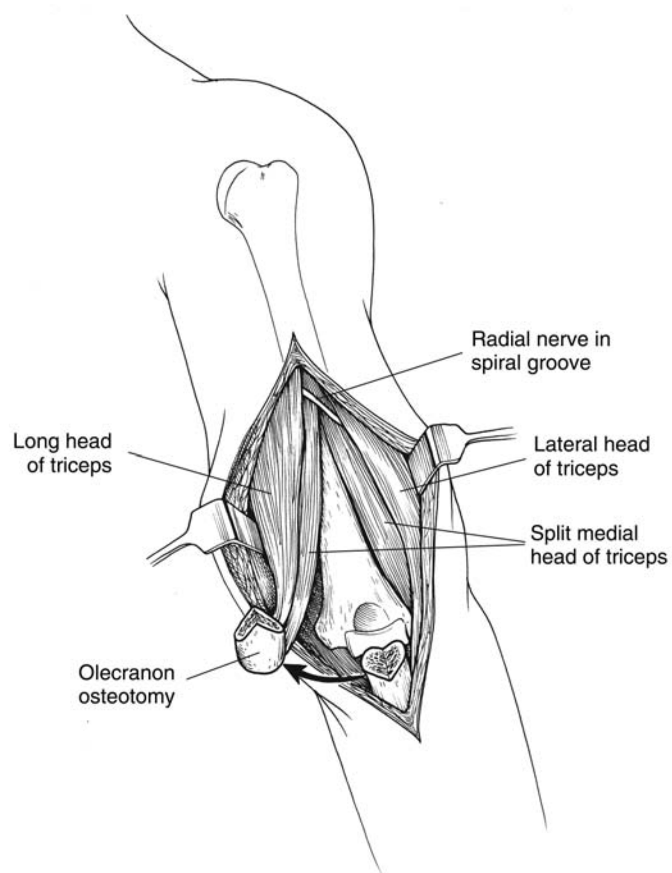
of the extensor mechanism enables improved visualization of the joint surfaces but at increased risk of postoperative extensor mechanism compromise.

Maintaining Extensor Continuity

Triceps-splitting or triceps-avoiding approaches have been recommended for extra-articular fractures or simple T-type intra-articular fractures. The triceps can be split from just distal to the spiral groove to the olecranon by first palpating and then dividing the interval between the long and lateral heads. The medial head, which lies adjacent to the humerus just distal to the spiral groove, can then be split in line with its fibers. Care must be taken when dividing the muscle proximally because the radial nerve most commonly overlies the origin of the medial head for two thirds of the circumference of the spiral groove.[2] Another concern is partial denervation of the lateral half of the medial head of the triceps if its nerve branches are not preserved.

Some surgeons advocate a straight midline split, which can be extended distally to reflect both the medial and lateral triceps insertions subperiosteally off the olecranon, providing excellent intra-articular visualization without extensor mechanism detachment.[16-18] Others have recommended a 75% lateral/25% medial split.[19] When combining a triceps-splitting approach with an olecranon osteotomy, however, the triceps split

Figure 8



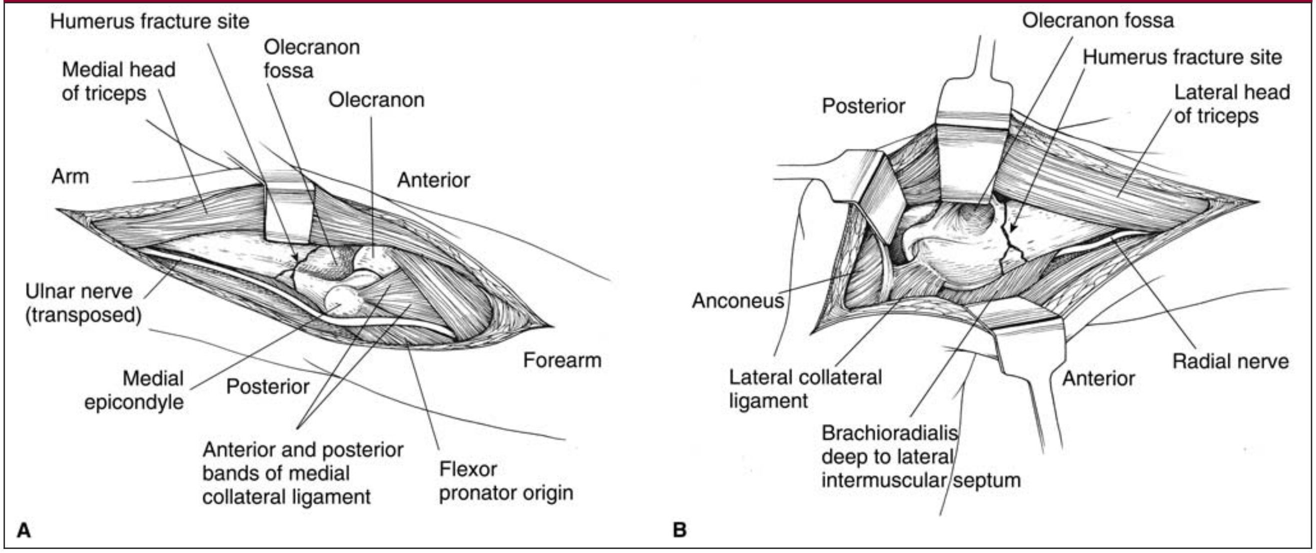
The triceps-splitting approach can be extended distally with the addition of an olecranon osteotomy. The osteotomy can be performed as illustrated, with reflection of the olecranon medially with the medial soft-tissue attachments intact (arrow). (Adapted with permission from Ebraheim NA, Andreshak TG, Yeasting RA, Saunders RC, Jackson WT: Posterior extensile approach to the elbow joint and distal humerus. *Orthop Rev* 1993;22:578-582.)

should retain more of the medial-sided triceps insertion onto the olecranon. The osteotomized olecranon can then be retracted medially with the bulk of the triceps attached, and the lateral triceps and anconeus reflected laterally[20] (Figure 8). Unlike a standard olecranon osteotomy, reflecting the anconeus with the lateral triceps preserves the innervation of the anconeus, maintaining the anconeal branch of the radial nerve as it courses along the lateral triceps muscle. Although small, the anconeus assists with dynamic stability of the elbow and provides a vascularized muscle bed for the lateral elbow.[21]

Paratricipital approaches may be performed medial to the triceps mechanism, lateral to the triceps, or both, with subperiosteal reflection of the triceps insertion in continuity with the periosteum of the dorsal ulna.[14,21,22] The medial paratricipital approach with triceps reflection, combined with mobilization of the ulnar nerve, provides excellent visualization of the entire distal humerus and proximal ulna. This approach is best suited for elbow arthroplasty and intra-articular distal humeral fixation of fractures with no proximal extension into the humeral shaft. The lateral paratricipital approach may be used for lateral column intra-articular fractures, particularly for the fracture extending into the humeral shaft. For simple intra-articular or distal extra-articular fractures requiring bicolumnar fixation, the medial and lateral paratricipital approaches may be combined without reflecting the triceps off the olecranon. However, complex intra-articular fractures with proximal extension beyond the distal third of the humeral diaphysis may require medial and lateral paratricipital approaches, with the addition of medial triceps reflection and ulnar nerve mobilization.

Midline posterior skin incision may be used for any of the paratricipital approaches because the skin flaps can be mobilized widely to allow access to both the medial and lateral sides. Midline skin incision also allows further exposure. The medial approach requires complete release and transposition of the ulnar nerve to the level of the first motor branch within the flexor carpi ulnaris. This approach takes advantage of the internervous plane between the triceps and the brachialis muscles. Proximal extension of this approach is blocked by the ulnar nerve piercing the intermuscular septum at the arcade of Struthers. Care must be taken not to injure the nerve at this level with zealous retraction. The medial column and medial aspect of the trochlea can be visualized with this approach (Figure 9, A). Distally, the dissection may be extended along the dorsal ridge of the ulna in the internervous plane between the extensor and flexor carpi ulnaris, allowing the extensor mechanism to be subperiosteally reflected off the olecranon while maintaining tendofascial continuity of the extensor mechanism.[22] In extreme flexion, this approach allows direct visualization of the joint surface nearly equal to that of an olecranon osteot-

Figure 9



A, Posteromedial view of the distal humerus, right arm. Medial paratricipital approach to the distal humerus. Anterior transposition of the ulnar nerve allows excellent visualization of the medial column. **B,** Posterolateral view of the distal humerus, right arm. Lateral paratricipital approach to the distal humerus. Distal extension can be achieved via the modified Kocher approach. Proximally, mobilization of the radial nerve allows access to the entire humeral shaft up to the level of the axillary nerve. (Adapted with permission from Shildhauer TA, Nork SE, Mills WJ, Henley MB: Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma* 2003;17:374-378.)

omy, with the exception of the anterior trochlea (Figure 10). Early active motion can be initiated after repair of the triceps to bone using nonabsorbable sutures. As the triceps remains in continuity, postoperative weakness is minimized. In their series of 49 total elbow arthroplasties, Bryan and Morrey[22] reported no triceps discontinuity or significant weakness.

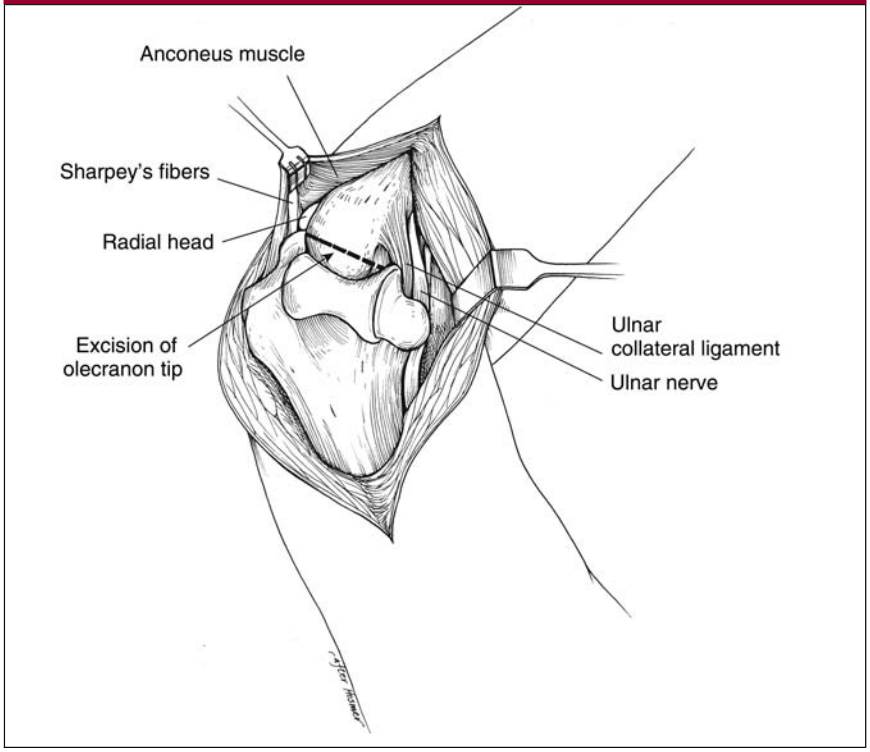
On the lateral side, the interval between the triceps and the mobile wad of three (brachioradialis, extensor carpi radialis longus and brevis) can be used to visualize the lateral column. When visualization of the radiocapitellar joint is needed, the dissection can be extended to include a Kocher approach. This maintains the anconeus with the lateral triceps flap, preserving both its innervation and blood supply.[14] The entire anconeus/triceps flap also can be elevated subperiosteally off the posterior humerus to allow direct posterior plating (Figure 9, B). Anterior extension of the exposure by elevation of the mobile wad is not recommended because it places the radial nerve at risk. Moreover, any proximal extension should identify and preserve both the radial nerve as it pierces the intermuscular septum just proximal to the brachioradialis origin and the posterior antebrachial cutaneous nerve as it branches off the radial nerve just distal to the spiral groove.[13]

Provided the distal extension of any paratricipital approach has not detached the extensor mechanism from the olecranon, such approaches can be combined with olecranon osteotomy if, after inspecting the fracture site, further exposure of the joint is deemed necessary. If the triceps has already been detached, another option is to osteotomize and remove the proximal tip of the olecranon. Removing the olecranon tip provides better intra-articular visualization for complex intra-articular fractures and simplifies intramedullary preparation of the proximal ulna for elbow arthroplasty. In our experience, this is rarely necessary, except in fractures with comminution extending into the anterior trochlea or for total elbow arthroplasty.

Detaching the Extensor Mechanism

O'Driscoll[21] combined a medial (triceps-reflecting) paratricipital and lateral (modified Kocher) paratricipital approach with distal extension to allow the entire extensor mechanism to be reflected proximally. As a unit, the triceps and anconeus muscles are freed from their fascial attachments medially and laterally, maintaining only their distal attachment to the olecranon. Via the triceps-reflecting anconeus pedicle approach, the triceps and anconeus are released subperiosteally from the ulna in a V-shaped tendofascial flap with the apex distal.[21] The rationale behind this approach is to provide an exposure similar to that of an olecranon osteotomy without the risk of olecranon nonunion, as well as for surgeries in which an osteotomy is

Figure 10



Medial triceps-reflecting approach as described by Bryan and Morrey.[22] The extensor mechanism remains in continuity with the deep fascia and periosteum of the proximal ulna. The ulnar nerve is transposed to gain better visualization of the distal humerus and to protect the nerve. Excision of the olecranon tip provides excellent intra-articular visualization. (Adapted with permission from Bryan RS, Morrey BF: Extensive posterior exposure of the elbow: A triceps-sparing approach. *Clin Orthop* 1982;166:189.)

contraindicated (eg, total elbow arthroplasty). However, unlike an osteotomy, which requires bone-to-bone healing, recovery of triceps function requires tendon-to-bone healing, which may represent a limitation of this technique. Furthermore, although the joint exposure achieved with the O'Driscoll technique is nearly equivalent to that provided by either an extended medial or lateral paratricipital approach alone,[22] it adds the potential complications of extensor detachment.

The olecranon osteotomy is the most commonly used technique for intra-articular fracture of the distal humerus. Of the techniques described, olecranon osteotomy affords the best exposure of the joint surfaces. Complications include hardware migration and prominence, delayed union, and nonunion.[23] The procedure involves elevating the anconeus insertion and the proximal aspect of the extensor and flexor carpi ulnaris origins so as to expose the olecranon while maintaining the triceps attachment. Unless exposure of the medial column is not necessary, we routinely transpose the ulnar nerve before performing the osteotomy.

Ideally, an apex distal osteotomy is made at the bare spot on the trochlear notch. Most of the osteotomy can be performed with a sagittal saw, although the articular side should be breached with an osteotome to create an irregular joint surface for later interdigitation. The olecranon with the attached triceps is then reflected proximally, separating the medial triceps from the medial intermuscular septum, and the lateral triceps from the anconeus and lateral intermuscular septum. The anconeus is denervated by this approach. When only distal exposure is required, we do not attempt to identify the radial nerve. However, when the exposure requires triceps mobilization >10 cm proximal to the lateral epicondyle, the radial nerve should be identified and protected.

Repair of the osteotomy can be performed at the close of the procedure with a variety of techniques, including a tension band construct with Kirschner wires or an intramedullary screw, an intramedullary screw without a tension band, or plate-and-screw fixation. We prefer a tension band technique with Kirschner wires and figure-of-8 fixation.

Proximal extension can involve either a lateral paratricipital approach with mobilization of the entire triceps muscle medially and elevation of the radial nerve[24] or a triceps-splitting approach proximal to the spiral groove with paratricipital extensions distal to the spiral groove.[25] For isolated lateral condyle fractures, we prefer a lateral paratricipital approach combined with a chevron osteotomy, leaving all medial periosteal and muscular attachments intact. The osteotomy is hinged open on the lateral side, allowing excellent visualization of the lateral column and articular surface without the need to violate the cubital tunnel or mobilize the ulnar nerve.

Summary

Humeral exposures are limited by the axillary nerve proximally, the ulnar nerve medially, and the radial nerve posteriorly and laterally. A thorough understanding of the internervous planes about the humerus is essential before undertaking any exposure of the humerus, particularly of the shaft. In general, nerves at risk should be identified and protected throughout the procedure. For the proximal humerus, the deltoid-splitting and deltopectoral approaches are familiar to most orthopaedic surgeons; a healthy respect for the potential dangers is essential to avoid neurovascular injury. For the diaphysis, we prefer the lateral paratricipital approach, for both its clean intermuscular dissection and its extensibility. Distally, for less comminuted fractures, we use either or both paratricipital approaches (with or without triceps reflection); for severely comminuted intra-articular fractures, we use an olecranon osteotomy. Once the triceps is reflected off the olecranon, however, olecranon osteotomy no longer can be performed.

Acknowledgment

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Additional Resources

CD-ROM: *Selective Exposures in Orthopaedic Surgery:* "Common Approaches to the Shoulder," by Dan Guttmann, MD, and Andrew S. Rokito, MD, editors: http://www5.aaos.org/product/productpage.cfm?code=02545

Related clinical topics articles available on *Orthopaedic Knowledge Online:* "Four-Part Proximal Humerus Fractures," by Joesph Zukerman, MD, Arash Araghi, MD, and Derek Plausinis, MD: http://www5.aaos.org/oko/shoulder_elbow/proximal_humeral/pathophysiology/pathophysiology.cfm

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