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Article

MODIFIED DELTOID SPLITTING APPROACH FOR PROXIMAL HUMERUS FRACTURES

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ABSTRACT

Reduction and fixation of fractures involving the epiphysis and proximal metaphysis of the humerus often require open surgery. Open shoulder surgery is challenging because the deltoid and rotator cuff musculature surround the joint and, in most approaches, exposure is limited by the proximity and importance of the axillary nerve. Understanding the importance of the deltoid and rotator cuff to glenohumeral function has led to the development of innovative, advanced, and less invasive shoulder approaches. Performing the different variants of deltopectoral and transdeltoid approaches to the glenohumeral joint has other advantages, disadvantages, and risks for each, all of which have techniques to extend and maximize exposure. The ability to perform each of these exposures gives the surgeon the flexibility to address the broadest range of pathologies in the best possible way. In this article, we present a new modified deltoid splitting approach that bypasses the area crossed by the axillary nerve and fully mobilizes it. This allows better visualization of the lateral aspect of the proximal humeral epiphysis required for plate placement. We believe this approach provides better surgical exposure and offers a useful alternative in managing complex multifragmentary humerus fractures.

KEYWORDS: *shoulder, deltoid-splitting approach, proximal humerus fracture, traumatology*

INTRODUCTION

Humerus fractures account for about 8% of all adult fractures, and their incidence increases with age (1). Comorbidities and bone quality can therefore complicate clinical decision-making. Patients and the healthcare system bear a significant burden from these injuries. Humeral fractures can involve the proximal epiphysis, diaphysis, or distal epiphysis. Management depends on the location of the fracture. Fractures of the proximal epiphysis are the most common. They make up about half of all humeral fractures. These injuries are one of the most controversial orthopedic trauma injuries to treat and are a common fragility fracture in older adults. Although much has been written about managing proximal humerus fractures, there are still many issues to consider regarding optimal management. Open reduction and internal fixation (ORIF) is the most commonly used surgical procedure. Of the various access routes to the proximal humerus, the deltoid splitting route is most discussed. The aim of this article is to summarize the different variants of the

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deltoid split approach and to present the surgical approach developed in our clinic, as well as the challenges and considerations associated with each of these approaches.

Proximal humerus fractures

The third most common fragility fracture in older people is the proximal humerus fracture (2). Their incidence is increasing in older people and the adult population. There is still a lot of research to do in this area. Most proximal humerus fractures occur in patients over 50, following a moderate fall. Due to the complexity of the shoulder, many factors influence functional recovery, including fracture type, fragmentation, bone quality, and patient-related factors (age, functional demands, preinjury shoulder function, and comorbidities). Management of these injuries is highly controversial for these reasons. Although the majority of fractures of the proximal humerus are treated non-surgically, there are several surgical treatment options. The most common surgical procedure is open reduction and internal fixation with a plate. Unfortunately, there are no absolute indications for surgical treatment, and it is still unclear which types of fractures are sure to benefit from internal fixation with a plate. Traditionally, the indications for using the plate as a means of synthesis have included the types of dislocated fractures according to the Neer classification system. However, Neer's classification showed low intra- and inter-rater reliability (3, 4). Therefore, in 2004, Hertel felt the need to develop a classification that simplifies fracture patterns by comparing them to Lego bricks (5). This was done to describe fracture patterns that are more prone to avascular necrosis of the humeral head and therefore more deserving of accurate reduction and synthesis with plate and screws. For purely descriptive purposes, it is useful to mention the AO classification (6). This classifies fractures into 2-fragment extrarticular, 3-fragment extrarticular, and 4-fragment articular. However, no clear parameters for the treatment of fractures of the proximal humeral epiphysis have been provided by any of the existing classifications.

More recently, a growing body of evidence from randomized controlled trials suggests that conservative treatment offers comparable functional outcomes to surgery, even for dislocated fractures. At the same time, complication rates for ORIF still vary up to 30% (7). Randomized trials have had small sample sizes. They also did not include all fracture types. For example, patients with large fracture splits, fractures with head splitting, fractures without neck involvement, and fractures with a "clear indication for surgery" were excluded from the most recent and largest randomized trial comparing surgery with conservative treatment. This is probably an indication that certain types of fractures are definitely in need of surgical treatment.

Therefore, the focus of research should shift from the comparison of different treatment modalities to the identification of specific patients and fractures that would benefit from surgery. Fractures such as fracture dislocations, fractures with head splitting, varus angulation/dislocation, and significant/incomplete head-diaphyseal displacement are well documented to have unfavorable outcomes following conservative treatment. In older people, such fractures may benefit from proximal humeral replacement rather than synthesis. This is because the latter has a higher risk of failure. However, plate fixation is the treatment of choice in younger, active patients. The aim of our study is to illustrate the different options for ORIF of proximal humerus fractures via the deltoid-splitting approach.

Surgical anatomy

The deltoid, subscapularis, supraspinatus, infraspinatus, teres minor, and teres major muscles are the muscles of the shoulder. The deltoid is a voluminous triangular muscle with a proximal base, and its apex lies on the lateral surface of the humerus. It can be divided into 3 bundles: anterior, lateral, and posterior. The deltoid's main function is to abduct the humerus up to 90°, its anterior head also contributes to humerus intrarotation and flexion. In contrast, its posterior bundle contributes to humerus external rotation and extension. The anterior part of the deltoid, which is attached to the lateral part of the clavicle, and the fibers that make it up run parallel to each other without any fibrous septa between them. The lateral head of the deltoid muscle runs from its proximal insertion along the lateral border of the acromion in a postero-anterior direction to its insertion on the humerus. This part of the deltoid comprises oblique fibers with a multi-pinnate arrangement, starting from a thick tendinous band that originates from the acromion. Similarly, a structure with the same arrangement of muscle fibers develops from the humeral insertion. Halfway along the lateral border of the humerus, the muscle fibers arising from the two bands interdigitate in a herringbone arrangement. Rectilinear fibers intimately associated with the periosteum are present in the posterior part of the deltoid, originating from the scapular spine (8).

The subscapularis originates from the scapula and contains several intercalated tendinous bands. These fuse laterally to form a flattened tendon in the upper two-thirds of the muscle. This tendinous portion has a variable insertion on the lesser tuberosity, the bicipital groove, and the greater tuberosity. The lower third of the subscapularis has an almost direct muscular insertion on the lower surface of the lesser tuberosity and the anterior surface of the humeral metaphysis through a thin membranous structure. The upper and lower part of the subscapularis muscle is innervated by the upper and lower subscapularis nerves, respectively. The superior fibers of the subscapularis interdigitate with the anterior fibers of the supraspinatus, contributing to the rotator interval. These subscapularis fibers fuse with the medial portion of the coracohumeral ligament and the superior glenohumeral ligament to form the 'suspension pulley' of the biceps longus tendon. This ligamentous sling stabilizes the intra-articular portion of the biceps brachii longus tendon. Internal rotation is the primary role of the subscapularis in shoulder movement. It can also contribute to adduction, abduction, flexion, and extension when positioned in variable positions. The upper fibers of the subscapularis contribute to the abduction, while the lower fibers contribute to the adduction.

Both active and passive mechanisms are required to stabilize the glenohumeral joint. The subscapularis plays an important role in both. During external rotation and abduction, active stability is provided. At the same time, passive glenohumeral stability is provided by the coupling of balanced forces across the glenohumeral joint, characterized by the subscapularis resisting the infraspinatus in the axial plane and the deltoid shear forces in the coronal plane, depressing the humeral head with lower fiber tension (9).

In the upper part of the scapula is the supraspinatus muscle. It has a fleshy origin from the supraspinatus fossa and overlying fascia and inserts into the greater tuberosity. It is joined posteriorly by the infraspinatus and anteriorly by the coracohumeral ligament. This tendon sends fibers in the anterior direction with the coracohumeral ligament through the bicipital groove to the lesser tuberosity. The coracohumeral ligament envelops the anterior border of the tendon. The anterior portion of the supraspinatus is stronger than the posterior half. The muscle fibers insert on an extension of the tendon within the anterior half of the muscle. However, the cross-sectional areas of the anterior ligament are slightly smaller than those of the posterior ligament. Therefore, a larger anterior muscle belly pulls through a smaller tendon area. Perpendicular to the direction of the tendon, part of the coracohumeral ligament passes over the articular surface of the supraspinatus tendon. This creates a lateral arch that is visible from the inside of the joint. This arch extends to the insertion of the infraspinatus tendon. A possible site of calcium deposition is this arch. The function of the supraspinatus muscle is important because it is active in any movement that involves the raising of the arm. At about 30 degrees of elevation, it exerts maximum force. When tested by selective axillary nerve block, the supraspinatus, along with the other accessory muscles (infraspinatus, subscapularis, and biceps), contributes equally with the deltoid to the torque of scapular plane elevation and forward elevation. The supraspinatus has an excursion of approximately two-thirds that of the deltoid for the same movement, indicating a shorter lever arm. Other rotator cuff muscles, particularly the infraspinatus and subscapularis, provide additional downward force on the humeral head to counteract deltoid shear forces. In order to use the biceps for the same activity, some patients rotate the shoulder externally. As the supraspinatus is bounded superiorly by the subacromial bursa and acromion and inferiorly by the humeral head, the tendon is prone to compression and rubbing. The limits of the supraspinatus tendon path are called 'supraspinatus outlet'. This space decreases with internal rotation and increases with external rotation. This shows the effect of the trochis.

The suprascapular nerve (C5 with some C6) innervates the supraspinatus. The suprascapular artery is the main arterial supply. It enters the muscle close to its midpoint, at the notch of the suprascapular notch at the base of the coracoid process (10).

Infraspinatus is the second most active rotator cuff muscle. It has a fleshy origin from the scapular infraspinatus fossa, overlying dense fascia and scapular spine. Its tendon insertion is in common with the anterior supraspinatus on the superior aspect and the lesser rotundus on the inferior aspect of the greater tuberosity. The infraspinatus is one of the two main external rotators of the humerus. It provides up to 60% of the external rotation force. It functions as a humeral head depressor. Even in the passive (cadaveric) state, the infraspinatus is an important stabilizer against posterior subluxation.

An interesting aspect of the musculature of the shoulder is that the same muscle can work in opposite directions depending on how it is positioned. In internal rotation, the infraspinatus, by circumscribing the humeral head and generating a forward force, stabilizes the shoulder against posterior subluxation. Conversely, it has a posterior traction line and stabilizes against anterior subluxation when the shoulder is abducted and externally rotated. The infraspinatus is a pinnate muscle with a median raphe covered by a strip of fat. This can be replaced during surgery to fill the space between the infraspinatus and the small round muscle. The infraspinatus muscle is innervated by the suprascapular nerve. Two large branches of the suprascapular artery are generally described as its blood supply (11).

The *teres minor* originates muscularly from the middle part of the lateral scapular border and the dense fascia of the infraspinatus. The teres minor inserts into the lower part of the posterior humeral tubercle. Its deep surface is adherent to the posterior capsule. It is separated from the superficial part by a fascial plane. The quadrilateral space is located laterally at its lower edge, and the triangular space is located medially. The posterior circumflex artery of the humerus and the axillary nerve border the small round in the quadrilateral space. The scapular circumflex artery lies just below this muscle in the triangular space. The long head of the triceps tendon, the alveolar fat, and the subscapularis muscle lie on its deep surface in the central part. Teres minor is one of the few humeral external rotators. It is important in controlling anterior stability, providing up to 45% of the external rotation force. It is also likely involved in the short rotator force pair in abduction, along with the lower part of the subscapularis. Posterior branches of the axillary nerve (C5 and C6) innervate the teres minor. Its blood supply comes from a number of vessels in the area, but the branch of the posterior scapular-humeral circumflex artery is the most constant (12).

The *teres major* originates from the posterior surface of the scapula along the lower part of the lateral border of the humerus. It has a muscular origin from the scapula and an insertion into the humerus posterior to the greater dorsal along the medial lip of the bicipital groove. This bony ridge is the continuation and posterior part of the lesser tuberosity. In their course, both the large dorsal and the large round make a 180° spiral, so that the previously posterior surface of the muscle is represented by fibers on the anterior surface of the tendon. In addition, the relationship between the great round and the great dorsal is reorganized so that the previously posterior great dorsal becomes anterior to the great round. In addition to the great dorsal, the great round is bounded superiorly by the triangular and quadrilateral spaces, posteriorly by the long head of the triceps, and anteriorly in the medial portion by the axillary space. Internal rotation, adduction, and extension of the arm are the functions of the teres major. During these movements, this muscle is only active against a force of resistance.

An additional function of this muscle in activities involving a well-positioned upper limb may be the upward rotation of the scapula. It is innervated by the inferior subscapular nerve (C5 and C6). Blood supply comes from branches of the subscapular artery, most often a single vessel of the thoracodorsal artery. The axillary artery may be the direct source of this branch (13).

The coracobrachialis has a fleshy and tendinous origin from the coracoid process, common with and medial to the short head of the biceps, and inserts on the anteromedial surface in the middle part of the humerus. On the lateral side, the coracobrachialis is bounded by its common origin with the biceps. Deeply, the coracobrachial bursa lies between the two conjoined muscles and the subscapularis. On the superficial surface are the deltoid, deltopectoral groove, and pectoralis major. These surfaces tend to be avascular. They may be crossed by a few small vessels. Innervated by small branches of the lateral plexus and musculocutaneous nerve, the action of the coracobrachialis is flexion and adduction of the glenohumeral joint. A single artery, usually axillary, provides the main blood supply (14).

The axillary nerve follows a course along the anterior subscapularis, crossing its inferior border 1 cm from the myotendinous junction and finally heading posteriorly where it is about 1 cm from the inferior glenoid border. Posteriorly, the nerve passes through the quadrilateral space before dividing into a posterior branch innervating the small round and skin over the lateral deltoid and an anterior branch running anteriorly deep to the deltoid and innervating all three heads. The anterior branch usually lies 5-7cm distal to the lateral border of the acromion. An anatomical variant, present in 20% of patients, has been described in which the anterior branch of the axillary nerve is less than 5 cm from the acromial border. In some cases, the distance is as little as 3 cm. Damage to this nerve will result in denervation of the deltoid, leading to significant shoulder dysfunction with little chance of functional recovery of the shoulder. Intraoperatively, the continuity of the nerve can be checked using the tug test, in which the surgeon hooks the nerve anteriorly, where it runs along the subscapularis, and posteriorly, where it runs along the inferior surface of the deltoid. A pull on one finger is then transmitted to the other. The humerus is used as a pulley (Fig. 1). Medial dissection of the conjoined tendon may injure the brachial plexus and brachial artery (15).

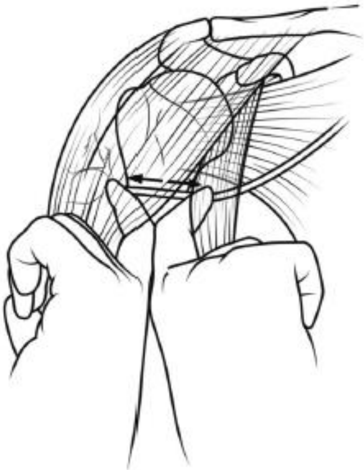

Fig. 1. *Pulley test.*

The articular surface of the shoulder humerus is spheroid, with a radius of curvature of approximately 2.25cm. A ring of ligamentous muscle insertions that control the stability of the joint is found along the axis of the spheroid. This ring comprises the two tuberosities, the intertubercular groove, and the medial surface of the neck of the humerus. The ligaments and muscles that control the stability of the humerus surround the head of the humerus in such a way that their tension exerts a constraining force towards the center of the joint. The spheroid is always more prominent than the ligamentous or muscular attachments in this position. The anteroinferior glenohumeral ligament maintains the stability of the joint. Its insertions are less prominent than the articular surface. With the arm in anatomical position (with the humeral epicondyles in the coronal plane), the humeral head is retroverted with respect to the transepicondylar axis. The intertubercular groove is approximately 1 cm lateral to the midline of the humerus. Approximately 9 mm posterior to the bicipital groove, the axis of the humeral head intersects the greater tubercle. The lesser tubercle (or tuberosity) lies directly in front of it, and the greater tuberosity is aligned with it on the lateral side.

The head-shaft angle is approximately 135 degrees in the coronal plane. Interestingly, this angle is smaller in smaller heads. It is larger in larger heads. Head size (radius of curvature) is strongly related to the patient's height. The anatomical neck of the humerus is the space between the articular cartilage and the ligamentous and tendinous attachments. Its width varies from approximately 1cm on the medial, anterior, and posterior humeral surfaces to virtually imperceptible on the superior surface, where there is no bony exposure between the articular edge and the rotator cuff insertion. The lesser tuberosity supports the subscapularis tendon insertion, while the greater tuberosity supports the supraspinatus, infraspinatus, and small rotator cuff insertions superiorly and inferiorly. The greater tuberosity extends the lever arm of the supraspinatus at elevations above 30 degrees because of its distance from the center of rotation. It also acts as a pulley. It increases the lever arm of the deltoid below 60 degrees.

When the arm is resting on the hip, the prominence of the greater tuberosity may even allow the deltoid to act as a head depressor. Below the level of the tuberosities, the humerus narrows into what is known as the surgical neck, owing to the high incidence of fractures occurring at this level. These two tubercles form an intertubercular channel, which is traversed by the long head of the biceps muscle. The intertubercular groove has a circumferential roof called the intertubercular or transverse humeral ligament.

The ligament has varying degrees of strength. The coracohumeral ligament is the main brake to tendon dislocation. The coracohumeral ligament originates from the coracoid as a V-shaped band with its opening directed backwards towards the joint. Tension in this area has an effect on shoulder function. The superficial glenohumeral ligament (floor) and the coracohumeral ligament (roof) make up the ring of tissue that forms the pulley that binds the biceps tendon. The intertubercular groove has a more superficial structure as it continues distally. However, its borders, called the lips of the intertubercular groove, continue to function as muscle insertion sites. Below the subscapularis, the medial lip of the intertubercular groove is the insertion site of the great dorsalis major and the great round; the insertion of the great dorsalis is anterior, often at the bottom of the groove. The pectoralis major muscle has its site of insertion at the same level, but it is on the lateral lip of the bicipital groove.

At its upper end, the intertubercular groove also serves as the entry point for the humeral head's main blood supply, the ascending branch of the anterior circumflex artery. At the beginning of the intertubercular groove or in one of the adjacent tubercles, this artery enters the bone. Near the center of the humerus, two shoulder muscles attach. On the lateral surface is the bony prominence of the deltoid tuberosity, on which the insertion of the great deltoid tendon is located. The coracobrachial insertion is located on the medial surface at approximately the same level. The retrograde direction of the articular surface and the prominence of this surface in relation to the muscle and ligament attachments are the essential relationships to be maintained during surgical reconstruction. The longitudinal orientation and the distance between the head of the deltoid and the insertion of the deltoid must be maintained. In fractures above the deltoid insertion that heal in varus humerus, the depressing effect of the supraspinatus head is ineffective in neutral, when shear forces generated by the deltoid are maximal (16).

SURGICAL APPROACH

Deltoid splitting (DS) approaches

Splitting the deltoid muscle allows access to the subacromial space, rotator cuff and glenohumeral joint. Several variations of the trans-deltoid approach have been described. The most commonly used are described below. A combination of locoregional anaesthesia with ultrasound-guided interscalene or supraclavicular block and/or general anaesthesia with an endotracheal tube emerging from the non-surgical side may be used. Both methods of regional anaesthesia have been shown to be safe. We prefer to use a modified beach chair position. The back is raised to 45 degrees and the thighs and knees are flexed. Although clinical complications with this position are rare, it remains controversial because it may be associated with cerebral hypoperfusion in high-risk patients. The neck must remain in a neutral position, with the head resting well-padded and firmly secured. This will prevent neurological complications such as stroke, traction brachial plexopathy, or posterior auricular neuropathy.

To facilitate access to the image intensifier from the head end of the table, the part of the table that supports the shoulder is cut away. By rotation of the C-arm of the image intensifier, good anteroposterior and axial 'modified' views can be obtained during surgery (Fig. 2). However, it is important to secure all anaesthetic tubing and to ensure that the equipment is clear of the C-arm path. This will prevent it from becoming dislodged during surgery. The entire arm is prepared and draped. This allows the assistant to move freely during the operation.

Fig. 2. *C-Arm position.*

A standardized approach is used for all surgical procedures. The supine position can be used. However, a radiolucent Jackson table is required. It is also possible to use a beanbag to support the patient, combined with an axillary roller and adequate padding under the peroneal nerve and bony prominences to position the patient in lateral decubitus.

There are several potential advantages to deltoid splitting (DS) approaches. Theoretically, reducing the dissection field could reduce the risk of osteonecrosis. However, comparative studies have not shown any differences. The various DS approaches avoid the stress on the anterior deltoid and thus the significant retraction that the deltopectoral (DP) approach can cause, which can compromise recovery. There are also several disadvantages to the DS approach. The dissection does not follow the anatomical planes. As healing progresses, the deltoid may adhere to the humerus and limit function if movement is not allowed immediately. In addition, there is a perception of risk to the axillary nerve, which is under the deltoid muscle (17).

Deltoid splitting minimally invasive plate osteosynthesis (MIPO) approach

In the DS minimally invasive plate osteosynthesis (MIPO) approach, the tip of the acromion is palpated. This is used as a reference point. On the lateral surface of the shoulder, a longitudinal skin incision is made from the projection of the lateral acromial border. The incision ends distally at 5 cm to allow access to the proximal humerus, greater tuberosity and humeral head. A 2.5-3.5 cm long incision is made approximately 7 cm from the apex of the acromion to insert distal screws (Fig. 3).

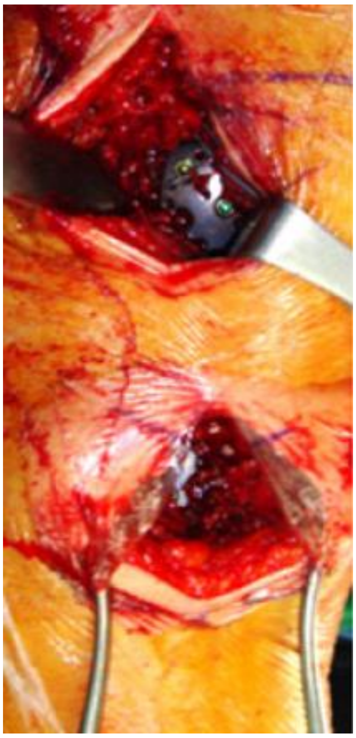

Fig. 3. *Deltoid splitting MIPO approach.*

The area between these two incisions contains the axillary nerve. It is considered the unsafe area. The scar can be unsightly. This incision crosses Langer's lines orthogonally. By applying axial traction to the humerus and pulling the rotator cuff, a good reduction can be achieved in most cases. Indirect reduction techniques such as ligamentotaxis have been used in some cases. In cases of a valgus displaced fracture configuration, reduction with a plate has also been used. To maintain reduction, the plate is placed proximally under the apex of the greater tuberosity. Reduction maneuvers and plate placement have been under fluoroscopic control. If non-resorbable sutures were used to insert the tendon, these were fixed in the corresponding holes of the plate. The plate is anchored proximally with stability screws at various angles. These are used to anchor the humeral head fragments. At the end of the synthesis, the non-resorbable sutures were tightened to the plate, ensuring correct tension of the muscle junctions (18).

Extended deltoid splitting approach

The incision begins at the anterolateral acromial angle, parallel to the deltoid fibers towards the deltoid insertion. The length of the incision varies depending on the extent of the fracture in the proximal metaphyseal area. The scar may be unsightly. This incision crosses Langer's lines orthogonally. The fibrous raphe between the anterior and middle heads of the deltoid is identified and then divided along its fibers. Distal traction on the arm results in the formation of a groove in the raphe. Using scissors dissection or a periosteal elevator, this gap can be opened proximally. This allows the subacromial and subdeltoid spaces to become accessed. Once divided, the subacromial bursa often masks the underlying structures. In order to visualize the greater and lesser tuberosities, a complete bursectomy must be performed. A finger is inserted tangentially to the lateral surface of the humerus and bent distally to palpate the neurovascular (NV) bundle consisting of the anterior branch of the axillary nerve and the posterior circumflex humeral artery. This is the only transverse structure perpendicular to the inferior surface of the longitudinal deltoid. Identifying and protecting this nerve is important. It is usually located 5 to 7 cm distal to the lateral border of the acromion, but in 20% of patients it is located at a distance of less than 5 cm.

It may be necessary to place a permanent suture to ensure that the split does not extend beyond this level. In line with the principle of the MIPO technique, extensive dissection to visualize the bone fragments is avoided. However, visualization of the bone fragments is good, which facilitates their reduction. With mobilization of the NV beam in the proximal and distal directions, deep fracture lines at the NV beam were reduced. Reduction of the joint and shaft segments has been possible under fluoroscopic guidance. Manipulation of the humeral shaft was controlled with reduction forceps. The forceps were inserted laterally to the bone and distally to the NV bundle. Reduction of the greater tuberosity (GT) fragment and/or the lesser tuberosity (LT) fragment was performed, depending on the type of fracture. The GT fragment was reduced and K-wires were in place for maintenance of the temporary reduction. LT was not reduced but left for later fixation. The plate was placed 15-20 mm below the apex of the proximal humeral epiphysis on the lateral surface of the proximal humerus. The height of the plate placement was determined to allow the lower head screws to enter the inferomedial quadrant of the humeral head and to allow the screws to support the humeral head calcar.

The plate was inserted from proximal to distal, deep to the NV bundle, between the two branches of the bone support clamps holding the humeral diaphysis (Fig. 4).

Fig. 4. *Extended deltoid splitting approach*

Proximal or distal mobilization of the NV bundle facilitated insertion of the lower head screws supporting the medial column. The rotator cuff was sutured to the plate. This was done to prevent tuberosity migration and varus collapse of the humeral head. To maintain external rotation postoperatively, care must be taken to preserve the infraspinatus fibers. Two strong sutures were placed in each tuberosity. This ensured a strong repair. The sutures were passed through the lateral holes of the plate. Stability was confirmed under fluoroscopy after tuberosity fixation was completed. To avoid injury to the nerve bundle, the layers of the deltoid raphe and deltoid fascia were not sutured (19).

Shoulder-strap incision approach

A strap incision is made. The apex is centered on the tip of the acromion. We use this type of skin incision because it follows Langer's lines around the scapular girdle (Fig. 5).

It tends to heal with a better aesthetic result than the more traditional direct lateral skin incision. In women, the line of the bra strap also partially hides the healed skin incision. An elliptical flap with a distal base is created. This is done by dissecting the subcutaneous tissue superficial to the fascia overlying the deltoid muscle. The creation of this flap allows complete exposure of the upper deltoid, which is then divided along its fiber line for 3 cm at its anterior raphe, located at the junction of the anterior and middle portions of the muscle. This site is relatively avascular as it is a watershed in the blood supply to the deltoid. This superior cleft provides the superior 'window' of the approach.

Fig. 5. *Shoulder-strap incision approach*

With further dissection, the entire anterolateral and posterolateral surfaces of the proximal humerus can be visualized. The anterior branch of the axillary nerve and its associated vessels are then identified. They are protected with a repere.

We have found that an index finger inserted through the proximal deltoid cleft and directed distally and laterally identifies the area of the nerve. It is felt as a narrow transverse band against the deltoid, 4-6 cm distal to the acromion. A large artery clamp is placed distally to this area and passed through the proximal deltoid cleft. This can be used to create an arterial loop around the nerve to protect it. In valgus fractures, the nerve is often close to the fracture site due to the geometry of the fracture. The deltoid split is then continued distally to the area protected by the sling. This creates an inferior 'window' allowing visualization of the proximal lateral humeral diaphysis.

We do not attempt to split the deltoid in the nerve area. This reduces the risk of traction injury in this area. Free-standing or manual retractors may be used in the superior and inferior windows to improve intraoperative visualization of the proximal humerus and the humeral diaphysis, respectively. Placement of 3 or 4 non-resorbable sutures 2 in the tuberosity fragments is recommended to facilitate atraumatic mobilization and minimize the risk of injury from repeated manipulation. The plate is placed through the superior 'window' just behind the posterior lip of the bicipital groove at the most anterior part of the greater tuberosity on the lateral aspect of the humeral head. Under fluoroscopic guidance, this will facilitate screw insertion into the posterior aspect of the humeral head.

Care should be taken to obtain good quality modified anteroposterior and axial intra-operative fluoroscopic views of the shoulder to avoid inadvertent penetration of the screw into the articular surface of the humeral head. Fixation of the plate at the junction of the metaphysis and diaphysis distal to the fracture is achieved with 2 or 3 cortical screws. These are inserted through the "window" of the inferior soft tissues. The fixation may be augmented with bone graft substitute or allograft to fill metaphyseal defects. For open reduction of posterior dislocations and anterior fracture-dislocations caused by propagation of a Hill-Sachs lesion (type I anterior fracture-dislocations), we have found this approach to be particularly useful. In these injuries, the deltoid incision provides direct access to the anteriorly or posteriorly dislocated humeral head. The head can then be dislocated from the glenoid rim to achieve reduction (20-26).

Modified deltoid-splitting approach

An incision of approximately 8 cm is made from the palpable anterolateral border of the acromion distally along the deltoid fibers (Fig. 6).

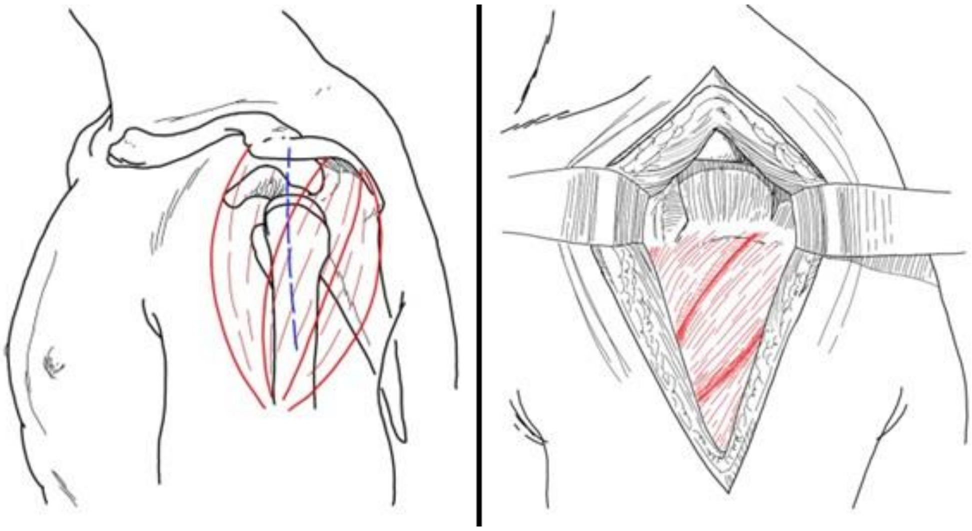

Fig. 6. *Incision for modified deltoid-splitting approach.*

The anterior, lateral, and posterior portions of the deltoid fibers are identified after visualization of the proximal portion. Divide the fibrous raphe along its fibers between the anterior and middle heads of the deltoid. The proximal window is developed (Fig. 7).

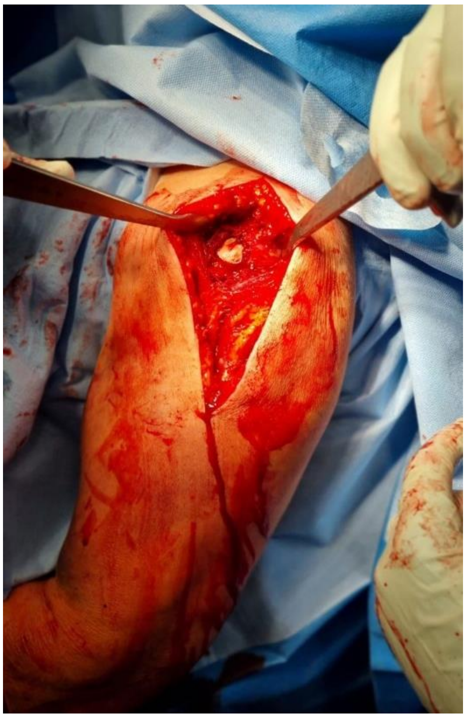

Fig. 7. *Proximal window*

The lateral wall of the humerus can be visualized. The lateral head of the deltoid has an oblique course. It develops from posterior to anterior in a cranial-caudal direction. Following the course of the lateral head of the deltoid in a cranial-caudal direction, a blunt dissection is performed between the lateral and posterior heads. This is called the distal window (Fig. 8). It allows visualization of the proximal metadiaphyseal portion of the humerus.

The proximal window allows the humeral head to be manipulated and the fracture margins affecting it reduced. Reduction is achieved either by direct fracture line control or indirect fracture control using fluoroscopy.

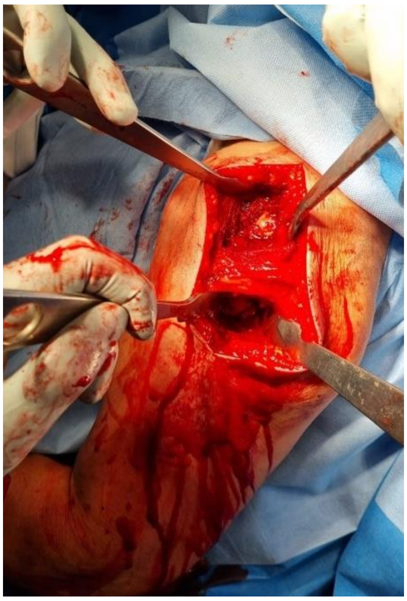

Fig. 8. *Proximal and distal windows*

Through this window, traction sutures can be placed at the osteotendinous junction at the level of the subscapularis, supraspinatus and subspinatus tendons. This is useful in reducing the multipart fracture of the humeral head. If there is intraspongiosal bone loss, an artificial bone graft may be used. Temporary K-wires may be used to maintain the reduction achieved to avoid interference with the next plate placement. Through the proximal window, the plate is placed and slid onto the bone plane, deep in relation to the lateral head of the deltoid: it is possible to check directly the correct position of the plate along the axis of the humeral diaphysis, respecting the bicipital shower and the height in relation to the apex of the greater tuberosity (Fig. 9).

Fig. 9. *Plate palcement.*

Thanks to the distal window, it is possible to reduce metadiaphyseal fractures or to position a clamp that allows management of the diaphyseal body for reduction of humeral neck fractures; the distal window is also useful for verifying the correct position of the plate along the axis of the humeral diaphysis.

The described surgical approach does not include isolation of the neurovascular bundle (NVB) consisting of the anterior branch of the axillary nerve and the posterior humeral circumflex artery.

The lateral head of the deltoid protects the course of the NVB throughout its development. The screws can be placed in the humeral calcar by cranial mobilization of the lateral head of the deltoid.

DISCUSSION

There are distinct advantages and disadvantages to each of the described variations of the DS approach. The aim of this article is to describe the different DS approaches in the surgical treatment of proximal humerus fractures and the evaluation of the specific indications. The DS approach allows a more intuitive reduction of the fracture under direct vision. This is due to the direct exposure of the lateral surface of the proximal humeral epiphysis. This reduces the need for fluoroscopy and allows for a more intuitive fracture reduction than conventional reduction. It also allows for faster and more accurate plate placement.

Compared to the other approaches, the deltoid splitting MIPO approach has the advantage of a smaller incision. This reduces the risk of infection and surgical wound dehiscence. However, the surgical incisions cross Langer's lines. This may result in keloids or cosmetically unsatisfactory scars. The incision required to expose the proximal window is small compared to the other options, which may result in partial visualization of the fracture margins, potentially making it difficult to reduce the fracture. In addition, the area of skin between the two incisions could limit the surgeon's ability to correctly position the oblique screws towards the inferomedial region of the humeral head, which is necessary to prevent varus deformity of the fracture site.

The predominant feature of the extended deltoid splitting approach is the identification, isolation and protection of the neurovascular bundle. This approach certainly reduces the perceived risk of axillary nerve injury; it also allows greater exposure of the bony surfaces, facilitating direct reduction of the fracture edges and easier positioning of the oblique screws, which are directed towards the infero-medial part of the humeral head. Greater peri-periostealisation of the bony surfaces is the result of the increased exposure. In addition, the risk of vasculoskeletal injury to the peripheral branches of the axillary nerve or the branches of the circumflex artery is increased by isolating the neurovascular bundle. Direct mobilization of the neurovascular bundle carries the risk of entrapment of the axillary nerve. The skin incision crosses Langer's lines. It is wider than in the MIPO approach.

The shoulder strap incision approach has significant aesthetic advantages. The incision follows Langer's lines, reducing the possibility of keloids and dehiscences. It also improves the aesthetic result of scars, which, in women, are hidden by bra straps. This approach allows protection of the neurovascular bundle by the muscular fibres of the middle head of the deltoid, which does not prevent its mobilisation, which is necessary for direct visualisation of the fracture edges in preparation for their reduction. Positioning the oblique screws towards the infero-medial part of the humeral head is also made possible by the mobilisation of the neurovascular bundle protected by the overlying musculature. The crescent incision allows a wide proximal window to be created. This is necessary in anterior or posterior dislocations of the humeral head. It should be noted that the skin incision is the widest of the DS variants studied. This is certainly a risk from an infectious point of view. Furthermore, this approach does not allow for distal extension. This is necessary in the event of intraoperative complications or in the case of multifracture fractures involving the more proximal part of the humeral diaphysis.

In the modified deltoid splitting approach, the neurovascular bundle, including the anterior branch of the axillary nerve, is not directly visualized but is protected by the course of the middle deltoid bundle. The plate is slid along the lateral cortex of the proximal meta-epiphysis of the humerus. It is therefore positioned deeper than the neurovascular bundle without compromising its integrity along its course. The dissection itself may increase the risk of NV injury to other axillary nerve muscle branches that are present within 1 cm of the deltoid raphe and to the co-existing posterior humeral circumflex artery, which is a major blood supply to the humeral head. Mobilizing the middle deltoid bundle allows visualization of the fracture edges, reducing them and placing oblique screws directed at the infero-medial part of the humeral head. The proximal and distal windows are all created with blunt instruments through the deltoid heads. The deperiosis of the bony surfaces that results from this is minimal. Reduction is mainly achieved through direct visualization, limiting the use of fluoroscopy, and simplifying surgical gestures. The skin incision crosses Langer's lines. It is approximately 10 cm wide. This procedure is easier to learn because of the blunt approach and direct visualization of the fracture lines. The easy distinction of the anterior, medial, and posterior heads of the deltoid at its proximal insertion enables easy isolation of the medial portion and easy development of the proximal and distal windows.

The almost complete absence of risk of injuring the neurovascular (NB) bundle, which is always protected by the medial bundles of the deltoid, allows even the young surgeon to approach this route with considerable confidence. Reduction of the fracture is intuitive due to direct visualization of the lateral part of the proximal humerus.

All surgical approaches, except the deltoid splitting MIPO approach, allow the development of a distal window. This is useful for direct visualization of the humeral diaphysis. Through this window, it is possible to mobilize the humeral diaphysis directly with a reduction forceps, allowing greater traction and therefore more effective ligamentous laxity.
In the Extended Deltoid Splitting and Modified Deltoid Splitting approaches, it is possible to increase the distal window by extending the access route along the lateral aspect of the humerus to the level of the elbow. This option allows these surgical variants to be functional in the event of intraoperative complications or fractures involving the humeral diaphysis. The fixation achieved in each of the described variants has allowed the patients to perform active and passive mobilization exercises without concern, with excellent functional results.

CONCLUSIONS

The DS approach is versatile for proximal humerus fractures due to the various surgical variations described. The direct visualization of the lateral surface of the humerus allows for an intuitive and direct reduction as well as fast and accurate plate placement. The reduction of the peri-periosteal area makes the DS approach more biologically effective.

Direct or indirect protection of the nerve bundle can be achieved with each of the different surgical approaches, making this approach safe.

The choice between the different surgical options described can be made by the surgeon based on the type of fracture and the patient undergoing surgery. They all have superimposable results in terms of radiological and functional outcome as well as safety.

In our opinion, the modified deltoid splitting approach is the most versatile, accurate, fast and safe of the approaches described. Its expandability allows us to use this surgical approach for complex fractures that involve the diaphysis of the humerus in addition to the proximal epiphysis, and to expand the surgical approach in the event of intra-operative complications. In addition, ORIF for proximal humerus fractures can be safely performed by young surgeons with satisfactory results due to the relatively short learning curve.

Conflict of interest statement
The authors declare that they have no conflict of interest.

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