13 Arthroscopy-Assisted Reduction-Internal Fixation in Greater and Lesser Humeral Tuberosity Fracture

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Proximal humerus fractures represent approximately 50% of all humerus fractures and approximately 5% of all fractures in humans (Horak and Nilsson 1975; Lewis et al. 2015). Although isolated lesser or greater tuberosity humeral fractures are less common, when they occur they warrant special treatment consideration. Isolated greater tuberosity fractures occur in 17–21% of proximal humeral fractures and 15–30% of glenohumeral joint dislocations (Bahrs et al. 2006; Green and Izzi 2003; Liao et al. 2016). Isolated lesser tuberosity avulsion fractures represent 2% of all proximal humerus fractures (Goeminne and Debeer 2012; Gruson et al. 2008; Lewis et al. 2015).

Several reports have proposed the injury mechanism for greater tuberosity fractures where the rotator cuff muscles cause an avulsion due to muscle action. A direct blow or fall onto the shoulder, or indirectly, such as falling on an outstretched upper extremity or on an abducted and externally rotated shoulder represents other greater tuberosity fracture mechanisms (Bahrs et al. 2006; Baudi et al. 2015). Lesser tuberosity fractures are related to the following three primary injury mechanisms: (1) an avulsion through the lesser tuberosity apophysis with the shoulder in a forced sudden abduction and external rotation and the subscapularis muscle eccentrically contracting to resist this force, (2) an axial load along the long axis of humerus applied to an extended and externally rotated shoulder, and (3) micro-trauma or repetitive trauma that creates an incomplete lesser tuberosity traction injury (Gruson et al. 2008; Lewis et al. 2015; Neogi et al. 2013; Robinson and Aderinto 2005).

Both lesser and greater tuberosity fractures are frequently associated with traumatic shoulder dislocations and axillary nerve injuries. However, other nerves such as the suprascapular, radial, and musculocutaneous nerve may also be injured. Associated neural injuries occur more commonly in elderly patients in association with soft tissue hematoma formation. Neural recovery generally takes 4 months or less (de Laat et al. 1994; Lewis et al. 2015; Toolanen et al. 1993). Arterial injuries may also be associated with tuberosity fractures that occur in conjunction with other proximal humerus fractures, glenohumeral fracture-dislocation, or frank glenohumeral dislocation (Lewis et al. 2015; Willis et al. 2005; Zuckerman et al. 1984). Glenohumeral joint labral, capsuloligamentous, rotator cuff lesions and articular cartilage damage may also occur in conjunction with tuberosity fractures (Schai et al. 1999).

The recent trend toward minimally invasive surgery has extended to surgical fracture management. The use of such procedures has the

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advantage of minimizing soft tissue damage using smaller incisions. This prevents further fracture region blood supply damage. Reduced soft tissue damage helps prevent postoperative infection and provides better cosmetic results (Barnes et al. 2010; Giudici et al. 2017).

13.1 Clinical and Imaging Evaluation

In the acute situation, it is not easy to clinically distinguish an isolated greater tuberosity fracture from a three- or four-part proximal humeral fracture or from acute rotator cuff injury. In each situation, the patient's chief complaint involves shoulder pain, and reduced or absent active mobility, particularly shoulder abduction and external rotation movements. A detailed history is essential to delineate the precise injury mechanism and the presence of any pre-existing shoulder conditions. A detailed, systematic physical examination is essential to help determine if any associated neurologic injuries exist. It can be difficult to precisely evaluate proximal upper extremity muscle strength in the presence of an acute injury. Sensory examination alone can be misleading, particularly with axillary nerve injury, as it is possible to have intact sensation while motor function is abnormal. Electrodiagnostic studies including electromyography and nerve conduction velocity tests should be obtained if the neurologic deficit does not resolve within 3–6 weeks (Green and Izzi Jr 2003; Gruson et al. 2008). In most cases, electromyography can confirm low-grade neuropraxia, related to stretch or external pressure from initial trauma, and can help map the recovery trajectory (Baudi et al. 2015).

Radiographic evaluation of the injured shoulder should always include the shoulder trauma series with a true anteroposterior (X-ray beam perpendicular to the scapular plane), scapula Y-view (X-ray beam parallel to the spine of the scapula), and Velpeau axillary view (with the patient standing, leaning backwards 30° over the X-ray table as the beam passes through the shoulder from above) (Fig. 13.1), (Green and

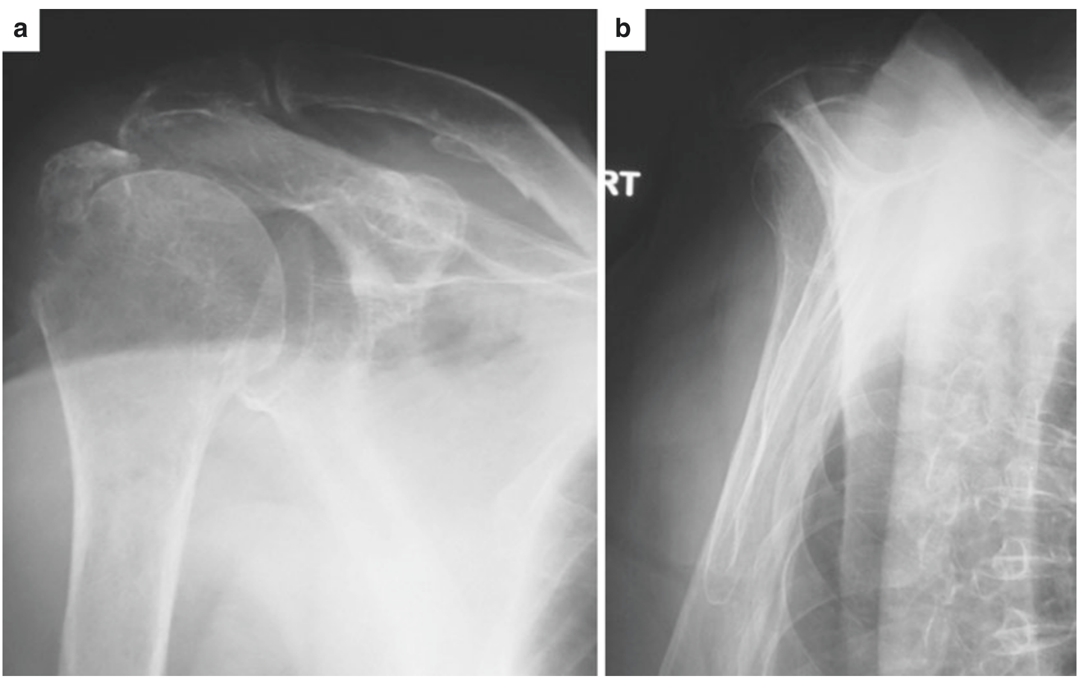

Fig. 13.1 Greater tuberosity humeral fracture. (**a**) Antero-posterior view. (**b**) Scapular-Y view

Izzi Jr 2003). Additional anteroposterior views in internal and external rotation can provide more details about the extent of supero-posterior greater tuberosity fracture displacement. Additionally, this X-ray view can help identify the presence of an occult, non-displaced humerus surgical neck fracture. Fracture displacement magnitude and pattern are critical to operative planning for humeral tuberosity fracture management. Additionally, this information helps when deciding if an arthroscopy-assisted surgical approach may be beneficial. Computed tomographic (CT) imaging may also be indicated to determine the number and pattern of fracture fragments, the direction and extent of displacement, occult fracture lines, and whether or not an intra-articular extension (three-part valgus impacted fractures) is present. This information may influence both the selected surgical approach and the choice of fixation device(s) (Gruson et al. 2008; Mora Guix et al. 2006). CT imaging should always be performed if plain radiographs do not adequately delineate displacement magnitude and provide adequate insight as to which surgical approaches should be considered. Axial imaging is most useful for demonstrating posterior displacement, but it may not always clearly demonstrate the extent of superior displacement. Coronal and three-dimensional reconstruction CT imaging could be used to better define the extent of superior greater tuberosity fracture displacement (Figs. 13.2 and 13.3).

Diagnostic ultrasound can be particularly helpful in trying to identify occult fractures in acute settings and provide accurate assessment of rotator cuff integrity when radiographic imaging is positive. The speed of performance, relatively low cost, and increasing availability in emergency departments make ultrasound particularly suited for diagnosing tuberosity fractures in emergency room settings and monitoring the clinical course after nonsurgical treatment (Green and Izzi Jr 2003; Patten et al. 1992).

Magnetic resonance imaging (MRI) is generally not indicated for tuberosity fracture evaluation. However, if plain radiographs fail to reveal a fracture, and the clinical course is not progressing satisfactorily, MRI can help identify the presence of an occult non-displaced greater tuberosity fracture, rotator cuff tear, or occult intra-articular injury (Gruson et al. 2008; Mason et al. 1999; Zanetti et al. 1999).

13.2 Indication for Surgical Intervention

There is no “gold standard” in terms of the surgical management of tuberosity fractures. Important factors to consider include which tuberosity has fractured, the extent of displacement, the direction of displacement, and amount of comminution. Additionally, important patient characteristic factors that should be considered include age, comorbidi-

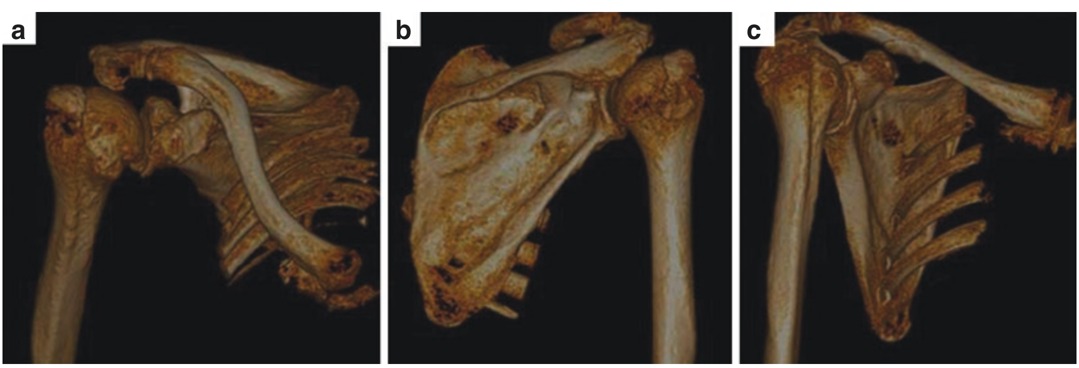

Fig. 13.2 CT-3D reconstruction (right shoulder). (**a**) Antero-posterior view. (**b**) Posterior view. (**c**) Anterior oblique view

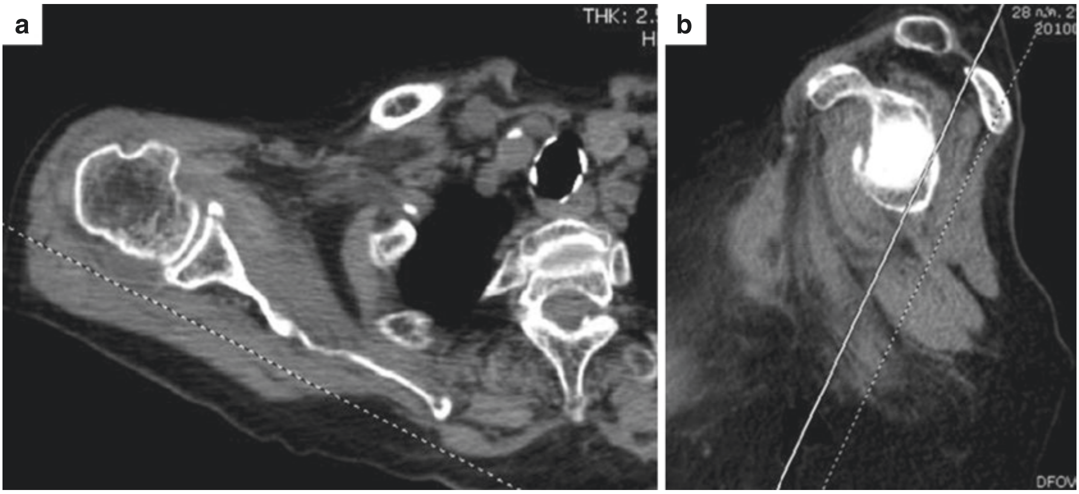

Fig. 13.3 CT- 2D (right shoulder) (**a**). Axial view (**b**). Sagittal view showing bone fragment at antero-inferior glenoid

ties, bone quality, dominant or non-dominant hand, and patient activity level (Baudi et al. 2015).

Neer (1970) initially recommended operative treatment when displacement was greater than 1 cm. Later, Bigliani and Flatow (1998) and Park et al. (1997) changed the indication to 5 mm. For younger, more active patients, athletes, or heavy manual workers, Resch et al. (1992) recommended 3 mm dislocation. More recently, Baudi et al. (2015) recommended that fracture displacement direction should be a surgical decision-making factor since superior or posterosuperior displacement is less tolerable for patients and more likely to cause subacromial impingement. These researchers recommended surgical treatment for superior or posterosuperior displacements greater than 3 mm, especially in young or active patients, athletes, or heavy laborers. Posterior displacement up to 5 mm is better tolerated, especially in the absence of an associated anterosuperior rotator cuff tear (Baudi et al. 2015). Gruson et al. (2008) suggested that this displacement could be increased to 1 cm in elderly patients with comorbidities who possess limited functional activity expectations (Gruson et al. 2008).

For lesser tuberosity fractures, the accepted indications for surgery include fragment displacement of 5 mm or 45° of angulation, having a mechanical block to internal rotation, continued pain, and weakness of internal rotation (Gruson et al. 2008).

Arthroscopy-assisted reduction-internal fixation (ARIF) for tuberosity fracture management is considered in cases of slight tuberosity fracture fragment displacement (3–10 mm). Fragment size and the degree of comminution are important factors when determining the type of fixation. The presence of a single large fragment, i.e., more than 2 × 2 cm or 3 × 3 cm, may allow for fixation with one or two screws. In osteoporotic bone, our recommendation is to use a screw combined with a tension band to reduce rotator cuff traction forces and facilitate earlier mobilization. In the presence of a small fragment that is less than 2 × 2 cm or that is comminuted and osteoporotic, we prefer suture anchor fixation in suture bridge fashion (Li et al. 2017; Vester et al. 2015). This technique can buttress the fracture fragment and maintain fracture reduction and soft tissue preservation. Appropriate contact pressure restoration using the tension band principle helps to promote bone healing and facilitate early shoulder mobilization.

13.3 Surgical Technique: Arthroscopy-Assisted Humeral Tuberosity Fracture Fixation

13.3.1 Position: Portal Placement

The patient is placed in the beach-chair position (Fig. 13.4a). A standard posterior portal is used for diagnostic arthroscopy. An anterosuperior portal is placed just anterior to the acromioclavicular joint. The lateral border of the acromion is divided into three equal parts by two lines. An anterolateral portal is created 2.5 cm laterally on the anterior line, and a posterolateral visualization portal is created 1 cm lateral to the posterior line. In lesser tuberosity fracture cases, an anteroinferior portal to perform suture management and medial-row knot tying using a 7-mm threaded arthroscopy cannula is added (Fig. 13.4b).

13.3.2 Diagnostic Arthroscopy: Subacromial Decompression

Diagnostic arthroscopy is performed to identify and treat any intra-articular pathology, such as labrum tear, long head biceps tendon lesion or entrapment, intra-articular surface rotator cuff (subscapularis, supraspinatus, infraspinatus) tear, a fracture extending intra-articularly, and a glenoid fracture. The arthroscope is shifted to the subacromial region, and acromioplasty is performed if indicated. Bursectomy is performed to improve visualization.

13.3.3 Greater Tuberosity Fracture Exposure: Fragment Identification—Reduction and Fixation

A shaver through the posterior portal is used to facilitate better visualization by evacuating blood clots and hemarthrosis. The location where the supraspinatus tendon-greater tuberosity fragment attaches to the humerus is then determined. Following this, debridement is performed on the undersurface of the fragment and at the fracture site.

At this point, displacement magnitude and the potential to perform fragment reduction, fragment size, and the degree of comminution are evaluated. The algorithm, to determine the preferred reduction and fixation technique, is showed in Fig. 13.5. If the fragment displacement is slight and the fragment size is more than 3×3 cm, we perform fixation using a percutaneous screw under fluoroscopy guidance with arthroscopic assistance.

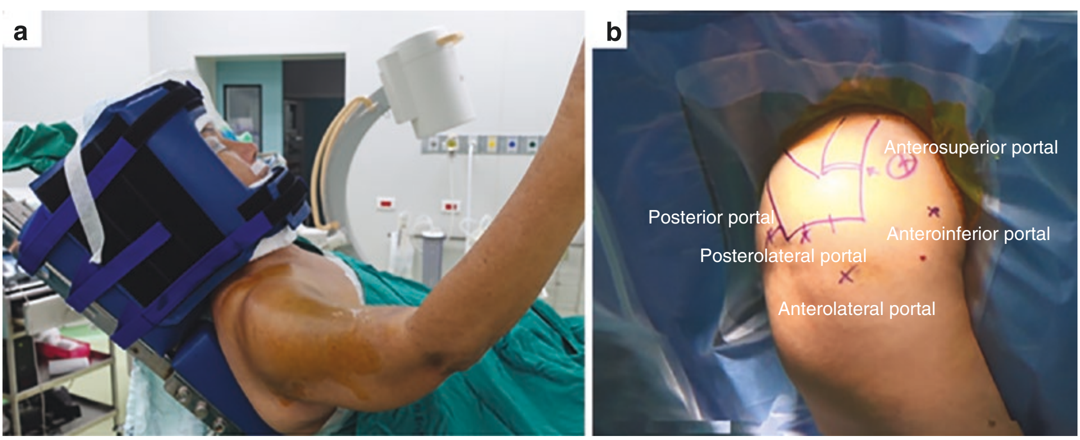

Fig. 13.4 (**a**) Beach-chair position. (**b**) Portal placement for arthroscopy assisted reduction–fixation

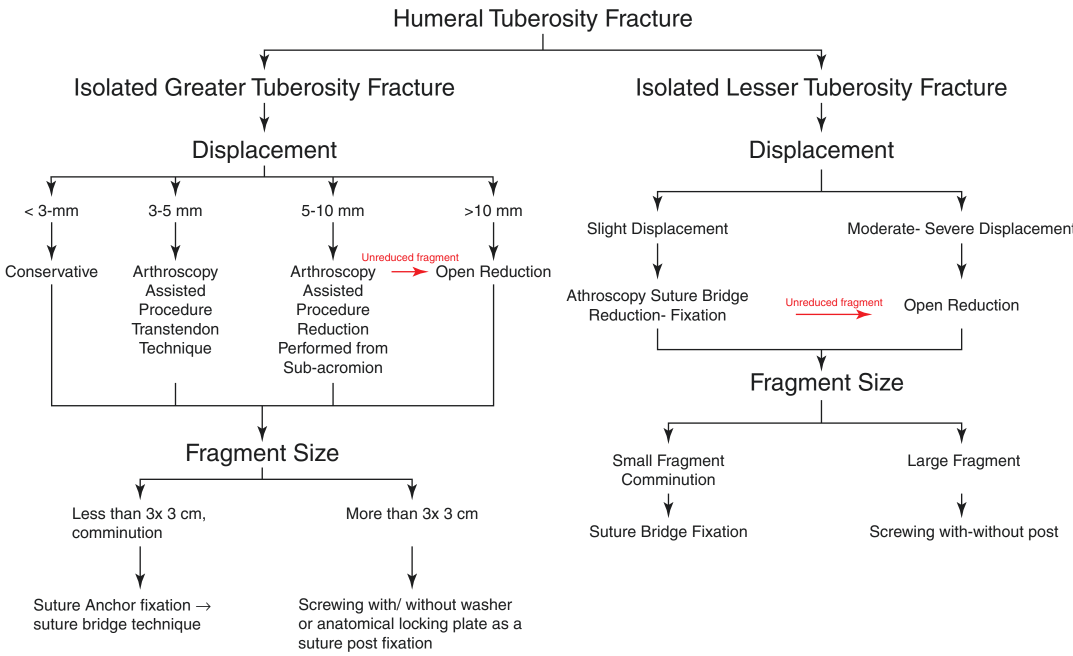

Fig. 13.5 Algorithm for isolated tuberosity humeral fracture management

If fragment displacement is 3–5 mm and the junction between the humeral head articular cartilage, if fragment size is less than 3 × 3 cm and/or comminuted, we prefer reduction and fixation using a suture bridge technique and a transtendon repair principle. Subsequently, a suture anchor is inserted at the articular margin of the humeral head through the intact rotator cuff, serving as a medial-row anchor. The exact suture placement location is managed under direct intra-articular visualization from the posterior portal, using a bird-beak instrument. A second suture anchor is then placed at the medial fracture site margin, and its suture strands are shuttled through the intact rotator cuff in a similar manner (Fig. 13.6a). Then, the arthroscope is moved into the subacromial space. The suture strands of medial-row anchors are then tied with a sliding knot under direct visualization. A posterolateral portal is created for visualization purposes, and a switching stick is used to shift the camera to the posterolateral viewing portal. The lateral fracture line is then re-identified. The anterolateral working portal is used for suture management and anchor placement. To avoid soft tissue interposition, a partially threaded 7-mm cannula is inserted into the anterolateral portal. A pilot hole is then created from the anterolateral portal, and the lateral-row anchor site is placed approximately 5–10 mm distal to the most lateral fracture line, just posterior to the bicipital groove. Then, both ends of the same suture are retrieved through the cannula. The anchor is inserted through the cannula while the strands are held firmly, ensuring smooth sliding of the anchor on the threads. The anchor is hammered into the pilot hole until the threads start entering the hole. Then, all strands are tightened one by one, and the anchor is fully secured. The position of the second lateral-row suture-less anchors should be 10 mm posterior to the first one, using the same protocol to create a suture bridge (Fig. 13.6b). Good reduction can be achieved using this technique with a stable construct and no tension at the repair site.

If fragment displacement is 5–10 mm, where the junction between the humeral head articular

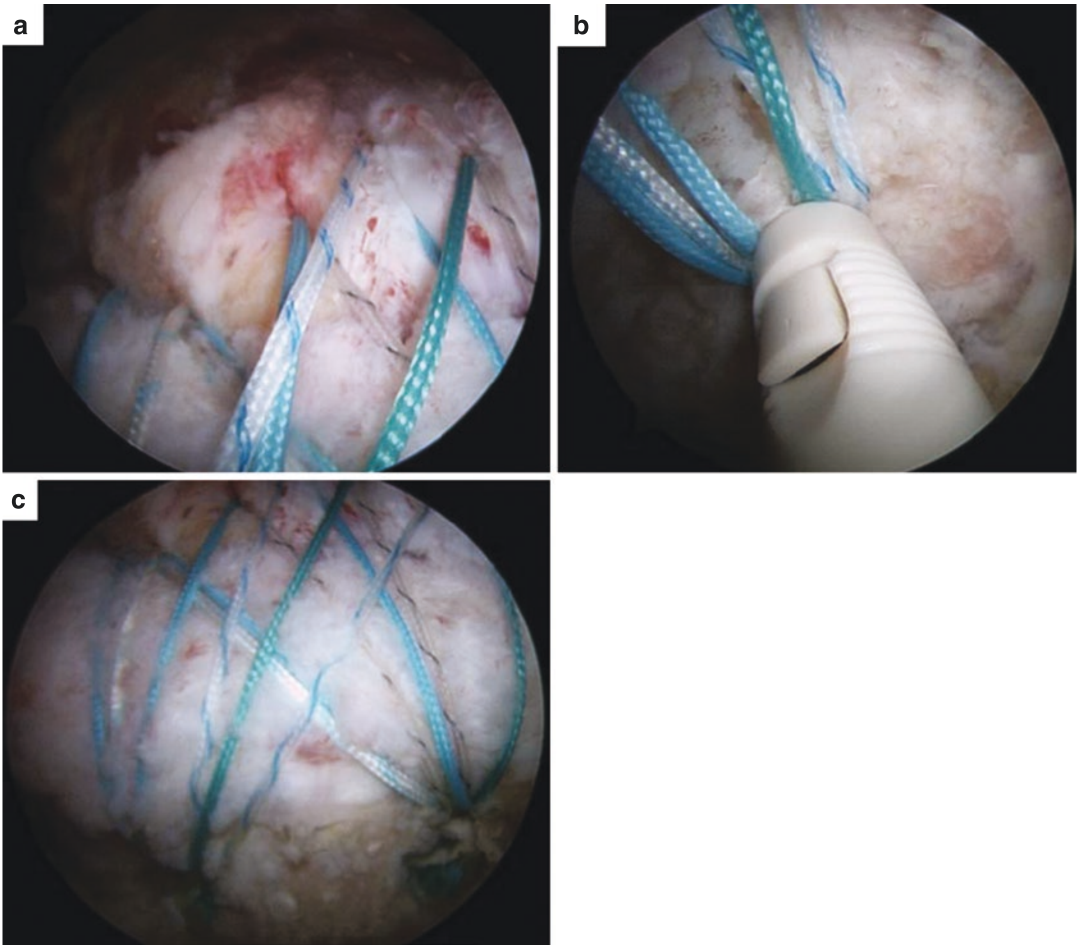

Fig. 13.6 (**a**) Medial suture strands insertion at bone-tendon junction. (**b**) Lateral row suture anchorage. (**c**) Suture bridge configuration for greater tuberosity humeral fixation

cartilage and the bone crater can be identified, and the fragment size is less than 3 × 3 cm and/or comminuted, reduction and fixation using a suture bridge technique in the same fashion as when performing a rotator cuff repair is performed. A posterolateral portal is created for visualization, and a switching stick is used to shift the camera to the posterolateral viewing portal. Posterior and anterosuperior portals are used for inserting the suture strands to the bone-tendon junction, using a cuff passer instrument, whereas the anterolateral working portal is used for suture management and anchor placement. A partially threaded 7-mm cannula is inserted into the anterolateral portal to avoid soft tissue interposition. We refresh and debride the bone crater (the raw surface where the fragment will be placed). Then, we put two medial double-loaded anchors at the articular cartilage-bone crater junction from the anterosuperior portal. A rotator cuff repair passer is used to insert the suture strands to the medial part of bone (greater tuberosity fragment) and supraspinatus tendon junction through the posterior or anterior-superior portal. Two different colored suture strands from each anchor are penetrated into the bone and tendon junction. In total, four penetrations are created with two threads in each hole. The distance between the two holes should cover the width of the tuberosity fragment. The suture bridge is created in the manner previously mentioned (Fig. 13.6c).

If the fracture or tuberosity fragment cannot be reduced to acceptable alignment, conversion to an open procedure is necessary, using a deltopectoral or deltoid splitting approach. With this approach, fixation can be performed using a locking plate as a suture post or suture anchor, similar to the suture bridge technique (Fig. 13.7a–d).

13.3.4 Lesser Tuberosity Fracture Exposure: Fragment Identification—Reduction and Fixation

An arthroscopy-assisted procedure for reduction and fixation of lesser tuberosity requires working in the subcoracoid space. Good visualization is mandatory for each step of this procedure. After diagnostic arthroscopy to identify any other intra-articular pathology and to confirm lesser tuberosity fracture, we evaluate the condition of the long head of the biceps tendon, which often is

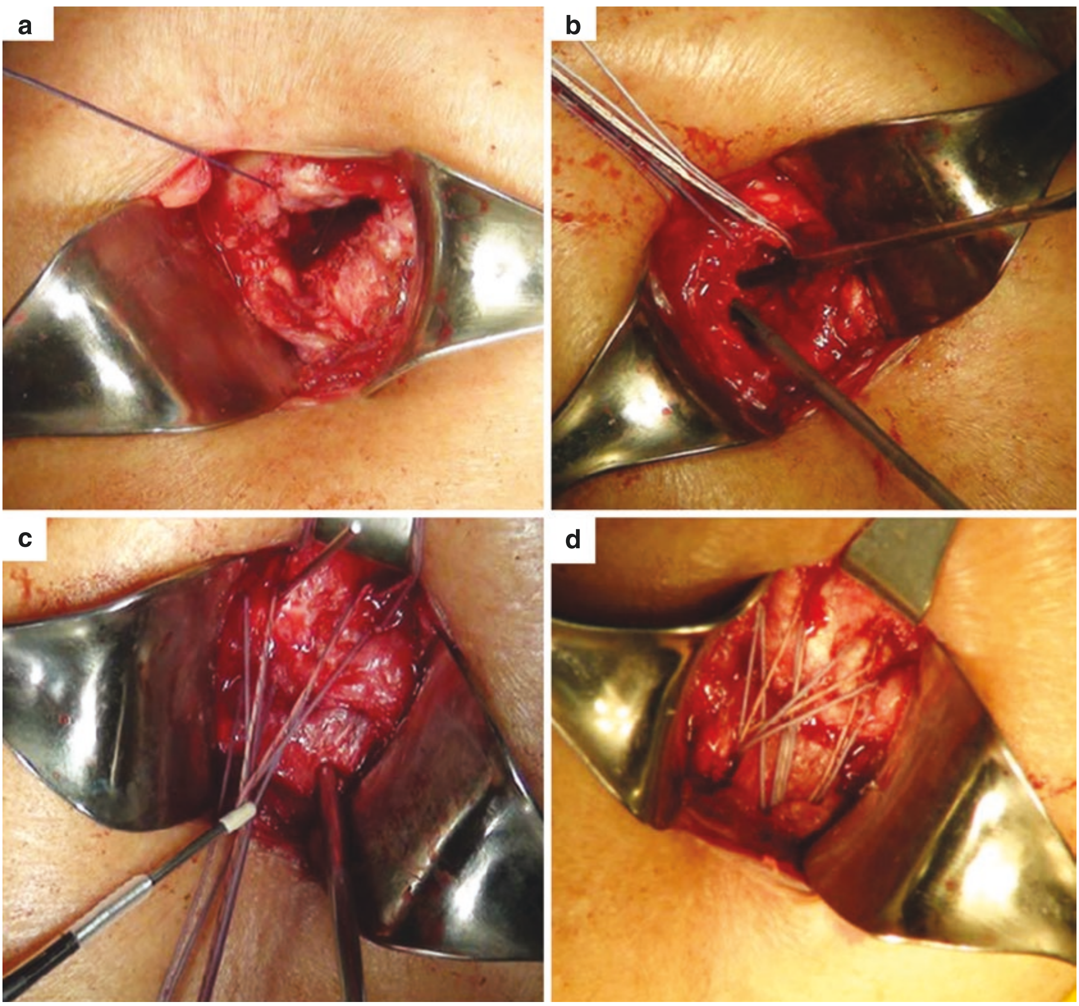

Fig. 13.7 Mini-open procedure of isolated greater tuberosity fixation. (**a**) Greater tuberosity avulsion fracture. (**b**) Medial row suture anchorage. (**c**) Lateral row suture anchorage. (d) Mini- open reduction-suture bridge fixation for greater tuberosity humeral fixation

entrapped between the fracture fragment(s), thereby obstructing reduction. In this situation, we perform biceps tenotomy or tenodesis to facilitate lesser tuberosity reduction and fixation. Through the anterosuperior portal, we perform a tenotomy of the long head of the biceps tendon.

Accessing the subcoracoid space is important to perform arthroscopy-assisted lesser tuberosity fixation. A shaver or electrocautery device is used to make an opening in the rotator interval just superior to the subscapularis tendon. The coracoid is usually hidden beneath a bursa that extends from the lateral border of the subscapularis to the anterior internal deltoid fascia.

A double-loaded suture anchor is first inserted into the fracture site through the anterosuperior portal (Figs. 13.8a and 13.9a). By means of a rotator cuff stitch, the subscapularis tendon is perforated immediately adjacent to the bone-tendon interface at the most inferior aspect from the anteroinferior portal. This suture strands can also be used to reduce the fracture fragment (Fig. 13.8b). Then, the two suture strands (different color) are retrieved through the anterosuperior portal, connected to loop end limb as a shuttle suture relay (Fig. 13.9b). The last two suture strands are also retrieved through the bone-tendon junction superior to the previous penetra-

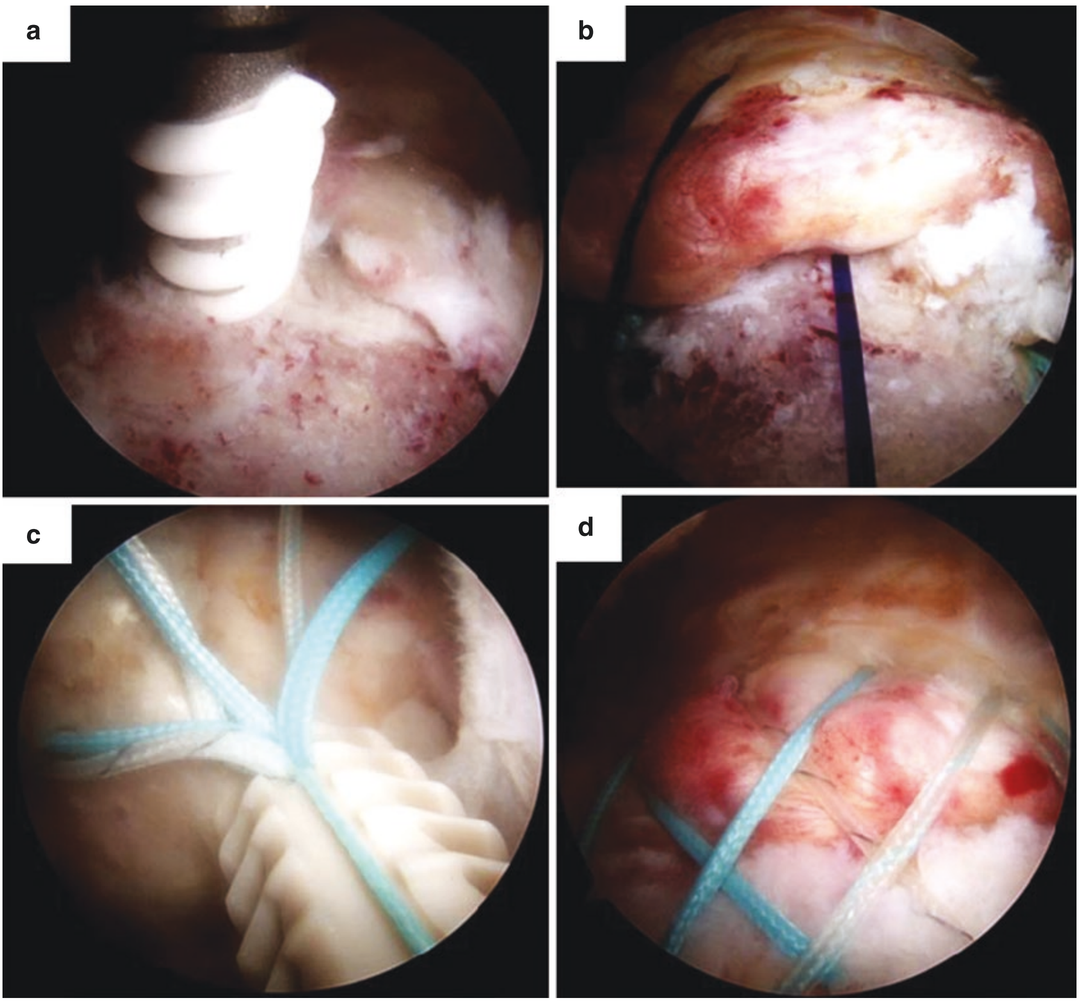

Fig. 13.8 Arthroscopic view of arthroscopy-assisted lesser tuberosity reduction and fixation. (**a**) Medial row suture anchorage. (**b**) Suture traction to assist reduction at bone-tendon junction. (**c**) Lateral row suture anchorage. (**d**) Suture bridge fixation of lesser tuberosity fracture

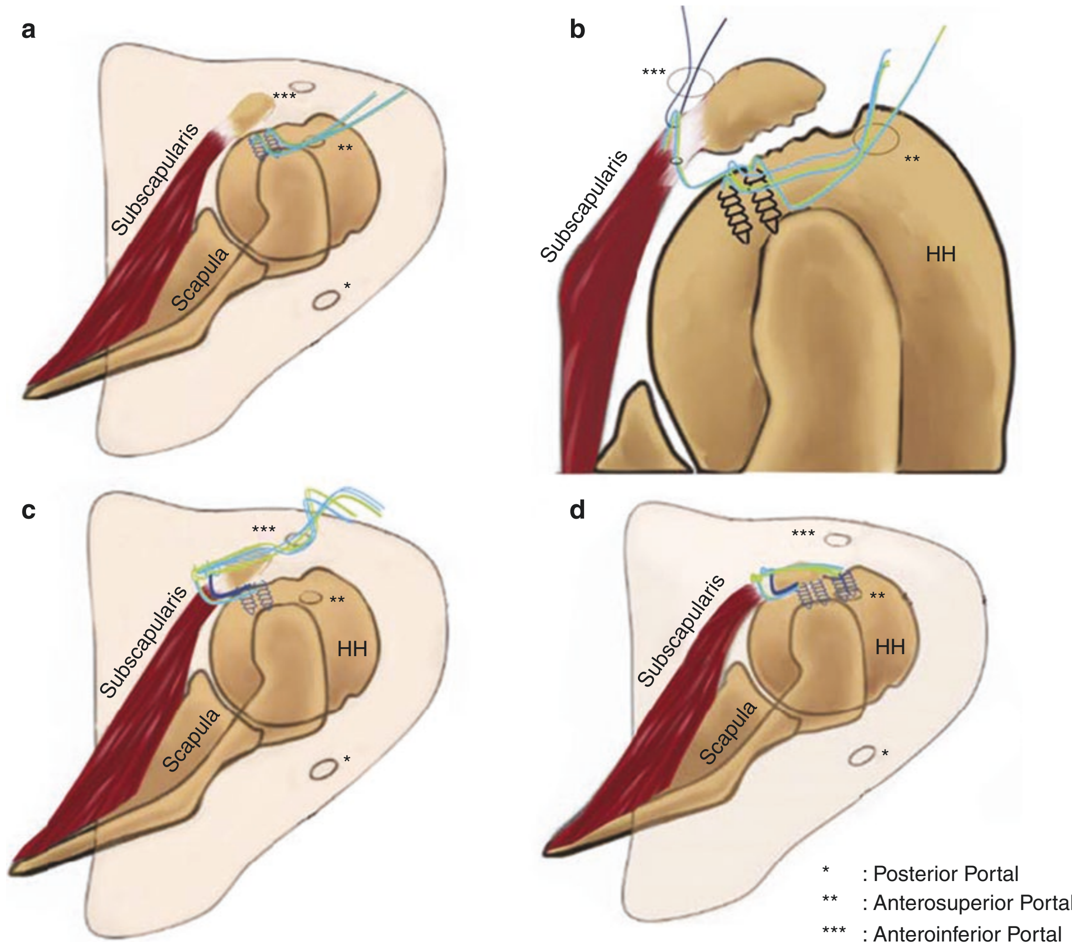

Fig. 13.9 Arthroscopy-assisted lesser tuberosity reduction and fixation. (**a**) Medial row suture anchorage. (**b**) Suture shuttle relay at bone-tendon junction. (**c**) Anteroinferior portal for suture management. (**d**) Lateral row suture anchorage as suture bridge fixation of lesser tuberosity fracture

tion (Fig. 13.9c). To increase the fracture coverage area and the initial fixation strength of the reduced fragment, a second double-loaded suture anchor is inserted into the raw fracture bed area. Using the same technique as described earlier, further bone-tendon junction penetrations are then performed. Then, knot tying is done at the medial row of pair suture strands between the first and second hole and between the third and fourth hole.

A pilot hole is then created from the anteroinferior portal, to position the lateral-row anchor site close to the bicipital groove. Then, both ends of the same suture are retrieved through the cannula, using four ends of two suture strands. The remaining suture strands are retrieved in the anterosuperior portal to avoid suture entangling. The anchor is inserted through the cannula while the threads are held firmly, ensuring smooth sliding of the anchor on the threads. The anchor is hammered into the pilot hole until the suture strands start entering the hole (Fig. 13.8c). Then, all suture strands are tightened one by one. The remaining threads are retrieved through the anteroinferior cannula, and a suture-less anchor is used to secure the threads in position. The position of second lateral-row anchors should be 10 mm inferior to the first one, using the same protocol to create a suture bridge (Figs. 13.8d and 13.9d). Good reduction can be achieved using this technique with a stable construct and no tension at the repair site. If the fracture or tuberosity fragment cannot be reduced to acceptable alignment, conversion to an open procedure using a deltopectoral approach should be performed. With this approach, fixation can be performed using a locking plate as a suture post or suture anchor similar to the suture bridge technique (Fig. 13.10).

13.4 Postoperative Rehabilitation

Following arthroscopy-assisted greater tuberosity fracture fixation, the affected upper extremity is placed in a sling for the initial 3 post-surgical weeks. Pendulum exercises are initiated immediately, followed by passive motion exercises with forward shoulder flexion, internal rotation, and external rotation at waist level (shoulder adducted) for 6 weeks under the supervision of a

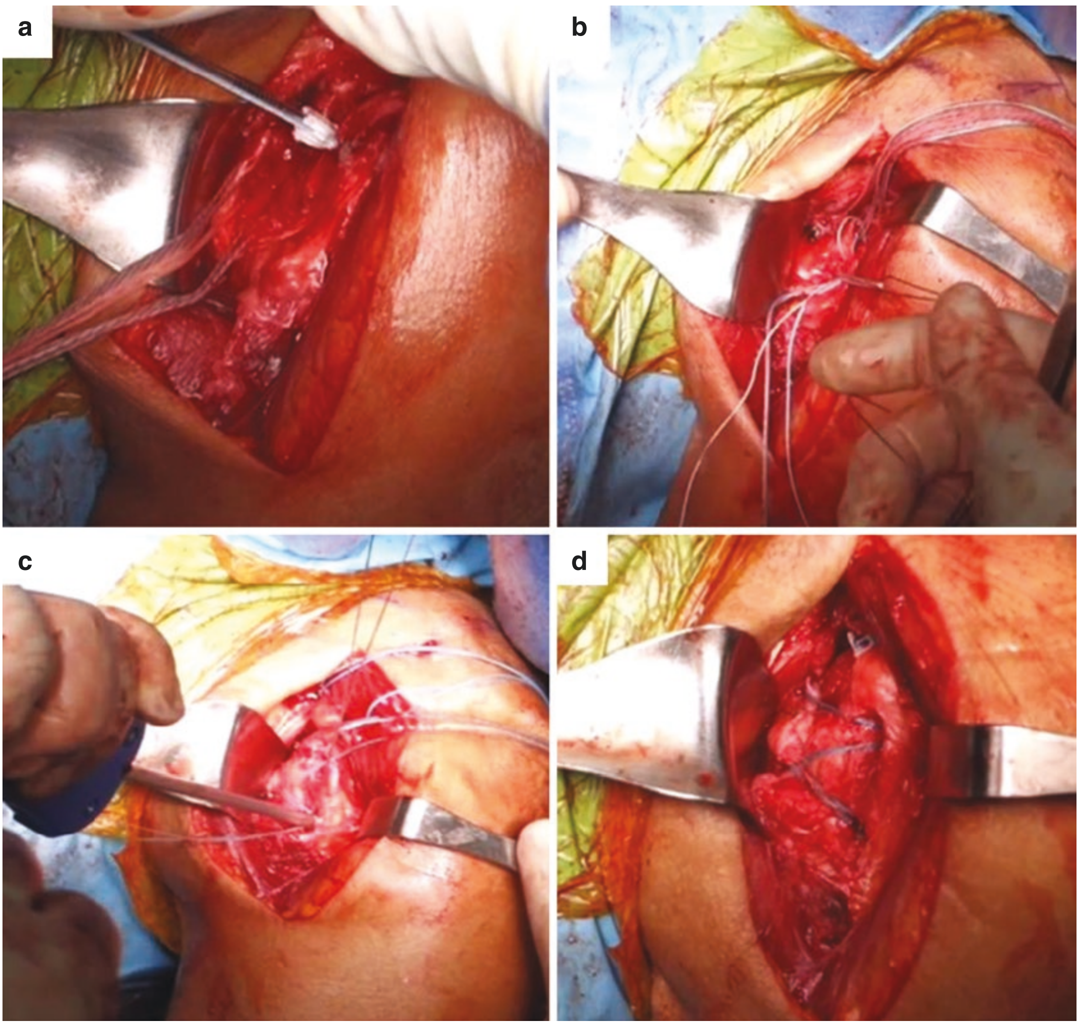

Fig. 13.10 Open procedure of isolated lesser tuberosity fixation. (**a**) Medial row suture anchorage. (**b**) Threads penetration to bone-tendon junction. (**c**) Lateral row suture anchorage. (**d**) Open reduction-suture bridge fixation for greater tuberosity humeral fixation

physiotherapist. Early shoulder abduction-external rotation or abduction of the shoulder to more than 90° is avoided during this 6-week period. At 6–8 weeks post-surgery, active and active-assisted range-of-motion and mild shoulder strengthening exercises are initiated. Isometric rotator cuff strengthening exercises are started at 3 months and are continued until 6 months post-surgery with a progressive exercise program.

In terms of arthroscopic reconstruction of isolated lesser tuberosity fractures, more conservative rehabilitation protocols are necessary to protect the repair during the initial 6-week period. The affected upper extremity is placed in a sling for the initial 3 weeks post-surgery. Early supervised passive motion exercises are initiated; however, motion is restricted to 90° of shoulder flexion, 60° of abduction, and internal rotation over the first 4 weeks post-surgery. External rotation is limited to 0°, and patients are instructed to avoid active internal rotation during the initial 6 weeks post-surgery. Patients are recommended active-assisted and active shoulder range-of-motion exercises at 6 weeks post-surgery and begin isometric exercises at 3 months post-surgery (Scheibel et al. 2005).

13.5 Discussion

Over the last two decades, several advancements in the management of displaced greater and lesser humeral tuberosity fractures have occurred. Because the rotator cuff tendons attach to the humeral tuberosities, fracture displacement can cause impingement (subacromial impingement related to greater tuberosity malposition or subcoracoid impingement related to lesser tuberosity malposition) and range of motion limitations (abduction-external rotation limitations for greater tuberosity malposition and internal rotation limitation for lesser tuberosity malposition).

There is a growing role for arthroscopic approaches to assist tuberosity fracture reduction and fixation. The arthroscopic techniques are suitable in cases of limited fracture displacement and smaller fragments. There are several advantages to perform arthroscopy-assisted techniques, such as direct visualization, minimum invasiveness compared with large arthrotomy with a relatively narrow visual field of the joint space, superior intra-articular fracture reduction and fixation accuracy, and potentially improved clinical outcomes (Atesok et al. 2011). In a retrospective controlled study, Liao et al. (2016) reported on a large series of patients who were treated surgically for displaced greater tuberosity fractures. In that study, they compared a double-row suture bridge technique with suture anchors implanted arthroscopically with open reduction and internal fixation utilizing a proximal humeral locking plate via the deltopectoral approach. They found that both techniques were effective for fracture healing and both groups had few complications. However, the arthroscopy-assisted technique group had superior results in terms of shoulder flexion and abduction postoperatively and required less time in the operating theater (Liao et al. 2016).

Some limitations may also exist using the arthroscopy-assisted tuberosity fracture fixation. This procedure requires considerable technical skills and there is a long learning curve. Arthroscopic procedures cannot be mastered via current operating room education alone; there is a growing need for alternative educational methods such as cadaveric surgery laboratories, anatomical models, and computer simulation modules to improve trainee technical performance in the operating theater (Atesok et al. 2011).

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