Malunion of the proximal humerus

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Summary Malunion of a proximal humerus fracture is difficult to manage once bone union has been achieved in a wrong position. Malunion may be encountered after conservative treatment or internal fixation of fractures, and also around a joint prosthesis. The malunion can involve the greater and lesser tuberosities, humeral head, bicipital groove, or the entire epiphysis. The nature of the malunion must be precisely characterized. Malunion can affect bone structures and the articular surface; any resulting displacements must be carefully measured. Clinical assessments will help to evaluate the functional repercussions and determine the need for correction. Radiographic imaging and CT scan guide the treatment plan. Arthroscopic surgery (acromioplasty or tubero-osteoplasty) can be used to treat biceps tenosynovitis or impingement syndrome in cases where full correction of the malunion is not required. Corrective surgery of a metaphyseal malunion is used to realign the proximal humeral into the proper position. Tuberosity osteotomy is the main predictor for a poor outcome following secondary arthroplasty.

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The management of proximal humerus fractures has evolved quickly over the past few years. The predominance of impacted, non-displaced surgical neck fractures and conservative treatment no longer systematically corresponds to most of the complex, displaced fractures in osteoporotic bone. The ageing population has greatly contributed to an increase in the malunion rate, which is estimated at 4 to 20% [1]. No proximal humerus fracture treatment method (conservative treatment, internal fixation, etc.) is immune to the risk of malunion; even primary shoulder arthroplasty performed in fracture cases has the risk of periprosthetic malunion [2]. By definition, malunion of the proximal humerus corresponds to the healing of a fractured bone in a non-anatomical position. This results in a painful and disabling deformity that may lead to the patient requesting a correction and functional restoration. The displacement and retraction of the tuberosities compromise the function of the rotator cuff muscles and tendons. Any displacement in the humeral shaft changes the mechanical structure of the humerus. The misalignment and/or remodelling of the humeral head results in joint incongruity, which does not provide optimal mechanical conditions; this can lead to stiffness due to the retraction of capsule and ligament structures. Thus the joint is at risk, as is the bone [1].

The prognosis for surgical treatment of the sequelae of proximal humerus fractures has improved because of the classification proposed by Beredjiklian et al. [3] and Boileau et al. [4—6]. Tuberosity osteotomy has long been recognized as the main predictor for poor outcomes in cases of secondary arthroplasty [4—9].

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Figure 1  Malunion below the tuberosities: a: anatomical structures of the proximal humerus, applied loads and potential resulting displacement: superior and posterior traction for the greater tuberosity (GT), medial traction for the lesser tuberosity (LT), anteroposterior and mediolateral tilt for the humeral head (HH) and medial translation for the shaft (S); b: radiograph of dry bone: grey arrows show the impact of the glenoid on the head. SN: surgical neck; AN: anatomical neck.

In determining the best treatment, various parameters of the malunion must be described: location and structures involved, pathology and amount of misalignment, functional consequences.

All aspects of the initial management of proximal humerus fractures (presentation, diagnosis, treatment, surgical technique) have a prognosis that is quite often disappointing. Secondary treatment of a malunion is an even greater challenge.

Definitions and mechanisms

Anatomy

The proximal humerus consists of four bone structures joined by two necks; three of these structures are directly subjected to tensile loads that could displace them if fractured (Fig. 1):

- two tuberosities, site of the distal insertion for the rotator cuff: greater tuberosity (supraspinatus, infraspinatus, teres minor) and lesser tuberosity (subscapularis). They are separated by the intertubercular groove, which is in turn covered by the transverse humeral ligament. The long head of the biceps muscle, which is surrounded by two layers of synovial membrane slides in this groove;
- one articulating structure, the humeral head, which is covered in cartilage and separated from the tuberosities by the anatomical neck;
- the upper part of the humeral shaft, separated from the tuberosities by the surgical neck, is the terminal bone insertion for three powerful adductor and internal rotation muscles (pectoralis major, teres major, latissimus dorsi).

The position of these bony structures relative to each other are important, as they regulate the tension and length of these muscle groups, the contraction force and the amplitude of the mobility of the glenohumeral (shoulder) joint. The humeral head must be properly oriented and centered relative to the glenoid cavity for the joint function to be optimal. The angular deviation in the coronal plane (degree of varus or valgus) is evaluated using the head-to-shaft angle and using the medial and posterior positioning of the head in the axial plane.

Mechanisms of malunion

Three situations may be at the origin of the malunion:

- problem with the initial reduction;
- and/or problem with the fixation leading to secondary displacement;
- and/or problem with the protection/stability leading to secondary displacement.

These three malunion mechanisms can occur in the context of conservative treatment, during or after internal fixation or around an arthroplasty implant. Osteoporosis and overly-aggressive rehabilitation may also be implicated [10].

In two-part, sub-tuberosity, surgical neck fractures, the epiphysis is tilted into varus or valgus, in ventral or dorsal inclination, and the shaft is pulled inwards, forwards and into medial rotation by the pectoralis major, teres major and latissimus dorsi muscles.

In three-part, sub-tuberosity, surgical neck fractures where the fracture line extends to the greater tuberosity, the epiphysial fragment is rotated backwards by the subscapularis muscle and the shaft is pulled inwards and forwards. In three-part fractures involving the lesser tuberosity, external rotation of the proximal humeral epiphysis sends the head forwards. In both cases, the proximal humerus does not have the correct rotation.

In four-part, intra-articular, head and tuberosity fractures, both tuberosities are avulsed and the corresponding portions of the rotator cuff may retract. The structural relationships in the glenohumeral joint are disrupted and the joint is no longer congruent: if the head has a valgus deformity in the frontal plane, the glenohumeral angle will be greater; if the head tilts into valgus, the joint space will be narrowed. Any rotation of the humeral head in the axial plane will also alter the glenohumeral joint congruity.

The described mechanisms and applied loads can result in bone, joint or combined bone + joint malunion and will have biomechanical consequences for the rotator cuff, joint capsule and ligament structures [11,12].

Description, classification and evaluation

Description and classification systems

Boileau et al. [4] proposed a classification system for the sequelae of proximal humerus fractures. In type 4 (severe
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Figure 2  Severe malunion. A shoulder arthroplasty can only be implanted once a tuberosity osteotomy has been performed. Based on P. Boileau et al. [4], Fig. 1, p. 353, with permission of Springer Science and Business Media BV.

Malunion of the tuberosities with joint incongruity, Fig. 2, the anatomy of the tuberosities is altered, which requires that a tuberosity osteotomy be performed to allow for a potential joint arthroplasty. These injuries can occur in combination with type 1 (head osteonecrosis) or type 2 (chronic dislocation) sequelae.

Beredjiklian et al. [3] has proposed three types:

- type I: malalignment of the greater or lesser tuberosity, displacement greater than 1 cm;
- type II: incongruity of the articular surface;
- type III: malunion of the tuberosities and humeral head relative to the shaft

The angular deformity of the articular segment is greater or equal to 45° in all three planes.

Malunion at the tuberosities (Fig. 3a–d) can lead to alterations in the intertubercular groove. Malunion of the intertubercular groove can lead to exceptionally painful, chronic biceps tendinopathies. This relationship between biceps pathology and intertubercular groove malunion must not be ignored [13]. Intra-articular malunion (Fig. 3e) results in altered structural relationships in the glenohumeral joint.

Based on these classification systems, the various cases of malunion can be grouped in the following manner:

- bone malunion: tuberosity, inter-tuberosity, sub-tuberosity, including periprosthetic malunion;
- joint malunion: with or without associated humeral head necrosis;
- combined bone and joint malunion: with or without associated osteonecrosis.

Parameters of the evaluation

The following elements can be used to define a malunion:

- the position of the four bone structures relative to each other; however some ambiguity still exists when it comes to measuring of tuberosity displacement. A 10-mm displacement is typically recognized as the threshold for acceptable displacement before the deformity is labelled a malunion. This distance is measured relative to the normal anatomical location of the involved tuberosity. The height of the overlap of the greater tuberosity above the humeral head can also be used as a measurement criterion, but must not be confused with the true displacement;
- the degree of misalignment in the coronal, sagittal and axial planes (problems related to humeral rotation); the humerus can no longer act as a crank shaft [3].

Effects on the soft tissues (tendons, ligaments, capsule)

The effects on the soft tissues are as follows:

- the upward misalignment of the greater tuberosity can lead to reduced abduction amplitude as it abuts under the acromion, or in the least can lead to and fuel subacromial impingement. If the tuberosity is displaced posteriorly, any abutment against the edge of the glenoid can limit external rotation. In both cases, there will be a loss of tension in the rotator cuff;
- medial displacement of the lesser tuberosity can limit internal rotation because of abutment against the glenoid border, but also induces loss of subscapularis tension and muscle strength. Obstruction of the coracohumeral interval can also lead to subcoracoid impingement;
- effects on the capsule: any rotational misalignment of the proximal humerus (axial deviation) induces excessive tension on the opposite side of the capsule and retraction of the unloaded side of the capsule. These two conditions can result in joint stiffness.

Malunion types as a function of the initial fracture treatment

Malunion after conservative treatment

Labelling a fracture as ‘non-displaced’ could lead to insufficient evaluation of the tilt of the head fragment, the position of one or both tuberosities, the angle of the anatomical neck and the angle of the surgical neck (Fig. 4a). A lateral view is essential here (Fig. 4b). The position of the intertubercular groove will reveal any tilt of the head fragment in the sagittal plane.

Tuberosity fractures

As recommended by Neer, displacement in the frontal plane is evaluated by the upward migration of the greater tuberosity. If the gap between the upper end of the greater tuberosity and the humeral head is greater than 1 cm, surgical treatment is warranted. But the measured displacement...
Figure 3  Malunion anatomy: a: malunion of the greater tuberosity above the humeral head: subacromial impingement, loss supraspinatus tension; b: posterior malunion of greater tuberosity posteriorly, posterior impingement, loss of infraspinatus and teres minor tension; c: malunion of lesser tuberosity, anterior view; d: malunion of lesser tuberosity, lateral view; e: malunion of head and tuberosities.

can be misleading if only the location of the greater tuberosity is taken into consideration, since the posterior displacement of the avulsed greater tuberosity will not be factored in.

Sub-tuberosity fractures, two-part or three-part
The angle between the glenoid and humeral head in the frontal plane shows the displacement of the humeral head. The most common errors during diagnosis occur with

Figure 4  Isolated tuberosity malunion and combined head and tuberosity malunion: a: malunion after conservative treatment. Anteroposterior view: increase in the glenohumeral angle (valgus tilt of the head fragment), greater tuberosity avulsion, misalignment of the intertubercular groove; b: malunion after conservative treatment: posterior misalignment of the greater tuberosity and intertubercular groove which are in a row, evidence of humeral head tilt.
sub-tuberosity fractures that extend through the tuberosity and type III head and tuberosity fractures. Impaction adds to the stability, but also indicates significant displacement (Fig. 5).

**Intra-articular, head and tuberosity fractures**

By definition, the anatomical neck is fractured, separating the humeral head from the tuberosities, which themselves are avulsed and separated from the humeral shaft by the surgical neck fracture line (Fig. 3e).

**Malunion after internal fixation**

The great number of fixation techniques available for proximal humerus fractures reflects on the difficulty of this treatment. After a literature review, it is clear that no technique is safe from the possibility of malunion. No matter which type of hardware is used, the key element is the quality of the anatomical reconstruction.

The goals of the initial treatment by internal fixation are the following:

- reconstruction of the medial part of the surgical neck;
- filling of the metaphyseal void;
- anatomical restoration and maintenance of bone contact between the humeral head, tuberosities and humeral shaft.

Four cases of malunion were reported among 24 fractures (17%) that were treated with percutaneous pinning, with no notable decrease in the functional outcome scores [14]. Three of these were surgical neck malunion in varus, two of which were caused by poor reduction. Although anatomical reduction is a fundamental goal, data surrounding the “most tolerable imperfection” is vague. Resch and Bayley [15] proposed placing the results of internal fixation into three groups:

- group 1: proximal humerus anatomy completely restored;
- group 2: greater tuberosity has more than 3 mm residual displacement;
- group 3: lesser tuberosity has more than 3 mm residual displacement.

These numerical boundaries seem to be a threshold between good, long-lasting results and poor results that could get worse over time. The bone malunion most often occurs during the initial treatment (Fig. 6).

Any flaw in the reduction of the humeral head articular surface (intra-articular malunion) will have a poor prognosis and an increased risk of osteoarthritis and necrosis. Inadequate reduction of a fracture-dislocation leads to a catastrophic situation, which combines Boileau et al. [4] type 2 and type 4 injuries (malunion and chronic dislocation), and could also include necrosis (type 1). This represents a paroxysm that we hope never to have presented to us for secondary treatment (Fig. 7).

**Periprosthetic malunion**

A poor functional result after shoulder arthroplasty for fracture may be due to an associated tuberosity malunion or to poor implant positioning.

But most often, periprosthetic malunion is due to poor positioning of the greater tuberosity, which ends up behind or above the implant. Boileau et al. noted that in 50% of cases, malunion around a humeral hemi-arthroplasty was correlated with poor results and upward migration of the greater tuberosity [16]. Poor functional results of hemiarthroplasty with four-part fractures have been correlated to non-anatomical reduction of the tuberosities [11]. When the greater tuberosity is displaced upwards and covers the implant head, it can limit abduction because of direct abutment against the superior edge of the glenoid; this upward displacement can also lead to a loss of tension in the supraspinatus muscle and decreased strength during abduction. Posterior malunion of the greater tuberosity will cause early abutment during external rotation. The range of motion will also be limited because of the tension lost in the external rotator, infraspinatus and teres minor muscles.

The malunion can also involve the lesser tuberosity. If it is too far laterally, there will be excessive tension on the subscapularis muscle and limited external rotation. If the intertubercular groove is not reconstructed or is forgotten, the result is side-by-side reconstruction of the tuberosities, which will inevitably result in excessive tension (Fig. 8).

Reconstructing the tuberosity around the implant is a true technical challenge [17]. Periprosthetic malunion of the tuberosities can be induced by the design or the poor positioning of the humeral component. Most of the fracture-type stems now have a less bulky metaphyseal segment and the lateral fin has been removed. Poor horizontal positioning of the tuberosities has been shown to lead to functional limitations that are beyond repair [11] (Fig. 9). Using either a “standard” or “fracture” humeral stem component made no significant difference in the quality of the tuberosity healing [18]. An excessively high implant (“perched” stem) places the rotator cuff and the repaired bone under tension. The wrong height puts the top of humeral implant below that of the greater tuberosity, which is never an acceptable...
Figure 6  Malunion of the tuberosities and head + tuberosities after conservative treatment: a: Malunion of the greater tuberosity after fixation with plate and screws, appearance of upward migration; b: greater tuberosity displacement is mainly posterior, which leads to compromised external rotation.

Figure 7  Malunion after internal fixation: a: malunion of bone and joint surfaces and chronic posterior dislocation after fixation with intramedullary locked nail (A/P radiographs); b: malunion of bone and joint surface and chronic posterior dislocation after fixation with intramedullary locked nail (CT scan image).

Figure 8  Malunion with migration of the greater tuberosity above the implant.

This condition leads to an overlapping tuberosity malunion. Problems with orientation of the implant head can also contribute to faulty positioning and non-anatomical healing of the tuberosities.

Tuberosity reconstruction around the humeral component during reverse shoulder arthroplasty for the initial treatment of fractures is a recent development. When the tuberosities can be repositioned and the tendons and muscles are functional, even a small improvement in external rotation is beneficial. However, a wrong initial position or poor fixation of the tuberosities could result in malunion that would be an even bigger problem in rotation than not having the rotator cuff muscles (Fig. 10). Loew claimed that immobilisation has no protective effect [18]. The protection
There is a risk of joint stiffness, which is a complication of the anatomical deformity. Even if the physiotherapist can improve part of the range of motion, it would be unrealistic to expect that rehabilitation can make up for the functional dead-end facing a shoulder with a post-traumatic malunion. The risk of rotator cuff tendon rupture is increased. A chronic dislocation (Boileau et al. type 2 [4]) makes it harder to treat the malunion after fracture-dislocation.

Management of malunion

Clinical and functional evaluation

The main symptoms of malunion are pain and limited joint range of motion. The pain must be characterized as precisely as possible. Any isolated signs of subacromial impingement or long head of biceps involvement can direct the therapeutic decision.

Evaluation of passive range of motion is a basic step in the clinical examination and indicates the amount of shoulder stiffness. Reduction of external rotation while in maximum abduction is highly indicative of greater tuberosity malunion. The range of motion of the scapulothoracic joint must also be determined separately.

Decreased strength may be evident in all movements—abduction, forward flexion and rotation. Reduced strength in internal or external rotation corresponds to a loss of tension. If pain allows, resisted movements can be used to test the supraspinatus in abduction (Jobe), the infraspinatus and teres minor in external rotation (Patte’s test, hornblower sign) and the subscapularis in internal rotation (Gerber lift-off test). The Palm-up, Yergason and O’Brien’s test, evaluates the long head of the biceps.

The effective voluntary activation of the three heads of the deltoid muscle (anterior, lateral, posterior) must also be verified. Measuring the arm length (distance between the top of the greater tuberosity or acromion and the top of the olecranon) is easy to perform and helps to estimate the tension on the deltoid muscle. Anterior instability will be felt by a patient presenting with greater tuberosity malunion because of the posterior abutment. Clinical assessment of the axillary and suprascapular nerves is essential.

Paraclinical assessments

The paraclinical assessments are as follows:

- X-rays: AP and lateral views are essential for measuring the axes and angles and for determining the characteristics of the malunion;
- CT scan: used to evaluate the orientation of the proximal humeral extremity and the volume and quality of the rotator cuff muscles;
- clinical observation of a nerve deficit requires that a reference electromyographic exam be performed before any treatment;
- joint fluid aspiration is recommended to look for infection before any secondary arthroplasty after internal fixation;

Figure 9 Periprosthetic malunion of both tuberosities which form a sheath around the implant head.

Progression of shoulders having a malunion

The risk of glenohumeral osteoarthritis secondary to malunion has not been defined. Intra-articular malunion logically would increase the risk of secondary osteoarthritis, as would tuberosity malunion, given the dysfunction caused by direct abutment or rotator cuff insufficiency. Both the humeral head and tuberosities are at risk for osteonecrosis. The presence of intra-articular and/or tuberosity malunion can result in areas of greater stress concentration and predispose the head to collapse (Boileau et al. type 1 [4]). The combination of malunion and osteonecrosis leads to an indication for arthroplasty and the main predictor of a poor outcome is tuberosity osteotomy.

Figure 10 Periprosthetic malunion with a reversed shoulder implant: rotation is impossible.
laboratory tests: normal levels of white blood cells and C-reactive protein must be established.

Treatment of malunion

The ideal treatment is prevention. A surgeon facing a difficult revision procedure often wonders how this could have been avoided! The formation of a malunion implies:

- a problem during the initial analysis of the fracture, the detailed description of the fracture lines and the fragment placement;
- a technical problem in performing internal fixation or arthroplasty for the fracture;
- a problem with bone healing because of poor initial fixation or non-standard bone fixation due to osteoporosis.

Based on the clinical and functional evaluations, and the determination of malunion parameters with imaging, the treatment goals must be precise and realistic. Can bone union be obtained? Does osteoporosis make joint replacement a better choice than internal fixation with reconstruction? Are we able to improve on the current condition? Are there any other identifiable injuries that could explain the shoulder pain (rotator cuff, instability, long head of biceps brachii)?

An "acceptable" malunion

This occurs when correction of the altered morphology would not lead to any functional improvement. The malunion is tolerated by the patient and does not justify any specific treatment. Clinical evidence of sub-acromial impingement can lead to an acromioplasty procedure with the sole goal of making is easier for the greater tuberosity to pass under the coracacromial arch. A coracoïdoplasty can reduce the anterior sub-coracoid impingement due to a tolerable lesser tuberosity malunion. Injury to the long head of the biceps tendon as it passes through the capsule or in the intertubercular groove can justify a tenotomy-tenodesis. Less than 15 mm of greater tuberosity displacement is considered as a positive criterion for an acromioplasty indication [19]. Arthroscopic release can improve function [20,21]. Evidence of partial or complete rotator cuff rupture justifies a surgical repair, as does a labrum and/or capsule tear related to the initial fracture-dislocation injury [22]. Joint mobilisation while under anaesthesia and soft tissue release can also help to simultaneously treat the post-traumatic stiffness [22].

Revision indication for surgical correction

Any surgical revision procedure on a site that has already been operated on must include joint fluid collection and tissue biopsy for microbiological testing. 

Head does not need to be replaced. Any material that would hinder the procedure should logically be removed.

Preserving the humeral head consists of a series of surgical steps that must be carefully planned for during the preoperative stage: glenohumeral release, tuberosity osteotomy, freshening of receiving sites, sub-tuberosity osteotomy, and fixation in anatomical position.

Tuberosity malunion with resection to remove the impingement: tuberoplasty-arthrolysis. Arthroscopic treatment is indicated to resect any bone fragment(s) that have healed in the wrong position. Resection of the tuberosity fragment and acromioplasty are usually effective in treating sub-acromial impingement secondary to greater tuberosity malunion, following conservative treatment, internal fixation or arthroplasty. The tuberosity can be used to correct the mechanical consequences of tuberosity malunion [23,24]. Resection of posterior and anterior heterotopic ossifications and release of capsule, labrum, bursa or ligament adhesions can free up the internal or external rotators and restore the subacromial and subdeltoid gliding planes. Symptoms of long head of biceps tendinopathy, because of anatomical alterations in the intertubercular groove, are an indication for tenotomy-tenodesis.

Tuberosity malunion requiring the greater or lesser tuberosity to be repositioned. Tuberosity osteotomy is necessary, which must be approached the same way as treating an avulsed rotator cuff tendon attachment. The preparation of the avulsed fragment, the release of the involved tendon for easy mobilization and the Hollings out of a bone recess at the attachment site are all technically demanding steps (Figs. 11 and 12). Lädermann et al. recently described the advantage of using arthroscopy to perform the tuberosity osteotomy (typically of the greater tuberosity) and to reposition it in a way to place the rotator cuff back under tension [23].

Sub-tuberosity malunion: varus malunion of the proximal humerus [24,25]. An osteotomy to correct the deformation and deviation of the proximal humerus must be kept extra-articular to stay away from the epiphyseal vascularisation. Analysis of the malunion will lead to a correction in the coronal plan, with a closing wedge valgus osteotomy at the surgical neck corresponding to the amount of correction wanted (Fig. 13), but will also correct the anterior or posterior tilt in the sagittal plane and any rotational problems in the axial plane.

Joint replacement is required. Secondary arthroplasty for the treatment of proximal humerus fracture sequelae is difficult to perform and often has disappointing results. The options for secondary arthroplasty for malunion comprise humeral hemi-arthroplasty, anatomical total shoulder arthroplasty implants and reverse total shoulder arthroplasty implants. We have no information on the use of humeral resurfacing heads for the treatment of proximal humerus fracture sequelae. The need to have at least 60% of the bone stock remaining limits this indication to malunion cases associated with limited osteonecrosis, limited impaction, or secondary osteoarthritis with or without tuberosity osteotomy.

No matter which type of implant is used, the main predictor of poor outcome is tuberosity osteotomy, which drops the Constant score from 70 to 45%. This negative effect remains despite improvements in implantation procedures and tuberosity repositioning techniques [4-7,12,26].

The most common indication is hemi-arthroplasty with a humeral stem [27]. The development of reversed total shoulder arthroplasty implants has led to new treatment indications.

Humeral hemi-arthroplasty. The presence of a malunion is a negative prognostic factor. Mansat et al. showed
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Figure 11  Bone and intra-articular malunion after internal fixation: a: superior greater tuberosity malunion. The distance, d, represents the length of correction needed to restore the anatomical position. SSP: supraspinatus; b: the tuberosity osteotomy must harvest a thick piece of bone and the attachment site must be prepared to provide a recess fit in the bone; c: fixation of the greater tuberosity using screw fixation and/or transosseous suture fixation. The supraspinatus tendon is also sutured to the infraspinatus and subscapularis.

Figure 12  Greater tuberosity malunion: a: osteotomy of the malunion and mobilisation of the lesser tuberosity, preparation of the attachment site; b: lesser tuberosity fixation with transosseous suture fixation. CP: coracoid process.

Figure 13  Lesser tuberosity malunion: a: varus sub-tuberosity malunion: sub-tuberosity valgus osteotomy must bring the surgical neck back to 45° relative to the shaft axis in the oblique plane, while preserving the medial hinge. Correction angle (A°c) is measured at the metaphysis and diaphysis junction for wedge-shaped resections; b: fixation with lateral plate and screws after valgus osteotomy.

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that satisfactory results after secondary arthroplasty for malunion went from 82 to 50% [8].

The poor results for greater tuberosity osteotomy can be attributed to three main mechanisms [4]:

- devascularization;
- retraction and loss of soft tissue elasticity;
- problem with restoring humeral length.

The possibility of implanting the humeral stem component without performing a tuberosity osteotomy must always be explored (Fig. 14) [9]. If this is not an option and a tuberosity osteotomy must be performed, the expected result becomes a fair prognosis. Here, we recommend using a fracture-type implant that has a window to allow for placement of a bone graft between the tuberosities or an implant that is hydroxyapatite coated if the tuberosity must also be repositioned.

In cases of chronic dislocation and intra-articular malunion, the appropriate surgical approach must be chosen to allow for the glenohumeral joint to be reduced, the current hardware removed and the humeral stem implanted. The preoperative planning must confirm that a tuberosity osteotomy is not required.

The possibility of secondary conversion to total arthroplasty from an initial humeral hemi-arthroplasty, which can have poor functional results because of glenoid osteoarthritis, typically improves the patient’s condition. The exception is for malunion cases, which have a poor prognosis [28].

Reverse total shoulder arthroplasty implants. Recourse to a reversed total shoulder implant can be justified if the rotator cuff is not functional or cannot be repaired (after nailing) or the tuberosities cannot be repaired. If the implantation can be done without tuberosity osteotomy, the procedure will be easier (Fig. 15). If a tuberosity osteotomy is required for the implantation, repositioning the tuberosity seems to be simpler since the tendons and tuberosities have been resected. The rotation cuff does not need to be spared in such cases. Release of contracted soft tissues will also contribute to improvement in the joint range of motion. Neyton et al. [29] showed better and faster functional results with a reversed shoulder implant relative to historical results with humeral hemi-arthroplasty under the same conditions (Boileau et al. type 4 malunion sequelae [4]). Keeping all or part of the subscapularis can preserve some degree of useful internal rotation. Similarly, sparing the teres minor muscle could help to provide a bit of external rotation. A positive hornblower sign before the arthroplasty is predictive of a poor outcome, especially in elderly patients.

Progression after treatment of proximal humerus malunion

Tuberosity union is never a certainty, even if the osteotomy is performed carefully and if thick bone fragments are used. Resportion translates to devascularization. There is a high complication rate (around 28%), as with any surgery for sequelae and revision [3].

Conclusion

The physician who chooses the initial treatment for a proximal humerus fracture should be the one responsible for addressing any potential complications or sequelae. A precise clinical, functional and imaging evaluation can identify pain symptoms that may respond to a simple treatment. Corrective surgery for bone malunion must be carefully planned and must take into account the rotational deformity of the humeral head. Joint replacement surgery...
for bone and intra-articular malunion consists of humeral hemi-arthroplasty implants or reversed total shoulder joint implants. Tuberosity osteotomy performed during arthroplasty remains the main predictor for a poor outcome.

**Disclosure of interests**

The author declares that he has no conflicts of interest concerning this article.

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