MINI-SYMPOSIUM: SHOULDER RECONSTRUCTION

(iii) Post-traumatic reconstruction for sequelae of fractures of the proximal humerus

R. Hertel*, E. Fandridis

Lindenhofspital, Bremgartenstrasse 117, 3012 Bern, Switzerland

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Summary
In spite of the development of new techniques and implants, undesirable early and late sequelae may occur after both nonoperative and operative treatment of fractures of the proximal humerus. In this review, we aim to give some clear directions on how to manage these often complex post-traumatic conditions, in an area where there is a little consensus on treatment in the literature.

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Introduction
Ageing and osteoporosis lead to an increased incidence of fractures of the proximal humerus. Kannus et al. have predicted a three-fold increase in the incidence of these fractures over the next three decades. The majority of them are minimally displaced and treated nonoperatively. Approximately, one-fifth of these fractures require operative treatment. Late sequelae may occur after either non-operative or operative treatment. The purpose of this paper is to discuss late sequelae that significantly affect the patient’s outcome, such as shoulder stiffness, heterotopic ossification (HO), avascular necrosis (AVN), malunion, non-union and post-traumatic arthritis.

Shoulder stiffness
Shoulder stiffness is a common complication after osseous injuries, such as fractures and/or fracture-dislocations of the proximal humerus; it may occur after both closed and open treatment. Motion loss in isolated directions may progress to global limitation of movement. Factors that contribute to this complication include the severity of the initial injury, inadequate operative technique (including non-anatomic reduction) and inadequate rehabilitation. Post-traumatic shoulder stiffness can be categorized according to Fig. 1. Shoulder stiffness after minimally displaced fractures may be related to soft tissue contractures and/or glenohumeral cartilage erosion. The soft tissue contractures can be subdivided into intra- and periarticular variants, accepting that intra- and periarticular adhesions frequently coexist. Malunions and nonunions can also result in shoulder stiffness, while associated soft tissue adhesions often contribute. Infection, especially low-grade infection, can be an additional cause of painful stiffness, and this should always be ruled out prior to the implementation of any treatment.

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The choice of treatment depends on the cause of the stiffness. In patients with mild limitation of shoulder motion or endurable pain due to soft tissue contractures, the treatment will include exercises, pain medications or intra-articular corticosteroids. Patients with severely limited range of motion due to soft tissue scarring and contractures, as well as patients who did not improve with nonoperative care, are to be considered for operative treatment.

Arthroscopic techniques are effective for intra- and periarticular arthrolysis (Fig. 2). Where hardware removal is required due to pain or impingement, we recommend a combined arthroscopic and open procedure. Arthroscopically, the intra-articular release can be performed and with the open procedure periarticular release can be completed. Regions of the capsule that require release are determined by physical examination. Loss of external rotation requires

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**Figure 1** Possible causes of post-traumatic shoulder stiffness. The stiffness can be related to more than one cause. For example, malunion may coexist with cartilage erosion, soft tissue contractures or infection, and so on.

**Figure 2** Arthroscopic release of post-traumatic shoulder stiffness in the presence of a humeral head arthroplasty. Right shoulder, sitting position.
a release of the superior and middle glenohumeral ligaments, the rotator interval and the coracohumeral ligament extra-articularly. Loss of elevation requires release of the antero-inferior capsule including the anterior band of the inferior glenohumeral ligament, while loss of internal rotation requires postero-superior and postero-inferior capsular release.\(^6\)

The treatment of post-traumatic stiffness caused by cartilage erosion depends on the severity of damage. Arthrolysis can be performed in the presence of mild arthritic changes, while shoulder replacement is an option in advanced arthrosis. Biceps tenotomy should always be considered when the biceps tendon is adherent to the bicipital groove. Stiffness after malunion with minimally distorted anatomy requires soft tissue release, while in the case of severely distorted anatomy, corrective osteotomy and soft tissue release may be necessary. Stiffness associated with nonunion can be managed by soft tissue release, internal fixation, and supervised rehabilitation according to the stability of the fixation. Stiffness associated with infection requires immediate treatment with irrigation, open and/or arthroscopic debridement combined with intravenous culture-based antibiotics.

**Heterotopic Ossification**

HO has been reported by several authors, especially after fracture-dislocations of the proximal humerus.\(^7\) Neer reported HO in 12% of patients with three- and four-part fractures including fracture-dislocations that were treated with closed reduction, ORIF or hemiarthroplasty. It is unusual for HO to occur after uncomplicated fractures, but it is seen not infrequently in patients with neglected fracture-dislocations.\(^8\) Pre-disposing factors to HO are: head\(^9\) and spinal cord\(^10\) injury, ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis, history of HO formation\(^11\) and extensive local soft tissue damage or dissection. Boehm et al.\(^12\) reviewed 121 patients who were treated with total shoulder replacements or hemiarthroplasties; 48 of 121 patients had sustained a fracture and/or fracture-dislocation of the proximal humerus. There was no statistical difference in the HO between total and hemiarthroplasty, and the proximal humerus trauma patient group did not present increased risk for HO formation. Interestingly, HO has little clinical relevance to the patient’s functional outcome.\(^7\) True bony bridging of the glenohumeral space is rare. Anatomically, we observed limiting HO in the substance of the subscapular muscle, the metaphyseal calcac region and the subacromial bursa.

Surgical resection is possible, when HO is the reason for limitation. Excision should be attempted only after the ossification has matured; that means when the osseous trabecular structure has been well formed and the cortical line has been clearly defined. For most patients, this requires a period of 6–9 months after the initial surgery.\(^11\) Standard radiographs and computed tomography (CT), especially three-dimensional (3-D) reconstruction images, are necessary for full evaluation of the ossification. Scintigraphy and biological markers are not so important for the assessment of maturation.\(^13,14\) Bone excision from the glenohumeral joint requires meticulous dissection due to the proximity of the axillary nerve and branches of the brachial plexus. In our practice, we aim at wide excision of the HO i.e. epineuroperiosteal dissection. Additionally, we use indomethacin 25 mg three times daily for 3 weeks.\(^15\)

**Avascular Necrosis**

AVN may occur as a late complication of fractures of the proximal humerus and its development is strongly related to the blood supply of the humeral head. Although studies have emphasized the importance of the anterior circumflex vessels and the arcuate artery,\(^16\) this has not been confirmed by anatomical and clinical studies in the fractured humerus. The arcuate artery is generally interrupted even in the most simple fracture patterns. The main perfusion to the humeral head is most likely derived from the posterior circumflex vessels.\(^17-19\) Lee and Hansen\(^20\) reported that revascularization through creeping substitution may also occur. In patients with a fracture of the proximal humerus and constitutionally high dominant anterior vessels, only a postero-inferior part of the head remains perfused initially. This ischaemic cranial part can be revascularized when adequate contact with bleeding cancellous bone and a stable mechanical environment is provided.\(^19\) Humeral head ischaemia is associated with fracture lines at the anatomical neck level, small length of the dorsomedial metaphyseal extension and disruption of the medial hinge. Head angulation, tuberosities displacement and glenohumeral dislocation are relatively poor predictors of head ischaemia.\(^19\) Hagg and Lundberg\(^21\) reported AVN rate of 3–14% after closed reduction of displaced three-part fractures and a rate of 13–34% after four-part fractures, while Sturzenegger et al.\(^22\) reported 34% incidence of AVN in a series of 17 patients treated with a T-plate. The extensive soft tissue exposure needed for internal fixation with bulky implants, was thought to be a factor for AVN in this series. However, AVN may be associated with satisfactory function if anatomic reconstruction was obtained.\(^23\)

The treatment of post-traumatic AVN depends on the patient’s disability and the radiological stage.\(^24\) In the early stages of AVN, in patients with no pain or limited joint motion, nonoperative treatment can be an option, while in patients present with pain or impaired function, humeral resurfacing arthroplasty can be a suitable solution (Fig. 3). In end stages of AVN with collapse of the subchondral bone and destroyed articular cartilage, shoulder arthroplasty with glenoid replacement is the primary option (Fig. 4). The application of stemless humeral resurfacing arthroplasty has several advantages over a stemmed prosthesis, such as the minimal bone removal, the uncomplicated revision surgery if necessary, the avoidance of stress risers, thus eliminating the risk of periprosthetic fractures, and the accurate recreation of proximal humeral anatomy. In our practice, most of the patients that we treat with post-traumatic AVN have already a Ficat stage III or IV. These patients are preferably treated with surface replacement arthroplasty.

**Nonunion**

Nonunion may result as a consequence of the initial injury or more frequently as a consequence of its treatment.
We define nonunion of the proximal humerus as the failure of the fracture to heal 6 months after the initial injury. The presence of rounded sclerotic fracture ends and the absence of bridging callus are generally considered criteria for nonunion. Both displaced and minimally displaced fractures of the proximal humerus may result in nonunion. We still do not know the incidence of post-traumatic nonunion. Factors contributing to nonunion include open fractures, interposition of soft tissues, inadequate fixation, devascularization, metabolic diseases, hematologic disorders, alcoholism, and poor patient compliance. Patients with nonunion of the proximal humerus experience pain and loss of function of a variable degree. Nonunion often is associated with soft tissue stiffness, and it is very difficult to assess the true glenohumeral motion due to the pathologic instability at the nonunion site. In our clinical

![Figure 3](image-url) Four-part fracture of the proximal humerus-type H-G-L-S that was initially treated with ORIF. AVN of the humeral head developed over a 4-year period. Successful treatment using a humeral resurfacing arthroplasty.

![Figure 4](image-url) Four-part fracture-type H-G-L-S. ORIF with k-wires. End stage AVN with associated arthritis. Successful treatment with a hybrid shoulder arthroplasty.
assessment, we palpate with one hand on both tuberosities and perform an assisted, active external rotation of the arm. If the tuberosities do not rotate, then the observed motion is due to instability at the nonunion site. We also observed that many of the patients present with a false positive external rotation lag sign due to the instability at the nonunion site, and not to a torn rotator cuff. Basic radiological assessment such as anteroposterior, axillary and lateral scapular views may not be sufficient to assess the degree of displacement, thus a CT scan is often valuable.

We suggest using a classification of humeral nonunions of the proximal humerus that is analogous to the binary fracture description.30,31 There are 14 possible nonunion patterns. They can be described with a sequence of four letters: H (humeral head), G (greater tuberosity), L (lesser tuberosity) and S (shaft). The letters can be used in any sequence and a short line between them, represents a nonunion plane. A surgical neck nonunion will be abbreviated like HGL-S. A three-part nonunion is an HL-G-S if the lesser tuberosity is attached to the humeral head or an H-G-LS if the lesser tuberosity is attached to the shaft, and so on. With this description, 14 basic nonunion patterns can be defined (Table 1). It is out of the scope of this paper to analyze every nonunion pattern. We will focus on the most frequent patterns.

### Greater tuberosity nonunion (HLS-G)

Closed treatment of greater tuberosity fractures may result in posterior and superior migration of the tuberosity due to the action of the supraspinatus, the infraspinatus and the teres minor muscles.32 Displacement of more than 5–10 mm may result in subacromial impingement and rotator cuff dysfunction.33 In patients with pain and rotator cuff insufficiency, reconstruction should be considered.

After debridement and decortication of the nonunion, mobilization and release of the rotator cuff is the most important step. Splitting of the rotator interval, dissection of the coracohumeral ligament and posterior capsulotomy or capsulectomy are mandatory in order to mobilize the retracted rotator cuff. Anatomic reduction of the greater tuberosity assures that proper tension of the rotator cuff is restored. In our practice, we perform debridement, decortication and rotator cuff release, followed by fixation of the greater tuberosity with transosseous sutures, plus in the case of larger fragments, augmentation with 2.7 or 3.5 mm cortical screws. We believe that especially small tuberosity fragments should not be removed, in order to allow better healing.

### Surgical neck nonunion (HGL-S)

Nonunion of the surgical neck usually requires operative treatment. The viability of the humeral head and the quality of the cartilage will define the choice of treatment. Preoperative work up may include conventional radiographs, CT scans and magnetic resonance imaging (MRI). In the presence of hardware a metal suppression CT scan can be used. Alternatively, the hardware can be removed, in order to have an MRI analysis. The intraoperative assessment of the head’s viability is an additional diagnostic tool. Clear backflow after the head is drilled in its central part and the use of Doppler laser, if available, may give a positive proof of head perfusion.

Treatment options are either head preserving or rarely replacement arthroplasty. Head preserving techniques are based on decortication, recanalization and stable fixation. For fixation there are several options, such as plates, nails, rods and tension bands.34–39 Additionally, bone grafts can be used either to enhance stability, to enhance healing or both. The use of intramedulary rods with or without tension bands, has not been satisfactory in reported papers, mainly due to the impinging metal.40 Several studies34,41 reported poor results after replacement arthroplasty and the reason was failure of healing of the tuberosities to the humeral shaft. We agree that indications for arthroplasty should be examined cautiously. In cases with a short proximal segment, fixation might be insecure, and large autologous bone grafts may be inadequate in elderly patients due to poor mechanical properties of the graft. Donor site morbidity, including fractures of the iliac wing, especially in the elderly patients, may also affect patient outcome. Although, there are several problems with internal fixation in surgical neck nonunions, most studies do support the use of plates.34,38,42 Blade plates, T-plates and angular stable plates can be considered as methods of stabilization. In most cases, healing is achieved and hardware removal is usually not required. Despite generally good results, complications do occur after ORIF, such as hardware impingement if placed too superiorly, AVN due to extensive medial soft tissue stripping, and infection.7,25,43 In our practice, the mechanical stability of the construct and preserving the biological potential remain the main goals to foster union. The mechanical stability can be enhanced by impaction of the humeral shaft with the head, and slight valgus overreduction (Fig. 5). We use an AO 1/3 tubular plate or a 3.5 blade plate in patients with good bone quality. We also use autologous bone graft in bone defects, but not routinely, in order to enhance the healing process.

### Malunion

Malunion may occur along the five basic fracture planes and therefore can be complex to understand.15 It is helpful to
analyze the malunion pattern in analogy to the HGLS system, as described above. The most frequent malunion patterns are greater tuberosity malunion, varus malunion of the humeral head, extension malunion of the humeral head, and lesser tuberosity malunion. We also agree that various soft tissue abnormalities have to be considered in pre-operative planning. Soft tissue abnormalities include stiffness, scarring, rotator cuff deficiencies and deltoid muscle lesions. We believe that any further categorization does not offer further help in choosing treatment directions, in consideration of the individual personality of any given malunion case. For instance, a patient with 40° varus malposition of the humeral head may function well, while another patient with the same deformity may be functionally impaired. In our opinion, soft tissue contribution to the poor function of any malunion is always a question, and scrutiny is mandatory to find the real cause of the patient’s problems. Rodosky et al. reported that soft tissue scarring and adhesions are the main causes of limited shoulder range of motion and presented good results after open release and trimming of any prominent spikes. A carefully combined clinical and radiological evaluation will probably reveal the cause of functional impairment. For instance, a shifted arc of motion with a normal range, is probably due to malrotation of the proximal humerus, and thus not to a soft tissue abnormality. X-rays in different degrees of rotation can also give valuable information on the deformity pattern. Most malunions are 3-D deformities, which can be precisely visualized by CT scan, including 2-D and 3-D reconstructions. Also, we should not ignore the importance of the initial trauma films, which will furnish information on the type of injury, and very likely on the cause of the malunion.

The treatment depends on the degree of the anatomical distortion, the type of soft tissue abnormalities, and the patient’s needs and expectations.

Malunion of the surgical neck

Malunion of the surgical neck may result in extension, varus or valgus deformity. Varus and extension malunions are more frequent, and in severe deformities may cause limited flexion or abduction. Varus angulation can also limit external rotation due to impingement of the greater tuberosity against the glenoid. Several authors have reported that osteotomy, such as valgus corrective wedge osteotomy, can improve shoulder function. In our practice, corrective osteotomies combined with focused soft tissue procedures produce reliable results (Fig. 6). Nevertheless, we would like to draw the reader’s attention to the fact that a medially hinged closing wedge osteotomy may not result in the desired anatomical correction as it may lead to lateralization of the center of rotation. Translation of the shaft with respect to the epiphyseal fragment is often necessary to restore the mechanical axis of the proximal humerus, i.e. to restore normal offset. An important element in planning the osteotomy, is to retain at least a 10 mm long medial metaphyseal extension, in order to preserve head perfusion. For fixation, anatomically contoured plates are not useful, because correction leads to shortening and shortening leads to a right-angled step in the lateral cortex. Therefore, a custom contoured plate with a double bend is required.

Malunion of the tuberosities

The greater tuberosity may be displaced posteriorly and superiorly various degrees, which may lead to a loss of abduction and external rotation. For marked displacement, corrective osteotomy of the greater tuberosity after mobilization of the rotator cuff should be considered. Arthroscopic acromioplasty is an option only for minimally displaced malunions of the greater tuberosity. In cases where the greater tuberosity lies far posteriorly, the anterior deltopectoral approach may be insufficient and a more extensive deltoid-off approach could be necessary. The methods of fixation may include sutures, screws and wires. In our practice, we mobilize the osteotomized greater tuberosity via a juxta-labral postero-superior capsulotomy. We have observed that in acute lesions the supraspinatus tendon is torn in the line of its fibers approximately 5 mm posterior to its leading edge. Since the tuberosity fragment is displaced, this results in a v-shaped opening of the supraspinatus. In chronic lesions, such as malunions, this opening is filled and obliterated with reparative scar.
tissue. In order to obtain anatomic reduction this v-shaped scar tissue needs to be excised. We usually stabilize the greater tuberosity with transosseous sutures and we augment the fixation with 2.7 or 3.5 mm cortical screws (Fig. 7).

Malunion of the lesser tuberosity is a common but underdiagnosed deformity. The functional impairment is related to a mechanical block of internal rotation (intra-articular impingement) or to impingement to the coracoid process (extra-articular impingement). Intra-articular impingement can be treated arthroscopically. The intra-articular step is due to the prominent rim of humeral head that usually remains attached to the lesser tuberosity. This prominent cartilage-covered rim can be trimmed in order to allow impingement-free internal rotation. If extra-articular impingement exists, osteotomy of the lesser tuberosity, mobilization of the subscapular muscle and secure fixation of the lesser tuberosity in the anatomical position may be necessary.

**Post-traumatic arthritis**

Post-traumatic arthritis is infrequent after minimally displaced fractures of the proximal humerus, but its incidence is higher after more complex injuries. Zyto et al. reported a 64% post-traumatic arthritis rate after three and four-part displaced fractures that were treated nonoperatively or with internal fixation. Possible causes of post-traumatic arthritis are malunion and nonunion with joint incongruity, including splitting injuries of the humeral head and malunions of the tuberosities, neglected unreduced dislocations, recurrent subluxations or dislocations and late stages of AVN.

In the management of post-traumatic arthritis, bone and soft tissue injuries should be carefully considered. Associated malunion or nonunion, stiffness and rotator cuff tear make the treatment of post-traumatic arthritis a real challenge. Infection and nerve lesions should be carefully assessed. Several authors have reported inferior results for shoulder arthroplasties undertaken for the sequelae of fractures than for hemiarthroplasties in acute fractures. They also reported less favorable results when post-traumatic arthritis was associated with malunion, nonunion or humeral head defects.

Patients with insignificant symptoms and mild shoulder arthritic changes can be managed with nonoperative care, while patients with considerable pain and impaired function may be considered for operative treatment. Hemiarthroplasty, total shoulder arthroplasty, reverse arthroplasty, shoulder arthrodesis and resection arthroplasty are the operative options in the surgeon’s armory. Extensive glenoid cartilage erosion remains the main indication for glenoid replacement, though many authors prefer to perform a hemiarthroplasty in young, active patients with intact glenoid cartilage. For others, the potential complications...
associated with the glenoid component are additional reasons for the choice of hemiarthroplasty. However, Boileau et al. reported the advantages of total shoulder arthroplasty over hemiarthroplasty, in terms of relief of pain and improvement in function. Copeland recommended drilling of the articular surface of the glenoid in order to promote formation of fibrocartilage, while biological resurfacing with various autogenic or allogenic materials (achilles tendon, fascia lata, dermis and anterior capsule) has also been reported. Future studies with long-term follow-up will determine the potential of biological techniques.

Resurfacing humeral arthroplasty with or without glenoid replacement is a surgical option for the treatment of post-traumatic arthritis. In our practice, the anterior deltopectoral approach is a standard, reproducible, simple approach that provides adequate exposure. The identification of the humeral neck and the removal of the superior and inferior osteophytes of the head, are the key points in anatomic component insertion. The humeral head resurfacing prosthesis also provides the option to accept some variation in proximal humeral anatomy (Fig. 8). Preservation of bone stock for future revisions, no stress risers for the shaft of the humerus, and the avoidance of intramedullary reaming, are other advantages of resurfacing arthroplasty. In our hands, hybrid shoulder arthroplasty, with a resurfacing humeral head and a polyethylene glenoid component, provided satisfactory medium term results.

Some authors have pointed out that greater tuberosity osteotomy is related to poor results after shoulder arthroplasty and that one should avoid it. We believe that post-traumatic reconstruction should replicate the proximal humerus as anatomically as possible, and that severe malposition of the tuberosities results in impaired function. Nonanatomic tuberosities reconstruction may lead to significant functional impairment and increase of the torque requirements. In our practice, tuberosity osteotomy followed by fixation with wire-cerclages provided a high rate of healing, and can therefore be considered for selected cases.

Shoulder fusion (arthrodesis) is a well-established procedure that is significantly less frequently indicated since the advent of shoulder arthroplasty. We agree that there are indications related to post-traumatic sequelae, such as chronic infection, post-traumatic brachial plexus injury, severe deltoid muscle insufficiency and failed shoulder arthroplasties in selected patients, which can be treated with shoulder fusion. Fusion is generally less well tolerated in elderly patients with poor scapulothoracic muscles.

Resection arthroplasty may also have a therapeutic role in post-traumatic salvage procedures. Resection arthroplasty may be indicated in infected shoulder arthroplasties, especially in patients with significant comorbidities or in those with severe soft tissue deficiencies, which may not be amenable to a further implantation.

Conclusion

Surgeons will be facing an increasing number of post-traumatic conditions, which may be due to the demographic
changes and our limited capabilities in treating complex and osteoporotic fractures. The spectrum of post-traumatic conditions is wide. Treatment plans should be customized and adapted to the particular situation. Directions for treatment can be derived, by analyzing the soft tissue abnormalities and the osseous deformities, with reference to the HGLS system of fracture classification.

References