Abstract

The objective of this chapter is to describe the surgical technique of fixation with polyaxial locking plates through a minimally invasive approach for the treatment of proximal humeral fractures.

The objective of the reduction is to achieve the “chair concept” given by the St. Gallen group. The fracture fragments (head, greater tuberosity, lesser tuberosity and the diaphysis with the medial metaphysis) are reduced to build a chair structure: the head is the seat and stands on three legs, which are the greater tuberosity, lesser tuberosity and the medial metaphysis or calcar. This chair finally stands on the diaphysis to complete fracture reduction. Preoperative planning is key to correctly address all the fracture fragments. Stay sutures will help in the reduction of the tuberosities; and through the “tuberosity window”, the gap created between both tuberosities, head reduction can be achieved.
Fracture fixation should be built with a locking plate for early movement, and in a minimally invasive way, to preserve soft tissues. External aiming devices with sleeves systems will allow percutaneous screw placing.

Complications are related with poor surgical technique. Screw joint penetration is the most frequent. Axillary nerve injuries, although very serious complication, hardly occur if the surgical technique is followed step by step.

Throughout this chapter we will explain, step by step, the surgical technique to reduce and fix proximal humeral fractures successfully. Tips and tricks are presented so patients can start physiotherapy right after the operation.

(Video: MIPO surgical technique for proximal humeral fractures: https://youtu.be/T4o_a8_9R0A)

Introduction

The treatment of proximal humerus fractures (PHF) has been and it is now controversial [1]. Conservative treatment is considered the gold standard when compared with the different treatment options available: percutaneous K-wires, open reduction and fixation with classical or locking plates, IM locking nails, or shoulder prosthesis [2-12]; but no conclusions according to which is the best treatment for these fractures can be withdrawn.

The increase of life expectancy has raised the incidence of these fractures; on the other side, quality of life has increased the activity level and demands from aged osteoporotic patients [13]. Fixation with polyaxial locking plates through a minimally invasive surgery (MIS) approach can provide a stable osteosynthesis in osteoporotic bone with low surgical injury to an elderly patient [14,15]. Soft tissues damage during surgery remains at its minimum. This would allow immediate physiotherapy treatment and recovery [16,17].

Indications for Minimally Invasive Plating Osteosynthesis (MIPO) in PHF include almost all fractures independent from the number of fragments and the grade of displacement. Intra-articular head split fractures can also be reduced and fixed through a MIS approach. In all cases a deep knowledge of the fracture and the fragments displacement is necessary preoperatively. Proper X-ray views and a CT-scan study should give enough information of the fracture, and if fixation with a plate and screws is possible.
A formal contraindication for MIPO is when the fracture is associated with a glenohumeral dislocation; in these cases, open reduction is advised. In cases with poor bone stock such as an intra articular head fracture in old patients, the screws won’t have any bone purchase and the fixation will fail. In such cases MIPO is contraindicated and other treatment options should be considered.

Throughout this chapter, we will explain the surgical technique in the treatment of PHF step by step: from the operation room setup to reduction and fixation with a polyaxial locking plate via MIS [16,17].

**Patient Position**

Beach-chair position with the shoulder girdle and the upper limb overlaying from the side of the operation table. This way the upper limb can be freely placed in any position. The arm hangs alongside the trunk with the shoulder in 0° abduction and neutral rotation. The forearm lays beside the thigh, on a support, in a way the elbow hangs suspended (Figure 1). As the beach chair position is in 80° vertical it may reduce cerebral perfusion; to avoid this serious complication reach this position slowly [18]. With this position, gravity helps in the reduction of the neck and shaft fracture fragment; avoiding medial and proximal rising displacement of the proximal diaphysis (Figure 1, X-ray image).

**Intraoperative X-Ray**

C-arm from the patient’s head at the fracture side. Pure antero-posterior (AP) glenohumeral views are used, with the C-arm perpendicular to the scapular plane (45° from the trunk) (Figure 1). Orthogonal views of the humerus are obtained with internal and external rotation of the shoulder.

**Surgical Approach: Antero-Lateral Transdeltoid MIS Approach**

The skin incision is made centred on the mid portion of the proximal humerus and runs from the lateral border of the acromion, extending 3 to 5 cm distal and lon-
gitudinally (Figure 2A). The subcutaneous tissue layer is then bluntly dissected to identify the avascular tendinous raphe dividing the anterior and middle thirds of the deltoid. Splitting these tendinous fibres of the raphe avoids further bleeding and respects the deltoid red fibres integrity throughout all the surgical procedure (Figure 2B). The length of the deltoid splitting should not extend more than 4 cm distally from the lateral border of the acromion to avoid axillary nerve injuries. The subacromial and subdeltoid bursa are incised exposing the fracture site (Figure 2C and Figure 2D). At this point, the axillary nerve is always identified by palpation. The axillary nerve is identified from anterior to posterior (from distal to proximal), attached to the inner surface of the deltoid, finishing in the posterior third of the deltoid, where the nerve turns in a curve coming from anterior around the neck of the humerus. The course of the nerve is distal to the distal end of the bursa. A skin landmark of the nerve’s path is drawn to avoid injuries to the axillary nerve throughout the operation and to avoid dangerous extension of the surgical approach (Figure 3). Room enough for the plate is created between the lateral shaft cortex and the deltoid muscle with the nerve; this action will minimize the risk of axillary nerve injury when placing the plate during fixation (17). This space is developed by blunt palpation with the finger. In the case of metaphyseal fracture extension, a long plate is needed; the distal deltoid attachment on the humerus should be released in its anterior part to let the plate sit correctly on the lateral shaft.

Figure 2: Anterolateral transdeltoid MIPO approach (right shoulder): Centred on the humeral head, extending 3-5 cm from the lateral border of the acromion (A); tendinous raphe between the anterior and lateral thirds of the deltoid (B); subacromial bursa (C); fracture site (D) with the LT in an anterior position, the GT in the back part, the head in front of the surgeon, and the shaft (S) in the inferior part of the incision.

In MIS the soft tissue envelope prevents the fragments from further displacement; once the fragments are reduced they remain in their reduced position as the soft tissues avoid their displacement. Although the surgical exposure is reduced, there is enough room to see and to make all the manoeuvres (identifying, suturing, and reducing), as the surgical approach is placed right at the fracture site. On the other hand, as in any other MIS we can use the moving windows concept and modify the surgical field: for PHF placing the shoulder in internal rotation gives better access to the greater tuberosity; while in external rotation, the lesser tuberosity appears in the surgical field.
Figure 3: The axillary nerve’s path is marked on the skin to avoid damage throughout the operation. External jig for MIPO with a sleeve system for percutaneous screw placing, minimizing the risk of nerve injury.

Figure 4: Fracture reduction objective: Saint Gallen’s chair with the head (H) on top of three legs: Lesser tuberosity (LT), greater tuberosity (GT) and medial hinge (M). The chair stands on the shaft (S).

Fracture Reduction Step by Step

The objective of the reduction is to achieve the “chair concept” given by the St. Gallen group [19,20]. The fracture fragments (head, greater tuberosity, lesser tuberosity and the diaphysis with the medial metaphysis) are reduced to build a chair structure: the head is the seat and stands on three legs, which are the greater tuberosity, lesser tuberosity and the medial metaphysis or calcar (Figure 4). This
chair finally stands on the diaphysis to complete fracture reduction at a second stage. Only final fragment reduction and plate fixation are done under fluoroscopy control. Fracture fragments are identified and individualized by palpation once the bursa is incised. Preoperative planning is key at this stage: the surgical exposure is limited, and the surgeon must know from the preoperative radiological studies (x-rays and CT-scan) where the fragments are located. The quality of the reduction accomplished through a MIS approach can be almost anatomical.

**Greater Tuberosity (GT) Identification and Reduction**

The GT is attached to the supraspinatus, infraspinatus and teres minor tendons. If there is only one fragment, the GT is displaced and located in the posterior part of the surgical approach. In case of comminution of the GT, fragments will be displaced according to the tendon attachments: the tip of the GT with the supraspinatus will be superior and towards the glena; the anterior part of the GT will be the anterior wall of the bicipital groove, and part of the lesser tuberosity fragment; and the posterior fragments will displace posterior and medial with the infraspinatus and teres minor. Thick absorbable braided guiding sutures are placed on the GT through the rotator cuff tendons, but not through the bone to avoid comminution of the GT (Figure 5A). Placing this suture is technically demanding: we recommend the use of a Langebeck retractor on the posterior side of the surgical approach with the tip pushing the GT adding external rotation of the shoulder to relax the rotator cuff. A simple Farabeuf retracts lightly the anterior rim of the approach. One suture goes through the supraspinatus pulling the fracture GT fragment downwards and anteriorly to reduce the fragment (Figure 6b). A second suture goes through the infraspinatus and teres minor pulling lateral and anteriorly. Only one suture is needed if the GT consists on one fragment, pulling lateral and anteriorly to reduce the fragment. This suture will come out from the wound and lay anterior.

**Lesser Tuberosity (LT) Identification and Reduction**

The LT is attached to the subscapularis tendon and it is located anterior and medial in the surgical approach. The fragment usually involves the bicipital groove and the anterior aspect of the GT. Only one thick absorbable
suture is needed through the subscapularis tendon. This is done in external rotation of the shoulder and with the Langebeck retractor in the anterior rim of the approach with its tip pressing the LT. Reduction is obtained pulling lateral and posterior from the suture. This suture will come out from the wound and lay posterior (Figure 5C). In the case the long part of the biceps tendon (LHBT) is in the fracture site, the LT and the shaft might be unreducible: the LHBT should be identified underneath the subscapularis tendon between the head fragment and medial metaphysis and passed over (anterior) the traction suture of the LT (Figure 7A). The tuberosities traction sutures can be passed through the plate suture holes as a tension band or tied to each other at the end of the procedure.

Humeral Head and Joint Surface Reduction: “Tuberosity Window”

The suture showing the LT is pulled anteriorly through the surgical wound. The suture attached to the GT is pulled posteriorly and inferiorly. The result of this manoeuvre is the exposure of the head (Figure 5B). In medial (varus) head displacement the lateral cancellous bone side of the fractured head fragment will appear in front of us; or the head cartilage surface in valgus displacement. This is what we have called the “tuberosity window”. Through this “tuberosity window” the head can be manipulated in order to achieve its reduction from valgus (lateral), varus (medial), posterior or anterior displacement. Different surgical tools (i.e. periostal elevator) in the medial hinge can help reducing the head displaced in varus (Figure 6c). The glenoid joint surface might help reducing the head: the head in valgus can be pushed against the glenoid with the thumb. The head is contained by the rotator cuff avoiding anterior, superior or posterior displacement; and inferiorly by the capsule. The head fragment might be compacted with the shaft, and no clear fracture line can be seen. In these cases, we recommend to create a new line, with an osteotome, giving as much bone stock as possible to the head, for a later better fixation with the screws. Care should be taken not to reach the medial hinge with the osteotome to preserve the third leg of the St. Gallen’s chair; and it may work as a fulcrum.

Once the head is reduced, the GT is pulled anteriorly and downwards and the LT posteriorly, closing the “tuberosity window” and obtaining a 2-part fracture: the proximal humeral segment (the Saint Gallen’s chair: the proximal humerus with the head and tuberosities in their places) and the diaphysis (Figure 6d). Rarely, frozen heterologous cancellous bone graft can be used in osteoporotic cases with poor bone stock in the humeral head and metaphysis to give physical support to the humeral head. We only use structural cancellous bone graft in comminuted fractures to give support to the head, if it is not held by “the legs of the chair”. When intra-articular or head split fractures are present, the displacement of each fragment must be carefully address preoperatively. Each fragment should be reduced independently using the same manoeuvres as described before. At least one of the fragments of the head includes one tuberosity which might help in the reduction.
**Figure 6:** Reduction and fixation intraoperative X-ray images. A four fragment fracture with lateral impaction of the head (a). GT reduction with a traction suture pulling in a lateral and anterior direction (b). Head reduction manoeuvre against the glenoid surface with an osteotome, trying to preserve as much bone stock in the head as possible (c). Proximal humerus reduction building the St. Gallen’s chair (d). Shaft reduction with traction from the elbow and lateral displacement; the chair sits on the shaft (e). Temporary fixation with two K-wires through the external aiming device (f). Shaft screws and cannulated head screws over K-wires (g). Avoid screw joint penetration checking k-wire and screw positions in internal and external rotation (h). Final PHF fixation with a MIPO technique (i).

**Shaft Reduction**

Once there is a 2-part fracture, the shaft is reduced towards the proximal humeral segment (the chair is placed on top of the diaphysis): a periostal elevator placed through the fracture site at the surgical neck can distract the diaphysis and then pulling from the hanging elbow achieve the 2-part fracture reduction (Figure 6e). If the medial hinge of the metaphysis is displaced medially, a gentle lateral traction from the axilla is done (Figure 7C and Figure 7D). A Hofman (pointed) retractor inside the shaft might help pulling the shaft lateral (Figure 7C). If the medial hinge is displaced laterally, usually impaction
and shortening occurs; but we do not recommend reduction with traction due to the gap that will be created. On the opposite, bone contact will secure fracture healing and shortening (2 cm the most) will not significantly affect shoulder function [21].

**Intraoperative X-ray**

Intraoperative X-ray is used at this point to check the accuracy of the reduction and to make the fine adjustments for an anatomical reduction. The fracture can be temporarily fixed with K-wires and checked with an image intensifier; we found this could make the correct placement of the plate more difficult. The sutures from the rotator cuff tendons control and help to maintain the reduction of the tuberosities; the head reduction is kept by the tuberosities and the St. Gallen chair construction; plus, the soft tissue envelope holds the fracture fragments while plating. We use only 2 K-wires through the plate and the external aiming device as provisional fixation (Figure 6f).

**Fracture Fixation MIPO**

For definitive fracture fixation we recommend the use of a polyaxial locking plate with non-thread head screws (cancellous or cortical) that can be locked afterwards with a cup system. This plate system should have an external aiming devise for a MIPO technique. Locking plates help to build a stable fixation in osteoporotic bone to allow early movement. The polyaxial screws allows for correct screw placing where there is more bone stock for better bone purchase (14). Guide sleeves are useful for secure screw placing in a percutaneous way (Figure 3). The final construction will have locking screws in divergent directions, giving enough stability for early recovery of shoulder motion with the ability to maintain the reduction until bone healing (Figure 6f-6i).

**Getting the Plate in: Shaft Reduction and Temporarily Fixation**

We get the plate in with its distal end sliding over the lateral cortex to avoid entrapping the axillary nerve between the plate and the shaft. The correct height position of the plate is 1 cm distal to the tip of the GT (Figure 6f). The distance between the acromion and the plate should be checked directly in the wound to avoid later subacromial impingement. The plate sits over the GT, centred on the proximal humerus. Traction sutures from the tuberosities stay proximal to the plate.

One K-wire is placed in the head through the aiming device, the plate and the GT. The height of the plate is correct if this K-wire is in the head’s midline. Shaft reduction is obtained by pulling from the elbow downwards and lateral from the axilla at the same time (Figure 7C-7D). Be aware to check the shaft can be moved lateral (reduced) from the proximal humerus before placing the k-wire in the shaft. This slight lateral movement and final reduction of the medial hinge will be obtained with the first screw in the shaft. We close the frame between the plate and the aiming device with a second K-wire through the most dis-
tal hole of the plate while reducing the shaft (Figure 6f). The plate sits centred on the lateral shaft cortex if we feel two cortices with the K-wire.

**Medial Metaphyseal Hinge Final Reduction and Shaft Fixation**

Stable shaft fixation requires three bicortical screws. Fixation starts with the most proximal screw in the shaft. This is a traction cannulated screw. The K-wire that will guide the screw should pass two cortices; this will tell us the plate sits in the centre of the lateral cortex of the shaft without taking an X-ray. Once the non-threaded head of the screw reaches the plate, the traction effect starts pulling from the shaft against the plate when it is a medially displaced, thus reducing the medial metaphyseal hinge (Figure 8A and Figure 8B). When the reduction is obtained, the first screw is locked with the cup. A second screw right distal to the first one is placed in the same way, without traction effect. The second screw is locked with the cup right when it reaches the plate. The third screw is the last screw placed before removing the aiming device (Figure 6g).

**Proximal Humerus Fixation**

The plate correct position is right over the GT. When traction is made with the most proximal shaft screw, the collateral effect is the fixation of the GT as it is compressed between the plate and the head. The cancellous screws going to the head will fix the GT and the head. Still, some lag and compression effect can be achieved by the locking screws due to the specific cup-locking mechanism. The aiming device will give fixed directions for the screws; if there is no good bone purchase, the screws can be placed in a polyaxial mode (without the external jig): with a free hand technique through the wound, a 30° polyaxiality is usually allowed, depending on the plate system used (Figure 6g-6i). The screws will be driventowards good bone stock locations for a better fixation. Polyaxiality is very helpful in head split fractures to drive the screws to both head fragments.

**Figure 8:** Lag screw for final medial metaphysis and shaft reduction. This screw is the most proximal in the shaft. A: medial metaphysis is displaced medial. B: The lag screw (most proximal screw in the shaft) pulls the shaft reducing the medial hinge.
The most frequent complication in plating fixation of PHF (open or MIPO) is screw joint penetration in the humeral head (6). To avoid this complication, we recommend the use of cannulated screws over thin K-wires: the K-wire is drilled only in the lateral cortex and then is gently pushed into the head cancellous bone, stopping at the subchondral hard bone. The position of the K-wire is checked in neutral rotation, and maximal external and internal rotation (Figure 6h); if the position of the K-wire is not correct or it is loose, we replace it in a polyaxial way: looking for a location with enough bone stock to obtain strong bone purchase. By doing so, the incidence of joint penetration is almost 0%; and if any screw penetrates, it is in the periphery of the head with low incidence on the joint movement. All the plate systems place between five and six locking screws in the head, to give enough stability for early motion.

Final Fixation of the Tuberosities with Sutures

The GT is compressed between the plate and the head and fixed by the head screws. If this is not enough and there are still fragments of the GT pulled by the rotator cuff tendons, we can use sutures going through holes in the plate that will definitively reduce and fix these comminution fragments. Wire cerclage may also be used. The LT is more unlikely to be fixed by screws unless it is linked with a head fragment. LT fixation is secured with sutures going through the plate or tied with the traction sutures coming from the GT. It is not possible through a MIS approach to place isolated screws to fix the LT. If there is a rotator cuff rupture associated to the fracture, it might be repaired at this moment. These techniques avoid further greater tuberosity displacement, impingement, and secondary supraspinatus insufficiency (video link: https://youtu.be/T4o_a8_9R0A).

Wound Closure

No drainage is needed; and the deltoid gap is sutured loose, without muscle fibre compression. The arm is placed in a sling.

RHB Protocol

Passive range of motion exercises are started on the first day after surgery, depending on pain and activity level. Small blood loss occurs during this type surgery. Patients are discharged home on the first or second day after surgery with the upper limb resting on a sling over the clothes. For active exercises, patients are allowed to dress, wash and feed themselves right from the very beginning. Carrying weights (more than 500 gr) is not permitted. For better comfort, the patient’s arm is placed on a sling for a maximum of two-three weeks. Afterwards, patients have individualised postoperative management. But as a guide, active range of motion is allowed four weeks after the operation or as soon it can be done pain free with active assisted physiotherapy; carrying weights is allowed only when the tuberosities are healed.
Complications

Many complications can occur in the treatment of PHF with locking plates via MIS. These complications are due to poor surgical technique and mistakes. The surgical technique description given in this chapter will help us avoiding these complications, improving the final functional results and minimizing the learning curve damage. Many of them have been already explained but we outline the most important:

- Injury to the axillary nerve can be prevented by preparing the subdeltoid space for the plate, identifying the nerve, and using all the guide sleeves. In all plate systems there is a hole for a metaphyseal screw, right where the axillary nerve is located: nerve place this screw in a percutaneous way as the potential risk of injury to the axillary nerve is very high. We didn’t experience any acute injury of the axillary nerve in 155 cases. Barco et al, also reported no cases of axillary nerve injury in 23 cases [15]. In other series the rate of axillary nerve injury with MIPO techniques varies from 2.2-4% [22-26]. In young patients with a powerful and bulky deltoide muscle, the nerve might be compressed between the plate and the deltoide muscle. In these cases, chronic irritation of the axillary nerve may appear a few months after the operation. The symptoms are: anterior third deltoidal atrophy with altered electromyography, but not pain and full range of movement. The axillary nerve recovers without consequences after plate removal. Some studies report electrophysiological changes of the axillary nerve and deltoide muscle after MIS in PHF, but did not relate to deltoide or functional impairment [26].

- Screw joint penetration is the most frequent complication. The main risk factor is intraoperative screw perforation of the humeral articular surface or loss of reduction, because of a poor “chair” construction or poor bone quality. With the tips given in the proximal humerus fixation section the complications rate decreases dramatically [27].

- Fracture displacement can be prevented by achieving an accurate anatomical reduction (St. Gallen’s chair concept), correct positioning of the plate and the screws where there is more bone stock, and firmly fixing the tuberosities to the plate [27].

Conclusion

It is possible to achieve a good anatomical reduction through an anterolateral transdeltoid MIS in the treatment of PHF. The main objective of the reduction is to build a chair (the Saint Gallen’s chair concept); and the aim of the plate is to maintain this construction until complete fracture healing. It is also possible to build a reliable fixation through this MIS approach. The osteosynthesis obtained
with a polyaxial locking plate is stable enough to keep the reduction until fracture healing is achieved and to start physiotherapy right after surgery. Satisfactory functional results for this procedure can be obtained even in 3-4 part PHF and osteoporosis with the potential benefits of MIS.

References


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