Intramedullary Locking Nail Fixation of Proximal Humerus Fractures: Rationale and Technique

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Introduction

Proximal humerus fractures (PHFs) can be classified in two-, three-, or four-part according to the Neer classification [1]. Approximately 20–50 % of patients with displaced, unstable two-, three-, and four-part PHFs with a vascularized, attached head fragment may benefit from operative management with reduction and internal fixation [2]. Optimal treatment for displaced or unstable two-, three-, and four-part proximal humerus fractures remains controversial [3–8]. Although no stabilization device has attained definitive superiority yet, most experts agree that minimal soft-tissue dissection and adequate fixation strength should be the goals of any internal fixation device [9].

Intramedullary fixation with a locked nail may be an attractive option, compared to locked-plate fixation, as it provides adequate (i.e., equivalent) fixation strength with minimal soft-tissue dissection. The Aequalis IM locking nail (Tornier,

Minneapolis, USA) is an intramedullary stabilization device for proximal humeral fractures, designed specifically to optimize tuberosity-fragment fixation and to provide stable support for the humeral head, improving proximal humeral reconstruction and fixation in osteopenic bone.

The goals of this chapter are (1) to summarize briefly the complications and problems encountered with pinning and plating of proximal humerus fractures; (2) to analyze the common complications and technological problems related to previous conventional IM Nails; (3) to define the rationale and characteristics of the ideal intramedullary (IM) locking nail; (4) to describe the unique features of the design of the Aequalis IM locking nail; (5) to describe the percutaneous guided technique for two-part fractures and (6) the superior mini-open approach for three- and four-part fractures; and finally (7) to report the early functional and radiological results obtained with this new IM locking nail.

Complications and Technological Problems Related to Pining and Plating

Although significant advancements have been made in fixation devices, the ideal fixation technique for proximal humerus fractures remains unclear.

Percutaneous pinning is attractive but does not allow immediate mobilization because of the risk of displacement of the bone fragments (Fig. 5.1).
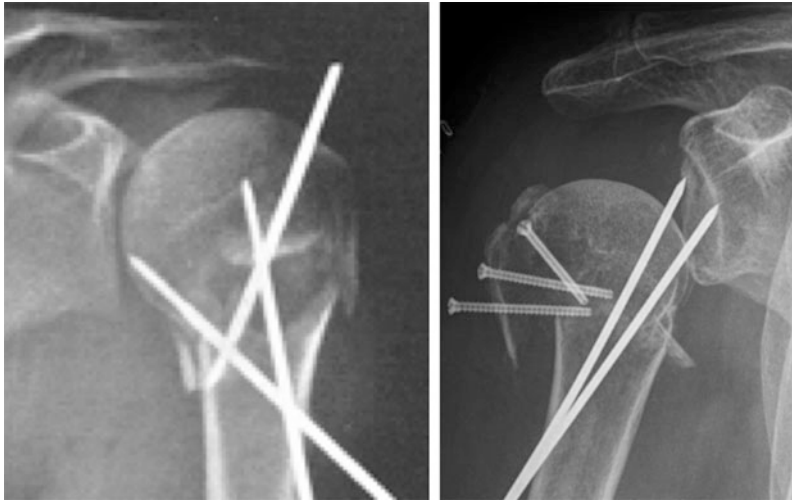
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Fig. 5.1 Insufficient stability of the fixation with pinning and example of early loss of reduction
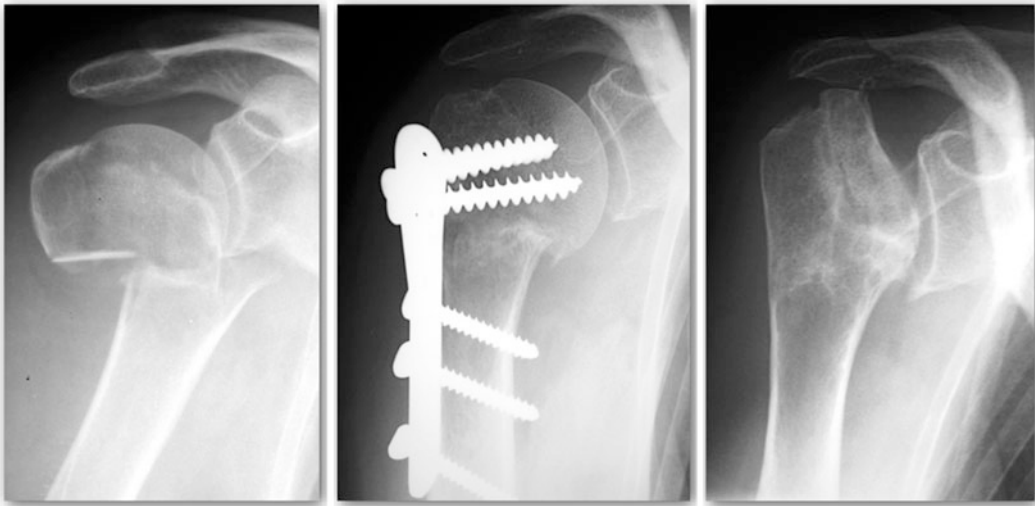

Fig. 5.2 Avascular necrosis of the humeral head after plating

Fixed-angle locked plates are very popular at the moment and have become a kind of "gold standard" for the treatment of PHFs [10]. However, there is some risk of complications, including hardware failure, screw penetration, and loss of reduction [11–15].

In case of two-part fractures, the risk of humeral head necrosis because of additional bone devascularization can occur (Fig. 5.2).

In case of three-and four-part fractures, we feel that locking plates provide inadequate biomechanical fixation because the screws are head-oriented, instead of being tuberosity-oriented. This may lead to what we have called the "unhappy triad after locking plate" which combines (1) humeral head necrosis, (2) loss of reduction and posterior migration of the greater tuberosity (i.e., a massive, retracted posterosuperior rotator cuff tear) because of the inadequate orientation of the screws, and (3) glenoid erosion and destruction because of screw penetration (Fig. 5.3).

Fig. 5.3 "Unhappy" triad: humeral head necrosis, tuberosity migration, glenoid erosion

The catastrophic results after failures of three- and four-part fracture plating have been clearly underestimated. The fact is that a failure after a locking plate burns all the bridges. A revision with hemiarthroplasty is not possible because of glenoid erosion and GT migration. An anatomical TSA is not possible either, for the same reasons, and more specifically because of the posterosuperior cuff insufficiency. The surgeon has to discuss the indication of reverse shoulder arthroplasty (RSA) often in a young patient. Unfortunately, it will be a RSA with poor functional results because of stiffness and absence of external rotator muscles.

Complications and Technological Problems Related to Previous Conventional IM Nails

Some reports on IM nails for displaced proximal humerus fractures have reported a high complication rate of 40 % [16–24] and a high revision rate of up to 45 % [25–29]. Based on our own experience, most of the complications and problems observed with existing IM nails are related to inadequate design of the nail itself, the inadequate orientation of proximal screws,

the absence of locking mechanism for proximal screws and the inadequate accompanying instrumentation.

Iatrogenic rotator cuff tears are seen when surgeons use a lateral entry portal to insert the IM nail, which is unavoidable with a proximally bent IM nail (Fig. 5.4).

The obvious advantage of a straight and low-profile nail is that it can be inserted through the muscular (not the tendinous) part of the supraspinatus and the superior part of the humeral head (not the greater tuberosity and the tendon footprint).

Acromial impingement (secondary to protrusion of the proximal end of the nail) is related to poor instrumentation and use of bended nail (Fig. 5.5). It can be avoided by using a precise and radiolucent instrumentation and a straight nail. Both iatrogenic cuff tears and nail protrusion are sufficient to explain the 20–45 % of postoperative shoulder pain reported in the literature after intramedullary nailing of humeral fractures.

Surgical-neck non-union is related to the unsuitable design of some nails, which are too long and too large distally, leading to premature "locking" through interference inside the distal medullary canal and distraction at the fracture site (Fig. 5.6). This complication can be easily
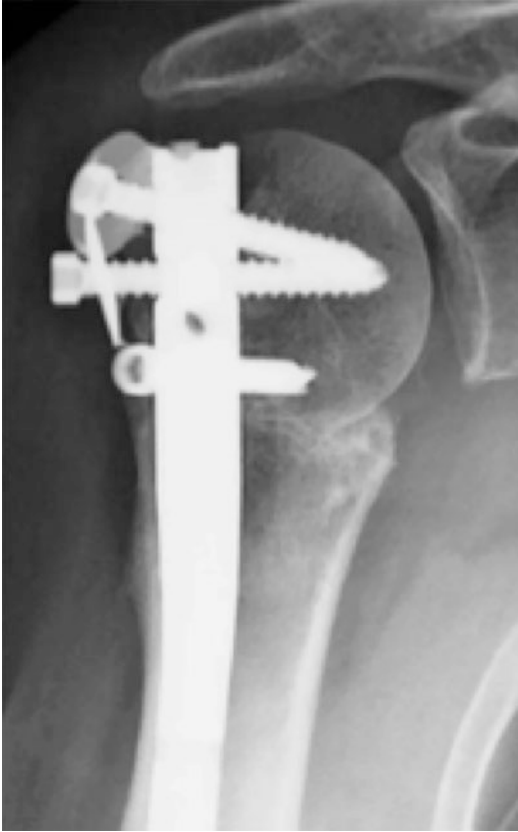
Fig. 5.4 Bent nail and its lateral entry point, leading to cuff tendon injury

Fig. 5.5 Proximal hardware protrusion and associated sub-acromial impingement

avoided by using a short, and small-diameter IM nail (low-profile) and by intraoperative compression of the fracture site.

Surgical-neck malunion in internal rotation is related to the absence of adapted instrumentation to control fracture and nail rotation. The most commonly committed error is to fix the fracture with the arm in internal rotation (the hand on the abdomen), which leads to an internal-rotation malunion of the diaphysis. Control of humeral retroversion and nail rotation is therefore of paramount importance.

Screw backout (and loss of tuberosity reduction) has a reported prevalence of 10–24 % with conventional intramedullary devices (Fig. 5.7). This complication is due to the absence of a locking mechanism for proximal screws: the screws are simply threaded into the interlocking

holes in many IM nails. These conventional IM nails fail as they rely only on screw torque in the bone to provide stabilization (Head-based fixation). The locking technology applied to the proximal screw holes, almost eliminates the possibility of screw backout.

Screw protrusion (and glenoid erosion) is another potentially disastrous complication seen with conventional IM nails (and locking plates) (Fig. 5.8). Again, this complication is related to the fact that the screws are oriented toward the head (Head-based fixation) and consequently toward the glenoid surface. Screw placement into the tuberosities rather than in the humeral head avoids the risk of this complication (Tuberosity-based fixation).

Fig. 5.6 Distraction at the fracture site

Fig. 5.7 Screw backout and loss of reduction

Design of the Aequalis IM Locking Proximal Humerus Nail

Nail toggling and fracture malreduction (Fig. 5.9). Fracture comminution and poor bone quality are not uncommon in elderly patients. This can lead to loss of fracture reduction and fixation. Varus bending represents a frequent physiologic displacement of proximal humerus fractures.

Based on the analysis of these pitfalls, the specifications of the ideal device can be defined (Table 5.1).

The novel design of the Aequalis Proximal Humerus Nail combines unique features that allow a less invasive surgical intervention, maintenance of the vascularization of the fracture fragments, angular stability of proximal fixation, and optimal screw orientation for fixation of the tuberosities.

The design of the Aequalis Proximal Humerus Nail is based on five principles: fixation of the tuberosities, supporting the humeral head, angular-stable locked screws, centering within the medullary canal, and medial articular insertion point (Fig. 5.10).
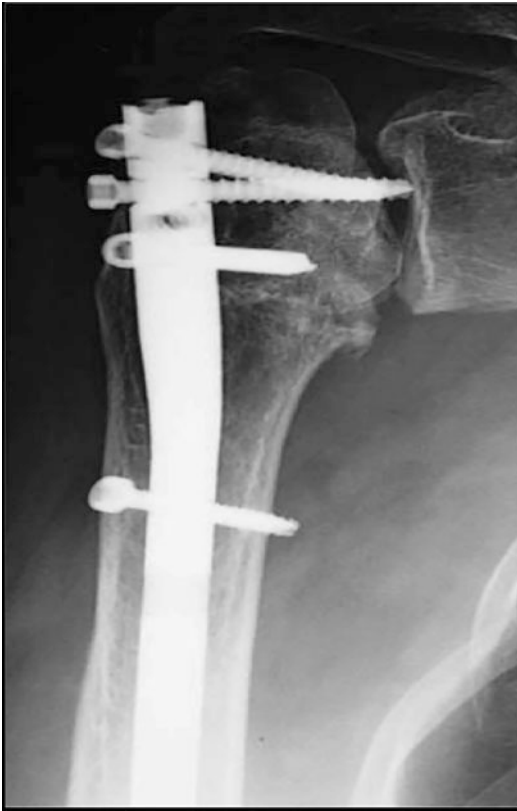
Fig. 5.8 Articular penetration of the screws and glenoid erosion

This straight, cannulated titanium nail, 130 mm long, offers several unique design features that support these five principles. The straight design of the nail avoids insertion through the rotator cuff tendon and reduces the potential for a varus reduction, and cannulation allows for a minimally invasive percutaneous technique. The divergent tuberosity based fixation provides optimum independent fixation of the greater and lesser tuberosities (Fig. 5.11), which also serves to maintain positioning of the humeral head without requiring screws to enter the central humeral head (Fig. 5.12).

The proximal screws are "locked" in the nail via a polyethylene bushing, providing angular stability for tuberosity and humeral head fixation.

Two interlocking screws that are divergent accomplish distal fixation by 20°, which
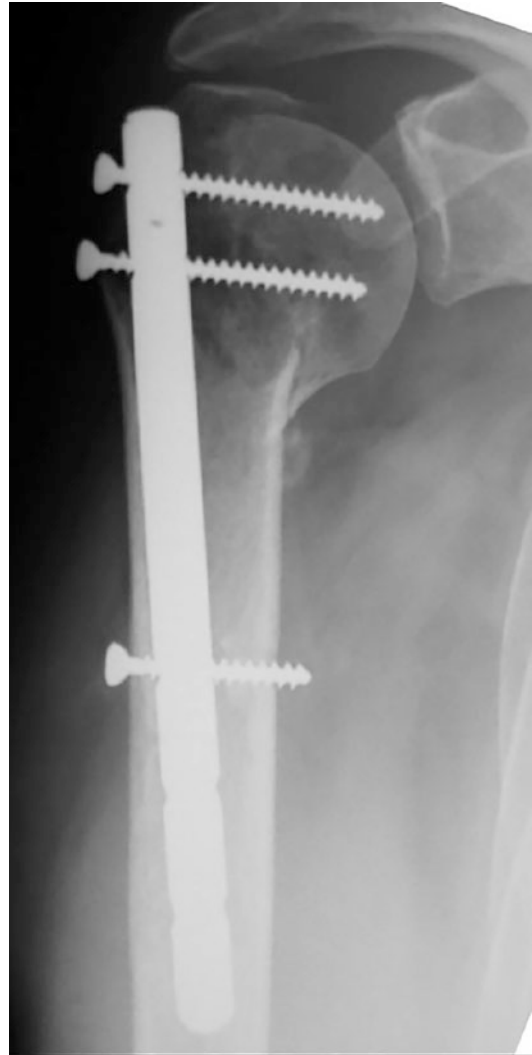

Fig. 5.9 Nail toggling, tuberosity migration, and varus displacement leading to malreduction

minimizes toggle of the nail and allows for distal centering in cases of a large humeral canal.

A radiolucent targeting guide facilitates accurate insertion and positioning of the nail and screws, with easy fluoroscopic visualization.

A version-rod, aligned with the forearm, can help achieve accurate rotational alignment of the proximal (epiphyseal) bone fragment in reference to the diaphysis.

The nail's design and optimal screw orientation must be chosen after extensive study of the three-dimensional morphology and geometry of

Table 5.1 Complications and problems related to existing IM nails, their causes, and possible technologic/design-related solutions

| Complications	Cause	Technologic solution
1. Nail design		
Rotator cuff tendon tears	Bent, large-diameter nail with lateralized entry point	Straight, small-diameter nail for medialized entry point
Iatrogenic greater-tuberosity fracture through entry point	Bent, large-diameter nail with lateralized entry point	Straight, small-diameter nail + awl + reamer to facilitate medialized entry point
Acromial Impingement secondary to nail protrusion	Proud/lateral (bent) nail + poor instrumentation	Straight, low-profile nail with accurate targeting device
Surgical neck non-union	Excessive nail length and size; obligatory distal locking	Shorter nail with fluted distal tip
2. Proximal screws		
Loss of tuberosity reduction and fixation	Poor (*humeral head-based*) screw orientation (=*latero-medial*)	Optimal (*tuberosity-based*) screw orientation (=*posteroanterior*)
	Poor or absent locking mechanism for proximal screws (=*bone-based fixation*)	Secure locking into nail through threaded holes (=*nail-based fixation*)
Proximal-screw loosening and back-out	Unlocked proximal screws (=*bone-based fixation*)	Secure locked proximal screws (=*nail-based fixation*)
Proximal-screw penetration through articular cartilage	Poor screw orientation (latero-medial)	Locking screws with posteroanterior orientation
Axillary nerve damage	Low/oblique proximal-screw positioning	Optimal screw position (high enough, horizontal)
Long-head-of-biceps tendon and bicipital groove damage	Uncontrolled nail rotation = penetration of bicipital groove	Control of nail rotation through instrumentation
3. Distal screw instrumentation		
Nail toggling, fracture displacement, malalignment	Aligned (non-divergent) distal screws	Divergent distal screws allowing nail centering and adding stability
Nail malrotation and surgical neck malunion	Uncontrolled nail and fracture rotation	Specifically designed instrumentation allowing accurate rotational control
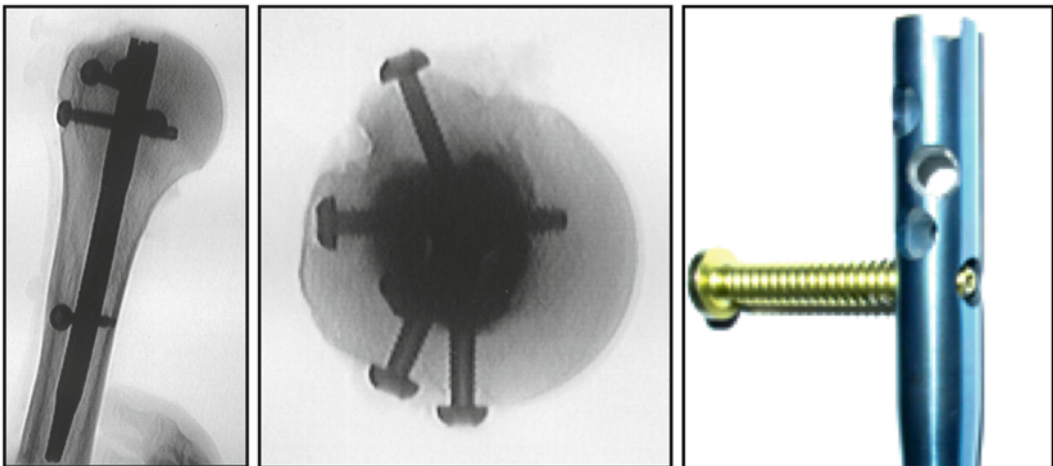
Fig. 5.10 Design of the Aequalis Nail
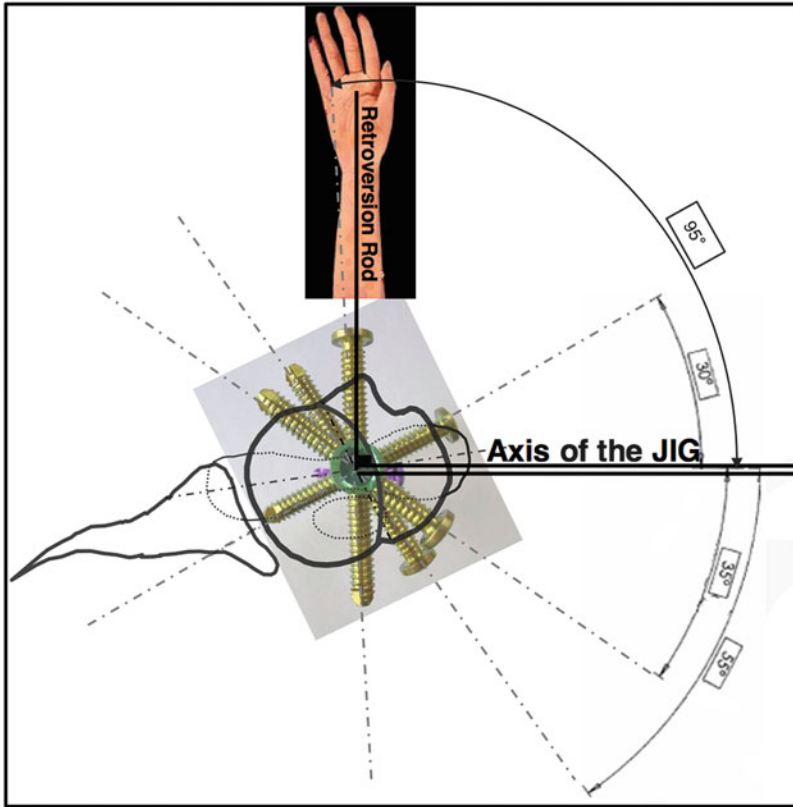
Fig. 5.11 Tuberosity based orientation of the proximal screws

Fig. 5.12 No screw directed towards the head

the proximal humerus [30] and of the pathophysiology of displaced unstable two-, three-, and four-part fractures [31–34].

The nail is indicated for two-, three-, and four-part fractures according to Neer's classification, non-unions, malunions, and impending pathological fractures. The design of the nail and its instrumentation allows effective insertion through an open or percutaneous approach.

Two-Part Surgical Neck Fracture with a Percutaneous Technique

Rationale

In two-part (surgical-neck) fractures, the epiphysis is correctly oriented and has a fixed position, because the internal-rotator and external-rotator

Fig. 5.13 Action of the muscles in case of surgical neck fracture: Adduction and internal rotation of the diaphysis

muscles are still attached and balanced. In other words, the head is facing the glenoid and is stable. The diaphysis is medially displaced (due to the medial pull of the pectoralis major, latissimus dorsi, and teres major) and in internal rotation (because the forearm is usually held against the belly) (Fig. 5.13).

Two main complications are specifically encountered with two-part (surgical neck) fractures, and must be anticipated:

1. *Rotational malunion* which occurs when the nail is locked proximally and distally with the arm in internal rotation; this leads to decreased humeral retroversion and consequently, external rotation. This complication can be avoided by using the outrigger alignment guide as described above.

2. *Surgical neck non-union* that occurs in cases of persistent distraction at the fracture site. This complication can be avoided by using a "backslap technique": consisting in retrograde hammering after first distal locking, which impacts the surgical neck fracture site, preventing non-union.

Percutaneous "Backslap" Technique

In two-part (surgical neck) fractures, the procedure can be performed percutaneously. The starting point is located either anterior or posterior to the acromio-clavicular joint, depending on the displacement of the epiphyseal fragment. The anterior portal is preferred in instances where the epiphyseal fragment is displaced in valgus whereas the posterior location or the "Neviaser" portal is preferred in instances
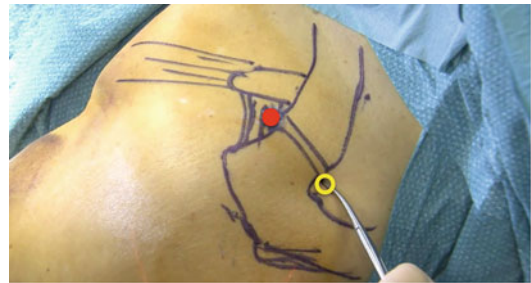

Fig. 5.14 Starting points of the percutaneous approach (left shoulder)

where the epiphyseal fragment has varus angulation (Fig. 5.14).

These entry points avoid the insertion point of the rotator cuff by staying medial to the tendon insertion and passing though the muscle fibers of the supraspinatus. The goal is to enter the humeral head medially and to leave about 5-mm of cartilage lateral. The surgeon must never try to enter the greater tuberosity and should not be afraid to pass through the cartilage of the humeral head: the hole in the cartilage will be filled with fibrous tissue and there is no functional consequence.

After location of the starting point under fluoroscopy with a spinal needle, an incision is made which is large enough (about 8-mm) to allow passage of the humeral nail. A blunt Kelly forceps is used to spread the muscle fibers down to the humeral head (Fig. 5.15).

A specific cannulated awl is then introduced into the incision and with a twisting motion and downward pressure advanced into the humeral head. The awl can then be used to manipulate the head fragment and allow for the passage of

Fig. 5.15 Control of the location under fluoroscopy. Patient positioning should allow access of the C-arm to obtain adequate radiographs
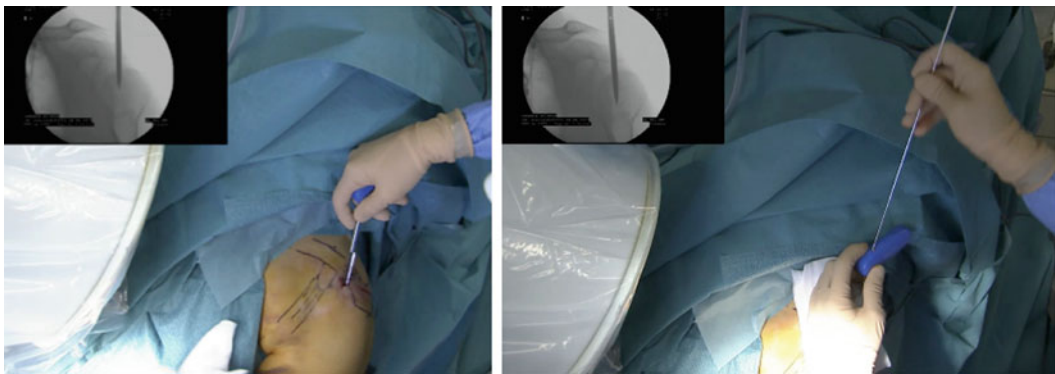

Fig. 5.16 Insertion of the guide wire through the awl

the guide-wire. It is crucial that the entry point for the nail is medial enough and enters the cartilage and not the greater tuberosity and the supraspinatus insertion. The guide wire is inserted through the awl and image intensification is used to confirm the awl and guide-wire position in the humeral head and the distal humerus (Fig. 5.16). The cannulated reamer is used to open the proximal portion of the bone and the nail is inserted with the attached targeting jig.

The Aequalis IM nail, which is cannulated, is introduced percutaneously, along the guide-wire first through the epiphysis and then through the diaphysis. The depth of the nail is confirmed under fluoroscopy utilizing a K-wire placed through the lateral side of the jig. The nail is inserted somewhat more deep (2 or 3 mm) to allow for backslapping and compression. The

K-wire should be at the level of the top of the GT, slightly below the level of the head to ensure the proper depth (Fig. 5.17).

At this stage, the diaphysis is still independent of, and can be rotated around, the epiphyseal fragment. The patient's arm must then be brought in neutral rotation to help with rotational alignment: this allows for the correct rotation of the diaphysis relative to the humeral head, which is again confirmed under fluoroscopy. A version rod "outrigger" is attached and aligned with the supinated forearm: this allows for the correct rotation of the nail inside the humerus, and consequently the correct orientation of the proximal and distal screws.

The first distal trocar for the static screw is then introduced and drilled with a calibrated drill. The correct screw placement is confirmed under fluoroscopy (Fig. 5.18). The second distal
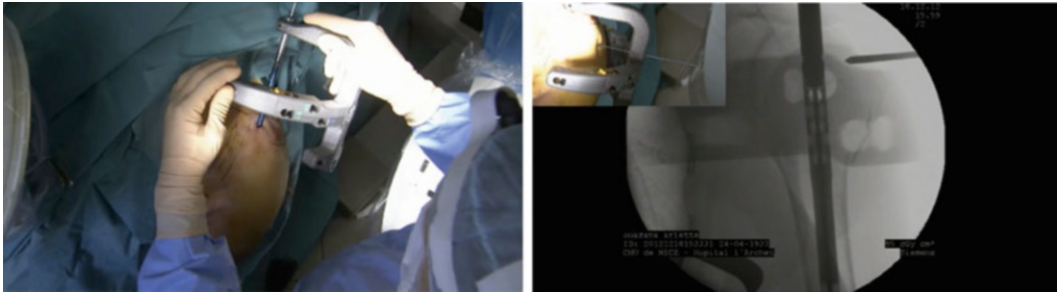
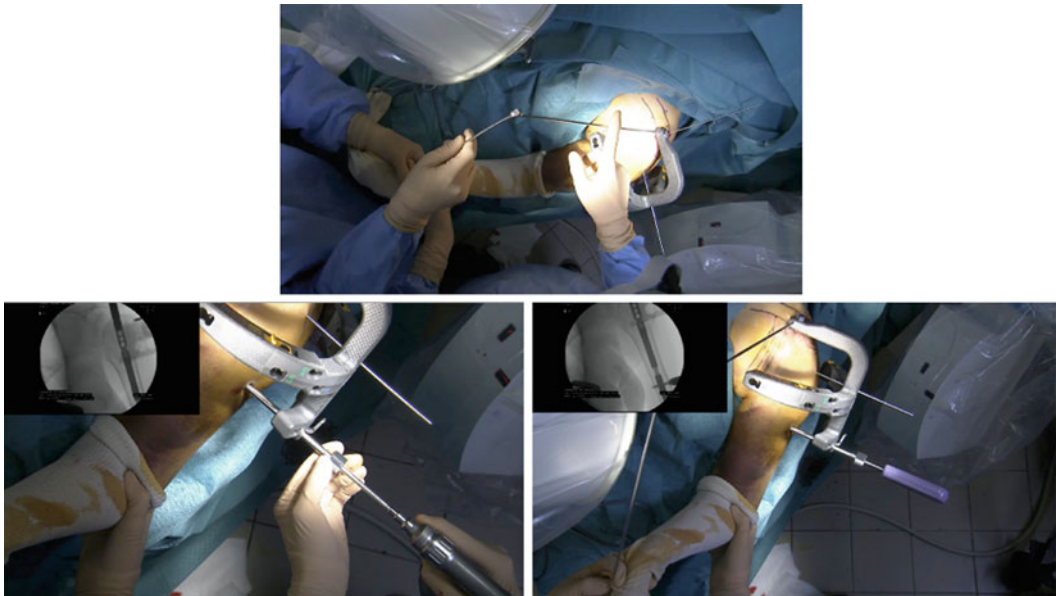**Fig. 5.17** Introduction of the nail and assessment of its depth

Fig. 5.18 As in the four-part fracture, the diaphysis can be rotated around the head fragment. In order to obtain the correct reduction the version outrigger is attached and aligned with a supinated forearm. This allows for the correct position of the diaphysis relative to the metaphysis, which can be confirmed under fluoroscopy. The distal trocar is then introduced, drilled with a calibrated drill and the correct screw placed through the trocar and length confirmed again under image intensification

screw ensures that the nail is centered within the diaphysis. The distal screws are small (3.5-mm) in diameter and their length is usually 22 or 24-mm. Following screw placement distally, the slap hammer can be attached to the nail and by "backing the nail out" utilized to compress the fracture fragments. The slot in the guide should be flushed with the top of the humeral head: this allows for confirming that the nail is at the right height. Fluoroscopy is used to confirm compression at the fracture site and correct height positioning. The outrigger ensures correct rotation is maintained during compression (Fig. 5.19).

Next, the tuberosity screws are placed superiorly to lock the distal and proximal bone fragments in the correct orientation. A similar approach is used superiorly by placing trocars through the guide-sleeves followed by drilling, screw placement and confirmation via
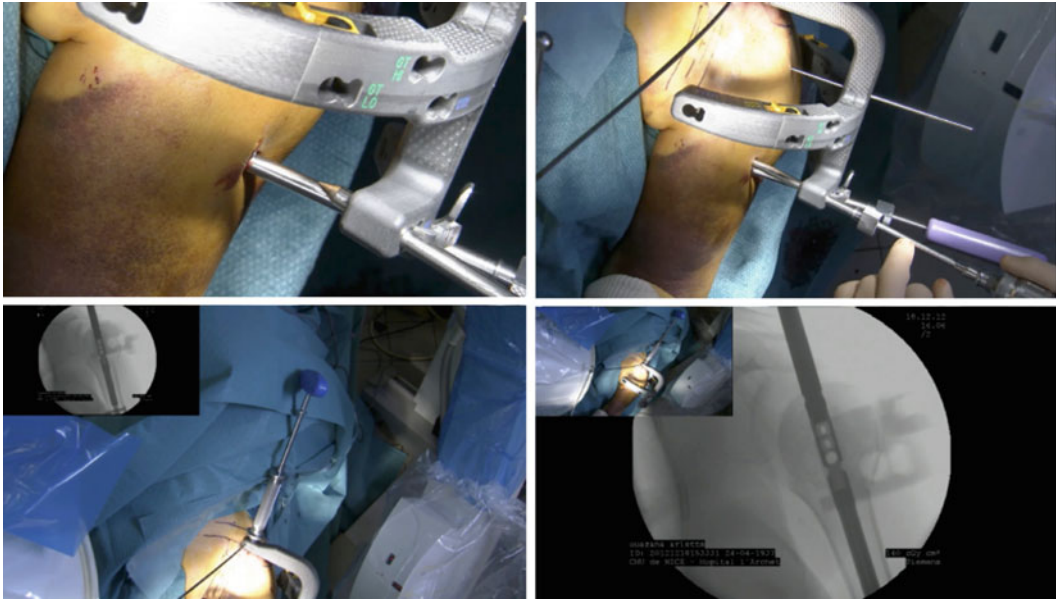
Fig. 5.19 The second screw is placed centralizing the nail in the diaphysis. The slap hammer is applied and utilized to compress the fracture fragments. The top of the slot should be level with the top of the humeral head and fluoroscopy used to confirm compression at the fracture site
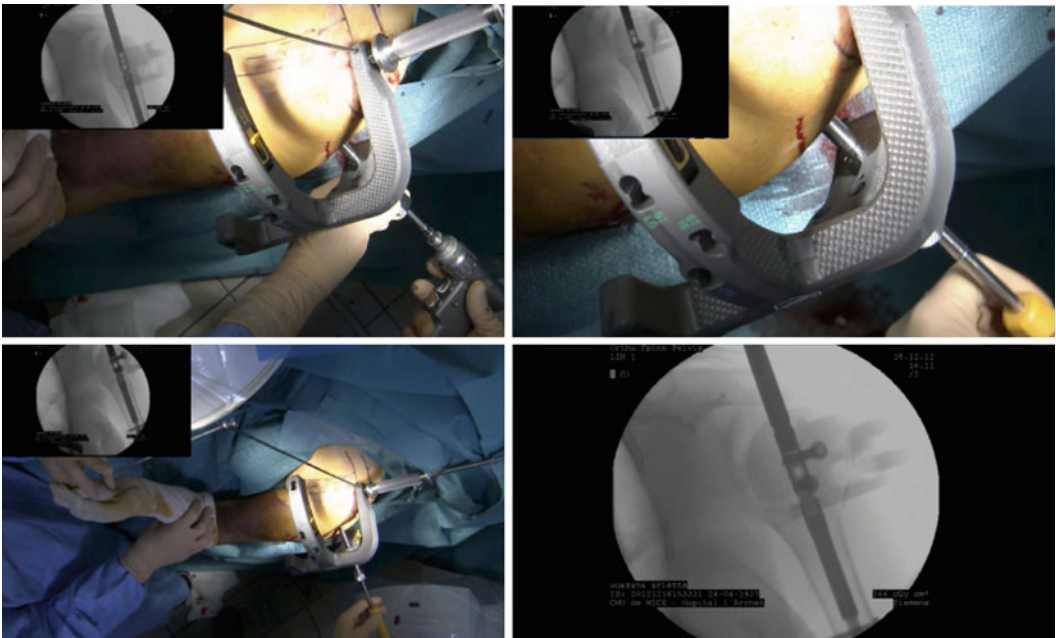

Fig. 5.20 Proximal locking

fluoroscopy. The version rod is again used to ensure the distal segment does not shift relative to the proximal segment, but once a single screw is placed, the rotation is locked at this point. The fluoroscopic images again confirm correct screw placement (Fig. 5.20).
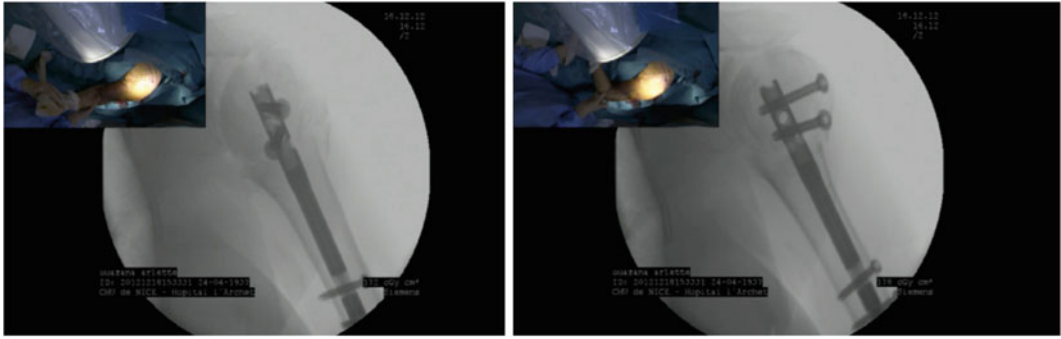
Fig. 5.21 The final fluoroscopic images confirm excellent compression and appropriate rotation of the entire humerus with external and internal rotation images or "live" fluoroscopy

The proximal guide is removed and the final fluoroscopic images are made to confirm the compression and appropriate rotation of the entire humerus with external and internal rotation images. These can be done under "live" fluoroscopy (Fig. 5.21). The skin is closed routinely.

Pearls and Pitfalls

In a two-part (surgical neck) fracture, two screws are inserted proximally (one in the GT and one in the LT) and two distally in the diaphysis. However, two screws only (one proximal and one distal) may be enough for a two-part fracture. We do not recommend dynamic distal fixation of the nail because the upper limb is subjected to more distraction rather than compression forces (as the femur or tibia). This may, in part, explain the rate of non-union after surgical neck fracture. We recommend *static distal fixation*: the distal screw(s) placement in the diaphysis first, followed by backslapping to impact the fracture site at the surgical neck, and then proximal fixation of the epiphysis. This technique allows for immediate compression of the fracture site, thus avoiding nonunion. The rotational control provided by the outrigger version rod allows for avoiding rotational malunion. Finally, the surgeon must understand that the proximal screws are locked by insertion through a polyethylene bushing located inside the nail, thus avoiding a possible screw backout. This locking technology

applied to the nail means that there is no need to catch the bone with long proximal screws: short (32 or 36-mm) screws are long enough since they are captured inside the nail. The metallic cannulas must be in contact with the bone: this ensures that the screws will follow the right direction (entering the holes of the nail) and will have the correct length. Each screw must be tightened until the slot of the screwdriver is flush with the entry of the metallic cannula.

In case of three-part GT fracture, the head fragment is internally rotated by the pulling of the subscapularis muscle. The main goal must be to derotate and anatomically reduce and fix the GT, which will effectively convert the three-part fracture into a two-part fracture. The "derotation" technique can be accomplished before or after nail insertion. The reduction is maintained by a bone hook inserted percutaneously or through a small transdeltoid incision.

Four-Part Fracture with a Superior Transdeltoid Technique

Rationale

In unstable three- and four-part fractures, displacement occurs because of the pull of the rotator cuff muscles on their attached tuberosities in the transverse plane, widening the gap created by the fracture plane posterior to the bicipital groove. In addition, there is internal rotation
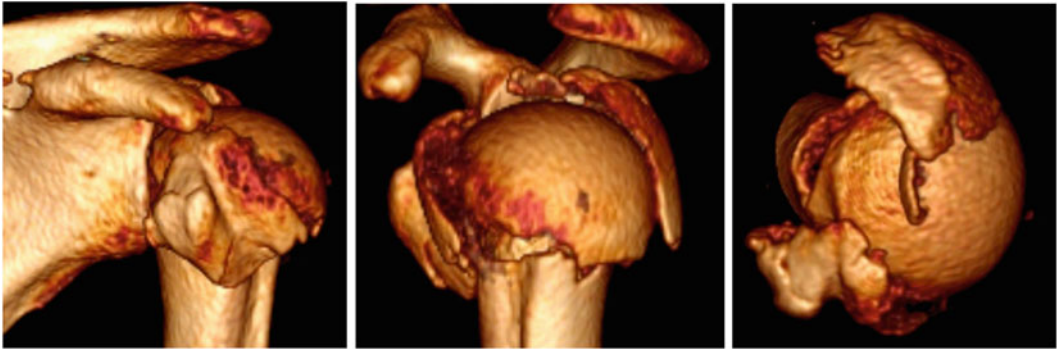
Fig. 5.22 3D CT-Scan showing the characteristic displacement of the tuberosities


Fig. 5.23 Plain radiographs, CT and CT with 3D reconstruction of a valgus impacted four-part fracture. Note the fracture line is posterior to the bicipital groove for the GT fracture

and/or translation of the diaphysis, like in two-part (surgical neck) fractures. The GT is pulled posteromedially by the infraspinatus and teres minor muscles, while the lesser tuberosity (LT) is pulled anteromedially by the subscapularis muscle (Fig. 5.22).

In four-part proximal humerus fractures, it has been demonstrated that the main vertical fracture plane separating the tuberosities is located posterior to the bicipital groove, and that the principal displacement of the fractured tuberosities occurs in the transverse (horizontal) plane [34] (Fig. 5.23).

In fractures involving the greater tuberosity, loss of reduction and fixation of the greater tuberosity leads to definitive retraction and atrophy of the two single external rotator muscles of the shoulder (infraspinatus and teres minor), resulting in definitive pseudo-paralyzed and stiff shoulder for which surgical options are limited. By contrast, posttraumatic humeral head necrosis is well tolerated if the greater tuberosity has healed in an anatomical position and there is no screw penetration or glenoid erosion. Thus, all efforts of the surgeon should not be directed toward the humeral head, but to the greater

Fig. 5.24 Landmarks and skin incision for a superior transdeltoid approach have been drawn out. A saber incision in line with Langer's lines is made (*red arc*). It is centered over the division between the anterior and middle deltoid (*green line*). The *blue arrow* is the site of the acromial osteotomy, which facilitates the deltoid repair at the end of the case
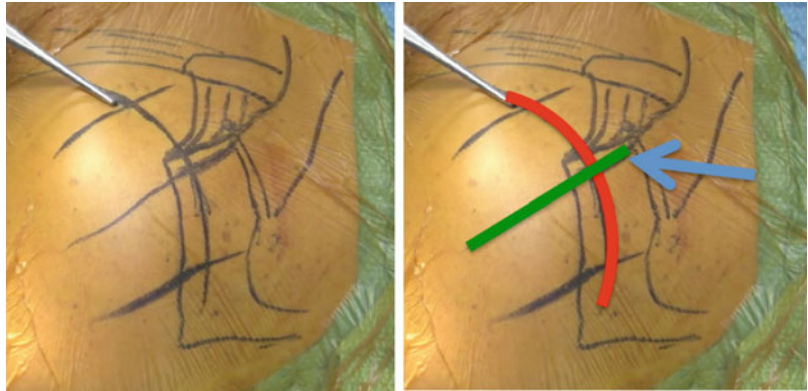
tuberosity fixation and reduction. The humeral head becomes stable when both tuberosities are reduced and fixed. The Aequalis Locking IM nail has been designed specifically to optimize tuberosity-fragment fixation and provide stable support for the humeral head, improving proximal humerus reconstruction and fixation in osteopenic bone. The design of the nail and the specific technique have been created to avoid the common complications and problems related to previous IM nailing of proximal humeral fractures.

Superior Transdeltoid Approach

A saber cut incision in line with Langer's lines is planned and created to expose the division of the anterior and middle deltoid (Fig. 5.24).

This division is found just lateral to the anterior edge of the acromion. A split is made between the anterior and middle deltoid fibers with the arm in slight abduction to help relax the deltoid. The saw is used to create an osteotomy of the anterior acromion, which will allow exposure for nail entry and facilitate later repair. The osteotomy is completed with an osteotome. The deltoid is split no more than 4 cm from the acromion to avoid injury to the axillary nerve. The saber incision helps to avoid splitting the deltoid to distally to prevent this from happening. Gelpy self-retaining retractors help to facilitate the exposure (Fig. 5.25).

A curved Hohman retractor is placed over the coracoid to help gain exposure for bursal resection. The bursa is excised to expose the greater tuberosity (GT), lesser tuberosity (LT), and head fracture fragments. Great care is taken to stay below the deltoid fascia to avoid injury to any branches of the axillary nerve (Fig. 5.26).

The vertical fracture (separating the tuberosities) is identified and then the fibers of the rotator cuff can be incised longitudinally to expose the head fragment if needed (Fig. 5.27).

The biceps tendon is identified and tenodesed to the overlying soft tissue. The biceps tendon may be entrapped within the fracture fragments. Stay sutures help to facilitate retraction of the cuff split to permit exposure and reduction of the fracture (Fig. 5.28).

Alternatively, a "mini-open" transdeltoid approach (allowing for tuberosity and head reduction) can be combined with a small medial incision (in front of the AC joint) for nail insertion.

Reduction and Temporary Fixation of the Epiphyseal Fragments

The goal is to transform the four-part fracture into a two-part fracture: this means to first reduce the head fragment with the tuberosities, and second to reduce and fix the epiphysis with the diaphysis. The head fragment must be elevated out of valgus. This is accomplished by freeing up the fracture fragments with a Steinmann pin or
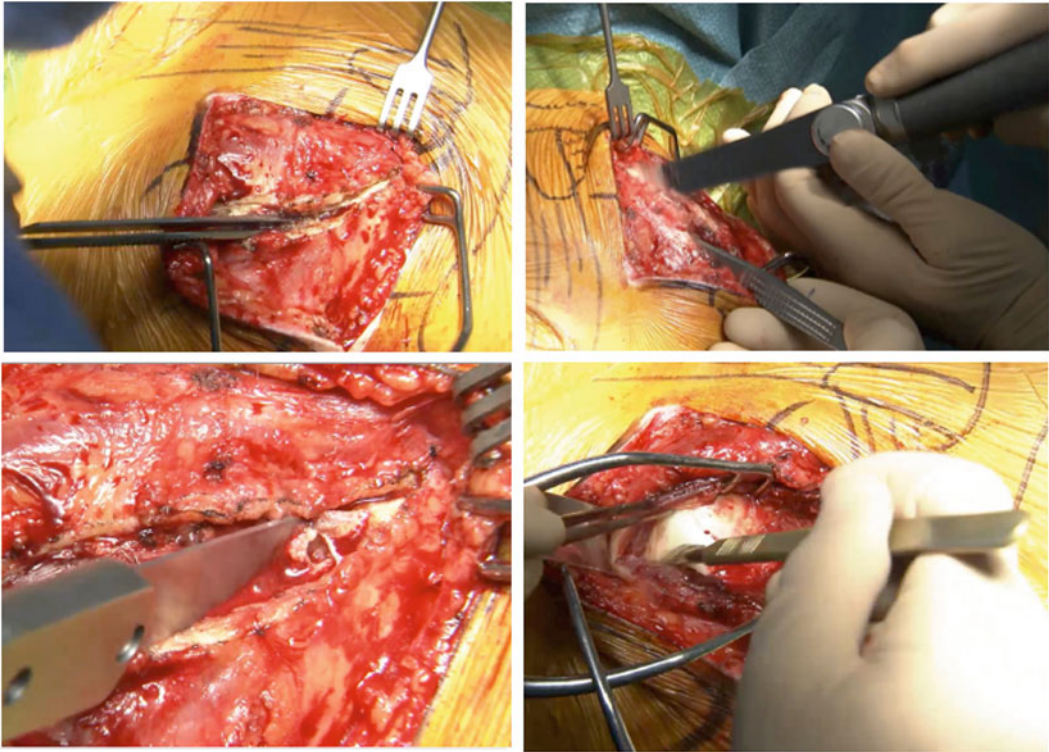
Fig. 5.25 A split is made between the anterior and middle deltoid fibers. A saw and then osteotome is used to osteotomize the anterior acromion to facilitate later repair. The deltoid is split no more than 4 cm from the acromion to avoid injury to the axillary nerve
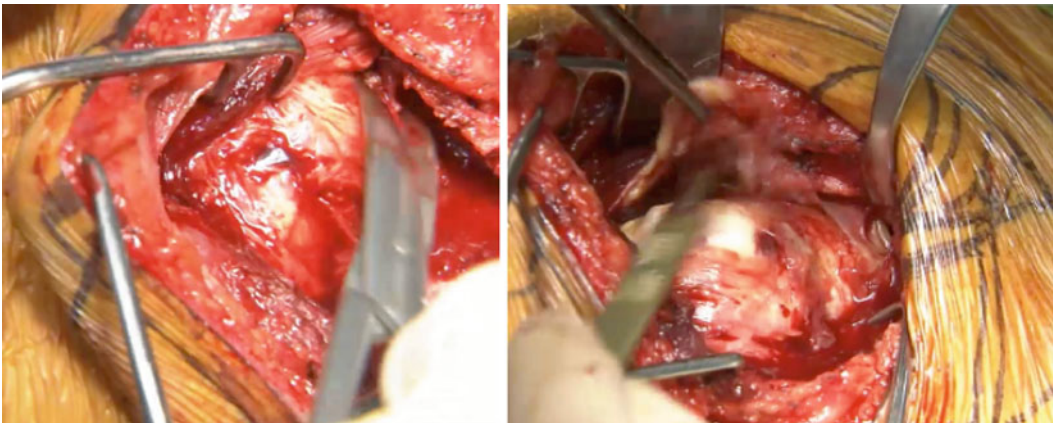

Fig. 5.26 Bursal adhesions are removed to facilitate exposure of the fracture. One must dissect below the deltoid fascia in order to avoid injury to branches of the axillary nerve

similar elevator. The humeral head can then be elevated out of its valgus position with an impactor (Fig. 5.29).

Next the "book" can be closed with the previous sutures placed through the Supraspinatus and Subscapularis, as the GT and LT are brought
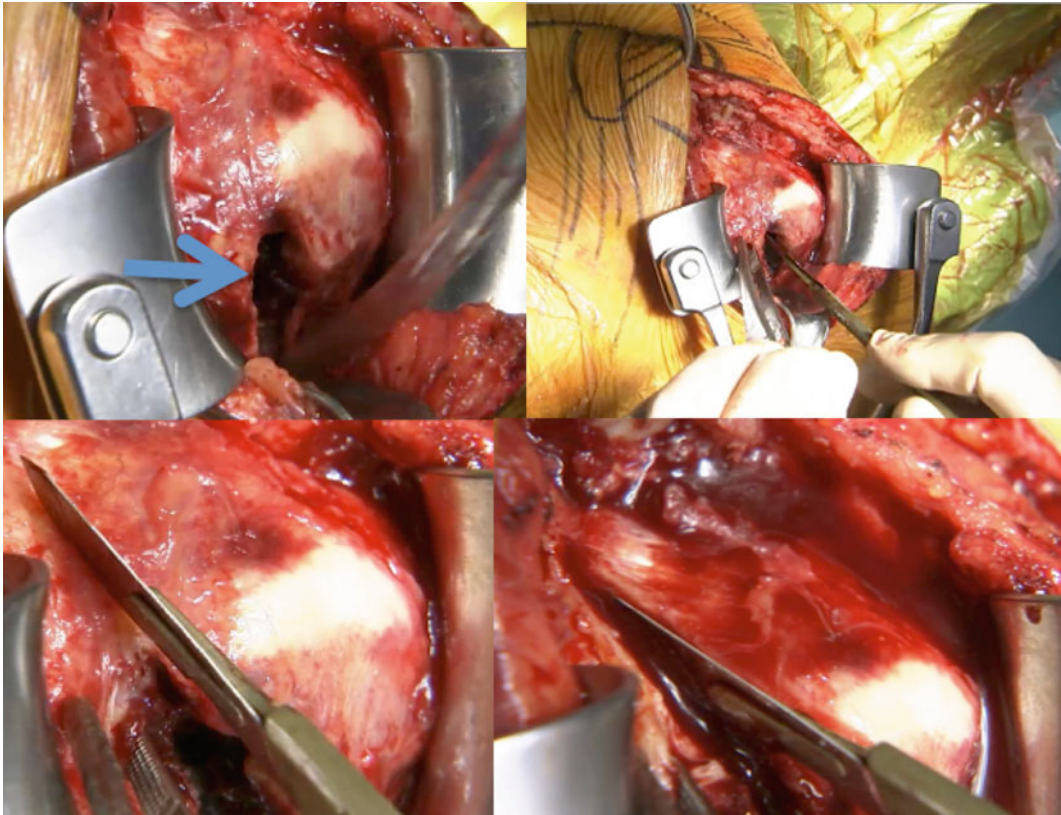
Fig. 5.27 The fracture is identified by the *blue arrow*, after bursa has been removed. The fibers of the RC are split longitudinally. Fracture hematoma is expressed from the joint upon entry

together supporting the humeral head reduction. The reduction of the fracture fragments is palpated with a forceps to confirm fracture lines have been opposed. The reduction is held with a pointed reduction forceps. Next, a small (2 mm) pin is introduced into the humeral head posterior to the eventual path of the nail, but allowing stabilization of the reduction of the head to the glenoid (Fig. 5.30).

Insertion of the IM Nail

The cannulated awl can then be introduced into the humeral head with a twisting motion straight in line with the humeral shaft. The entry point is just posterior to the bicipital groove and medial to the insertion of the rotator cuff. Again, about 5-mm of cartilage should be left lateral to the

hole made for insertion of the nail. This hole in the cartilage does not articulate with the humeral head and allows preservation of the rotator cuff insertion. After the awl is introduced, the guide-wire can be placed and correct positioning confirmed with fluoroscopy (Fig. 5.31). The awl is removed and the humeral head reamed to accept the nail. The reamer is only used to expand the proximal humerus for the proximal portion of the nail.

Control of Height and Rotation of the Nail

The nail is introduced with the jig and seated to the etch mark on the guide which will seat the nail slightly over the top of the humeral head. A pin is inserted into the lateral side of the jig to
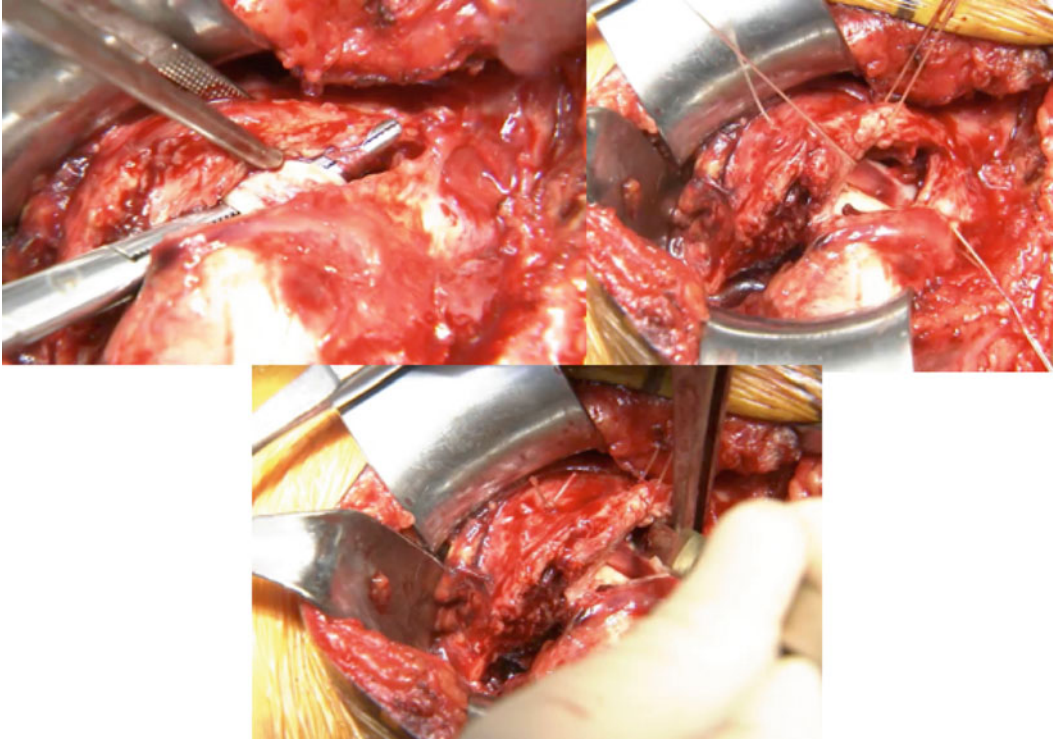
Fig. 5.28 The biceps tendon is identified and tenodesed to the overlying soft tissue. Stay sutures help to facilitate retraction of the cuff split to permit exposure and reduction of the fracture

ensure the proper depth of insertion, which is also confirmed under fluoroscopy (Fig. 5.32). The top of the nail is located below the articular cartilage. The version of the humeral head and its position relative to the tuberosities must be checked. This is uniquely accomplished with this particular system with an outrigger attachment that is aligned to the forearm. Thus, the arm must be placed in neutral rotation and the version rod aligned with the forearm.

Definitive Fixation of the Epiphyseal Fragments

With the version rod aligned with the forearm (Fig. 5.33), the proximal GT screws can be placed. Again the trocars are inserted through the guide-sleeves and advanced to the cortex. By applying pressure to the outermost trocar

(the trocar nearest the guide) the inner trocars can be seen to "back out" as they are advanced against the cortex. This ensures the drill sleeve is directly against the bone. The outer cortex is then drilled. There is no need to drill the inner cortex as the screws are captured within the locking mechanism of the nail. This ensures that the screws will not penetrate the head errantly. When the drill is advanced past the nail it is replaced with the appropriate sized screw. As the screw is advanced through the nail, the polyethylene locking mechanism can be felt to engage the screw.

The two locking screws are placed in the GT. The LT locking screw is then placed proximally in a similar manner to complete the construct (Fig. 5.34). A fourth additional locking screw can be added at the calcar level to stabilize the humeral head medially if needed. We rarely use this fourth screw.
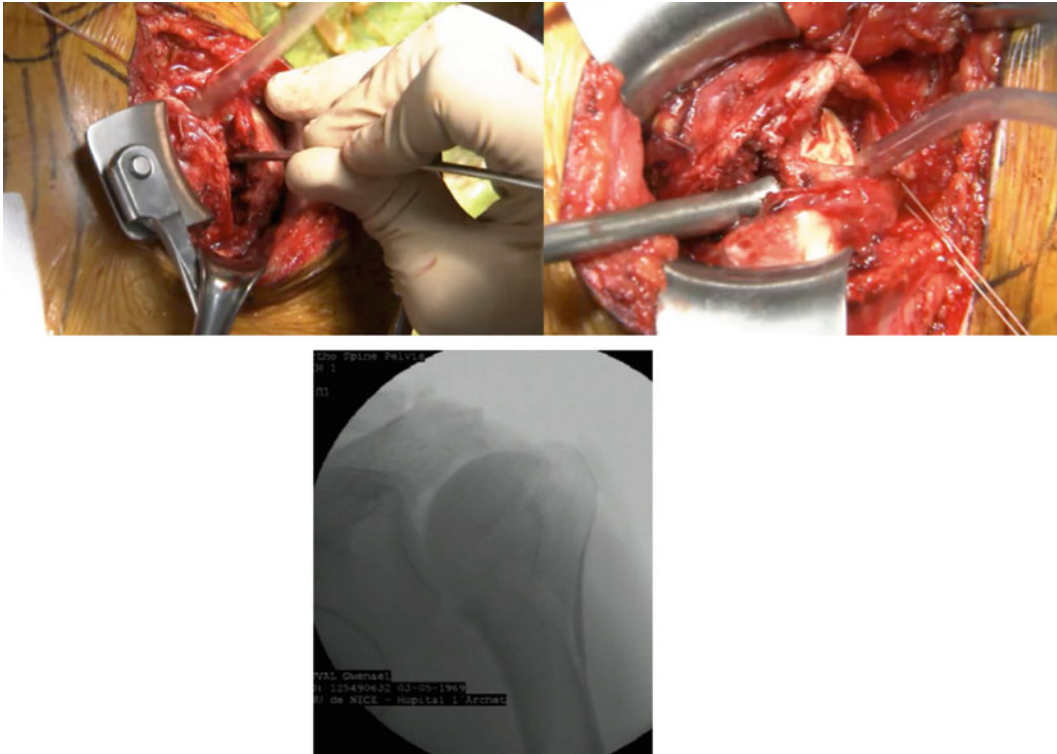
Fig. 5.29 A Steinmann pin is introduced through the fracture site to free up the fracture fragments and allow reduction of the humeral head. An impactor can be introduced into the fracture to further facilitate this reduction. Image intensification is used to confirm reduction

Reduction of the Epiphysis with the Diaphysis

At this point, the three proximal fragments are reduced and fixed to the nail with the locking screws, and the distal screws can be inserted to secure the nail within the intramedullary canal. This will lock the nail in its correct orientation within the medullary canal. A calibrated drill is inserted through trocars that are inserted into the guide, which ensures correct targeting and position of the screws and avoids injury to neurovascular structures. The near cortex is drilled and far cortex can be palpated by tapping the drill. The drill is measured after penetration of the lateral cortex. The correct length screw is then inserted through the trocar and screwed in place. The second distal (diaphyseal) screw is then placed in a similar manner, allowing for centering of the nail in the medullary canal (Fig. 5.35).

Final Control and Closure

The arm is internally and externally rotated and screw position is confirmed with fluoroscopy. During live fluoroscopy, the humeral head can be seen moving in rotation with the rest of the humerus despite the fact that there is no screw directed toward the head (Fig. 5.36). The humeral head fragment is stable because first, the nail acts as a strut, and second the reduced tuberosities provide a "seating surface" for the head. In addition, the reduced rotator cuff tendons and muscles entrap the head inside the glenohumeral joint.

Finally, the split in the rotator cuff is repaired with side-to-side sutures. The hole in the humeral head will be covered with fibrocartilage and will not articulate with the glenoid. The acromial osteotomy and deltoid split are then repaired and the skin closed routinely (Fig. 5.37).
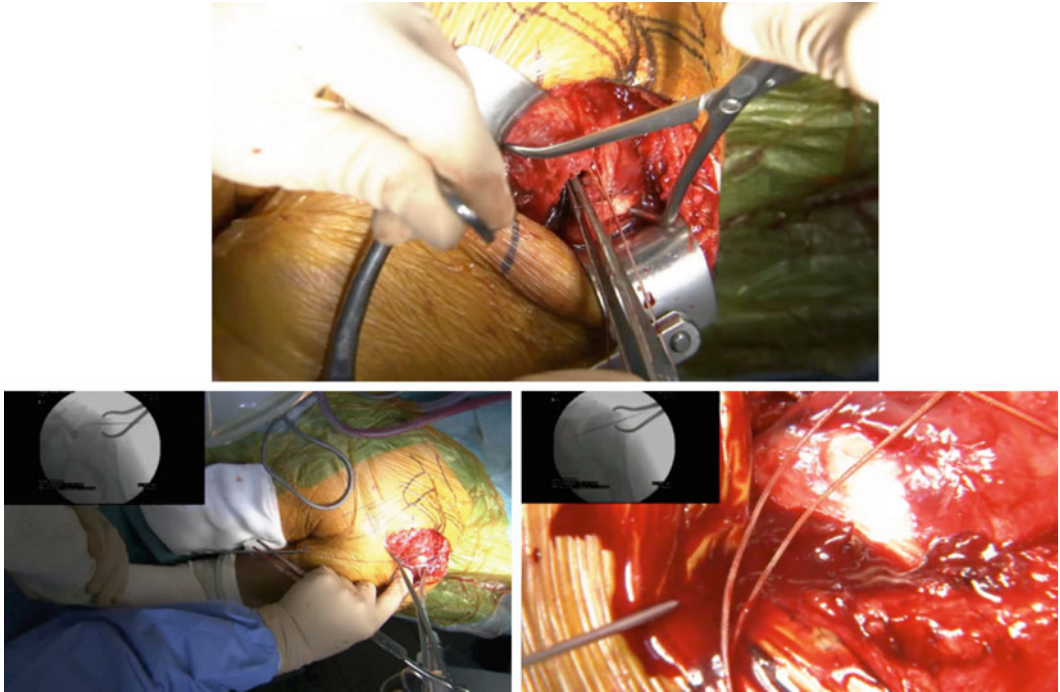
Fig. 5.30 The "book" of the GT and LT are closed over the humeral head with a pointed reduction forceps. The forceps is in line with the fracture fragments and confirms the fracture lines have been closed. A pin is introduced into the humeral head posterior to the path of the nail, but allowing stabilization of the reduction of the head to the glenoid
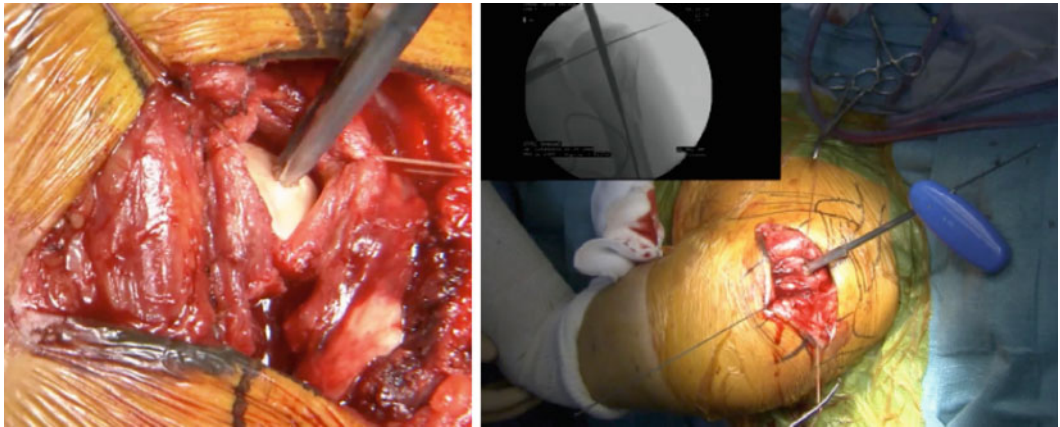

Fig. 5.31 The awl is introduced into the humeral head with a twisting motion straight in line with the humeral shaft and the guide wire introduced through the awl into the shaft. This is confirmed with fluoroscopy
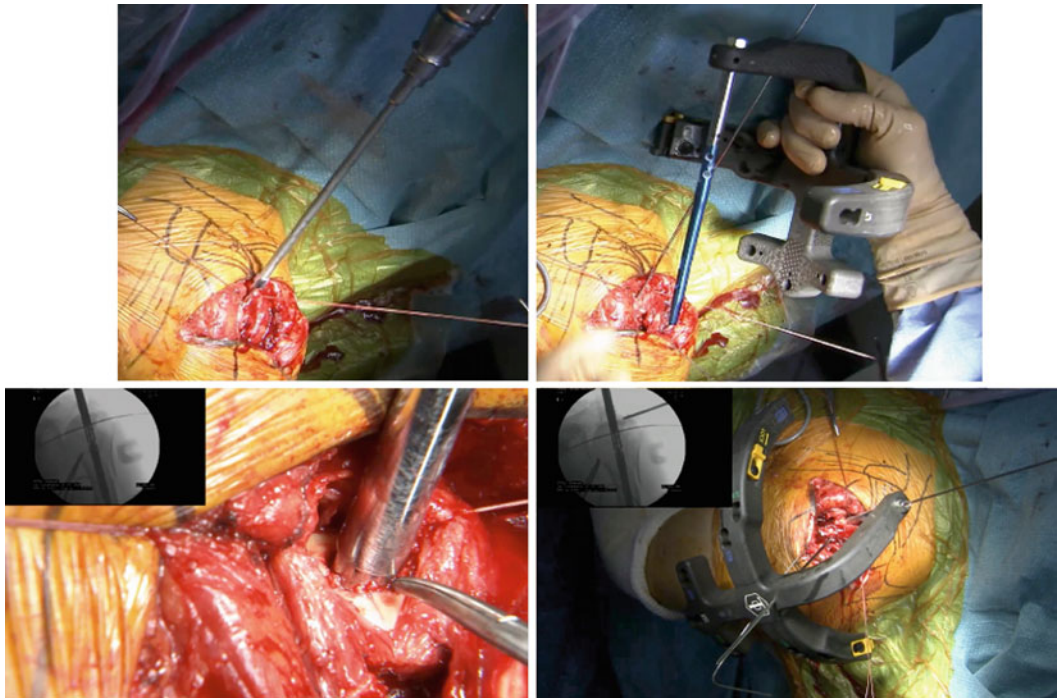
Fig. 5.32 The awl is removed and the humeral head reamed to accept the nail. The nail is introduced and seated to the etched mark on the guide which will seat the nail below the humeral head. A pin is inserted into the lateral side of the jig to ensure the proper depth of insertion which is confirmed under fluoroscopy
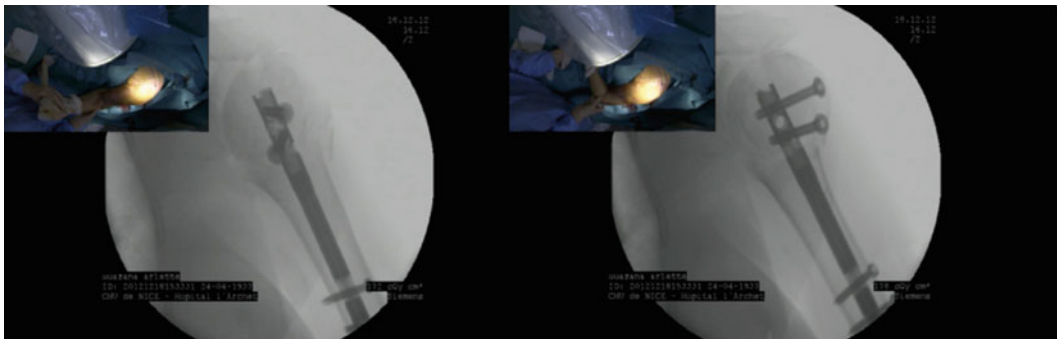

Fig. 5.33 The version of the humeral head is checked with the outrigger attachment which is placed parallel to the forearm. This will ensure correct version of the nail to the humeral head and tuberosities

Postoperative Care

Sling with abduction pillow that allows the proximal humerus to rest in neutral rotation and slight abduction (relax the rotator cuff and decrease tension on the greater tuberosity) and is worn for 3–4 weeks. Gentle pendulum shoulder exercises as well as mobilization of the elbow, wrist, and fingers are started immediately. External rotation of the shoulder with the arm at side and internal rotation with the hand in the back by a physiotherapist are prohibited for 6–8 weeks postoperatively.
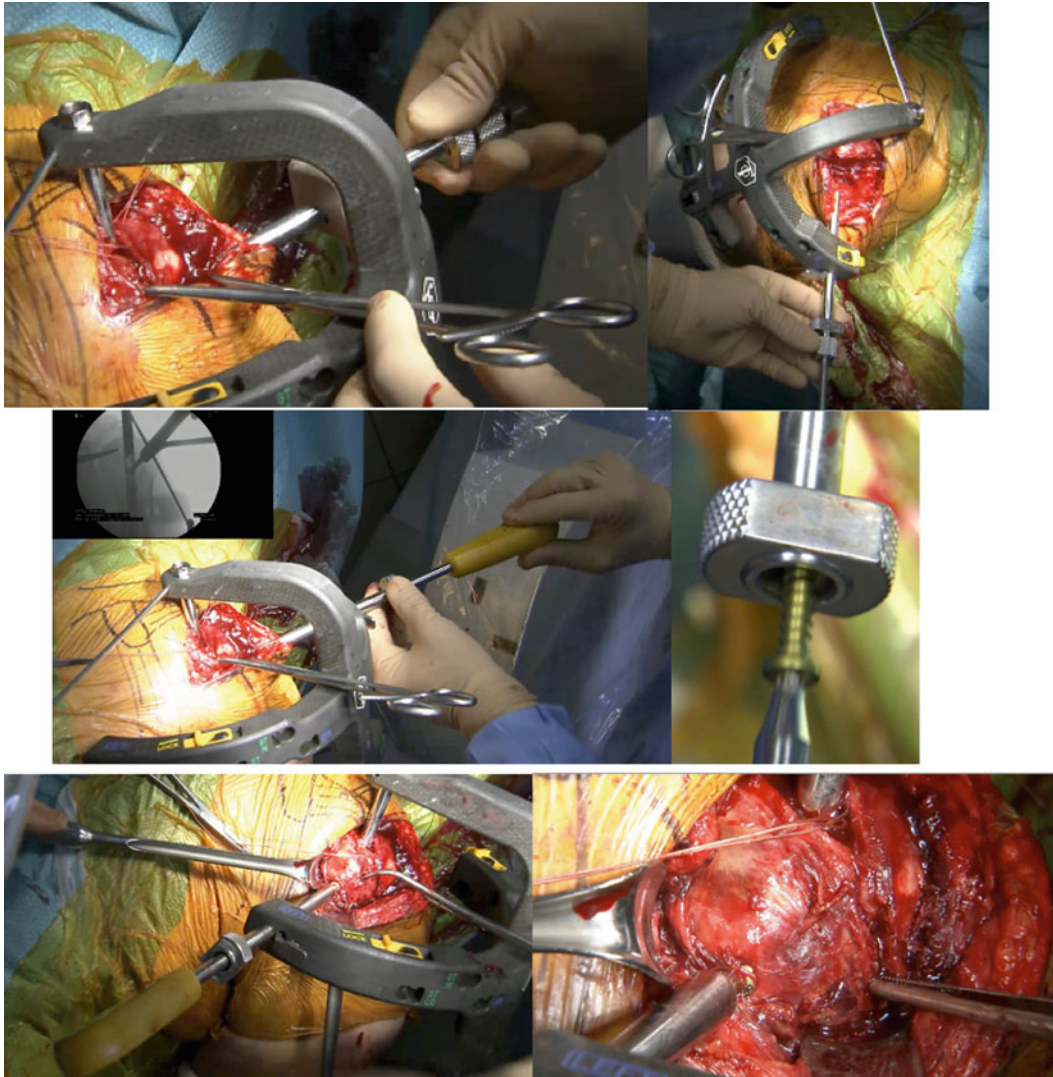
Fig. 5.34 The GT screws are then placed proximally. These are again advanced through the trocars. The skin incision can be retracted to avoid placing an additional incision on the skin. The anterior cortex is drilled and the screw inserted through the trocar. The LT screw is then placed proximally

Results of the Aequalis IM Locking Proximal Humerus Nail

Between 2008 and 2013, 94 patients with acute displaced Neer two-, three-, or four-part proximal humerus fractures were treated with the Aequalis IM locked nailing. Of these 94 patients, 90 patients were successfully prospectively followed for an average of 12 months (6–31 months) to obtain clinical and radiographic outcomes. Three patients had bilateral fractures, resulting in 97 proximal humeral fractures included in this analysis group. Fifty-two females and 38 males were included in the study, with a mean age of 58 years (17–86).

According to the Neer fracture classification criteria, 44 fractures were two-part surgical neck fractures, and 1 two-part fracture dislocation, 30 fractures were three-part fractures, 1 of which had a humeral head split, and 15 fractures were four-part, 3 of them were fracture-dislocations.
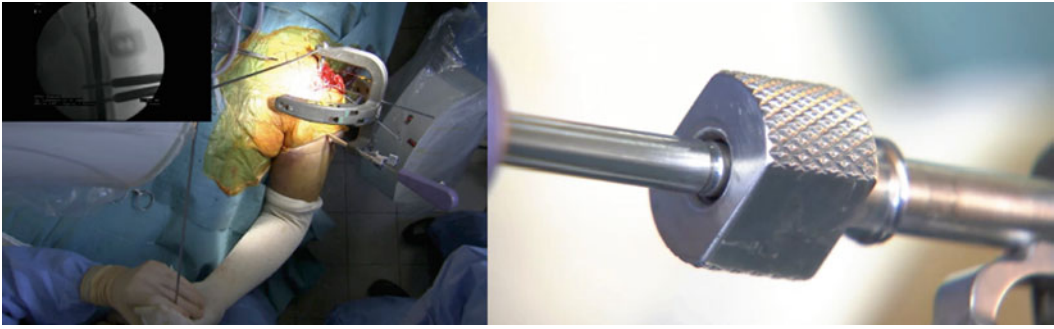
Fig. 5.35 The distal screws are inserted to secure the nail within the intramedullary canal. The calibrated drill is inserted through the guide and depth measured after penetration of the lateral cortex. The drill is advanced with a tapping motion to "feel" the opposite cortex prior to penetration to ensure accurate measurement. The correct length screw is then inserted through the trocar. Again there is an etch line to ensure the proper depth of insertion
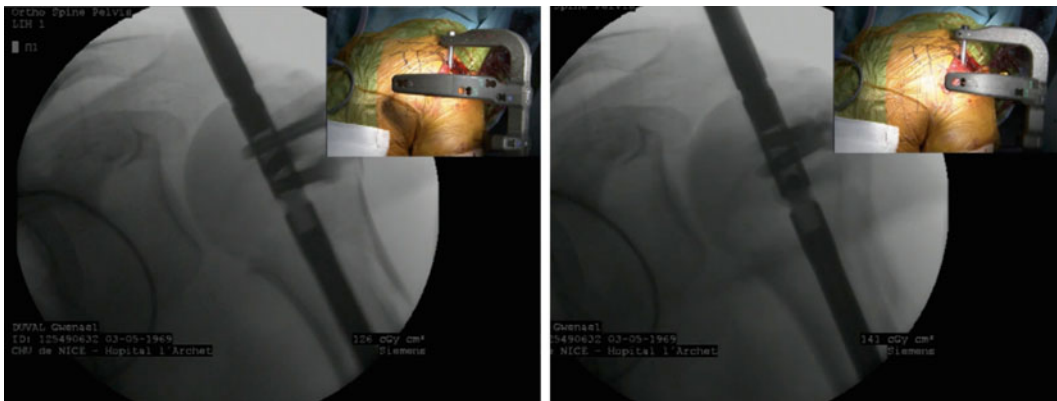

Fig. 5.36 The arm is internally and externally rotated and screw position is confirmed with fluoroscopy

The functional results for the 97 shoulders are summarized in Tables 5.2 and 5.3. The average Constant score was 67 points (range, 24–94) and the average age adjusted Constant score was 83 % (range, 26–117). The average pain score for the study group was 13, on a scale from 0 to 15. Average active forward flexion was 134° and average external rotation was 44°.

All patients had radiographic imaging available to assess fracture healing, osteonecrosis, and implant complications (Fig. 5.38). Ninety-six fractures showed radiographic healing, where one fracture (1 %) showed evidence of delayed union at 6 month, and two additional fractures (2 %) had a slight malunion of the greater tuberosity. No patients included in this evaluation had non-unions of the greater or lesser tuberosities.

Avascular necrosis (AVN) was noted in four shoulders (4 %), two of which required additional operative intervention. The two patients underwent shoulder replacement and had both a good functional result. Short and long-term complications included three incidences of prolonged stiffness, associated with symptomatic proximal screws. They underwent arthroscopic proximal screw removal with arthrolysis during the same operative intervention. One patient experienced postoperative bilateral posterior dislocation, due to seizure, leading to early revision.

The following perioperative complications were noted: one drill-bit was broken intraoperatively and retained, two nails were left slightly proud, one humeral head was placed in varus, one patient had calcific tendinopathy,
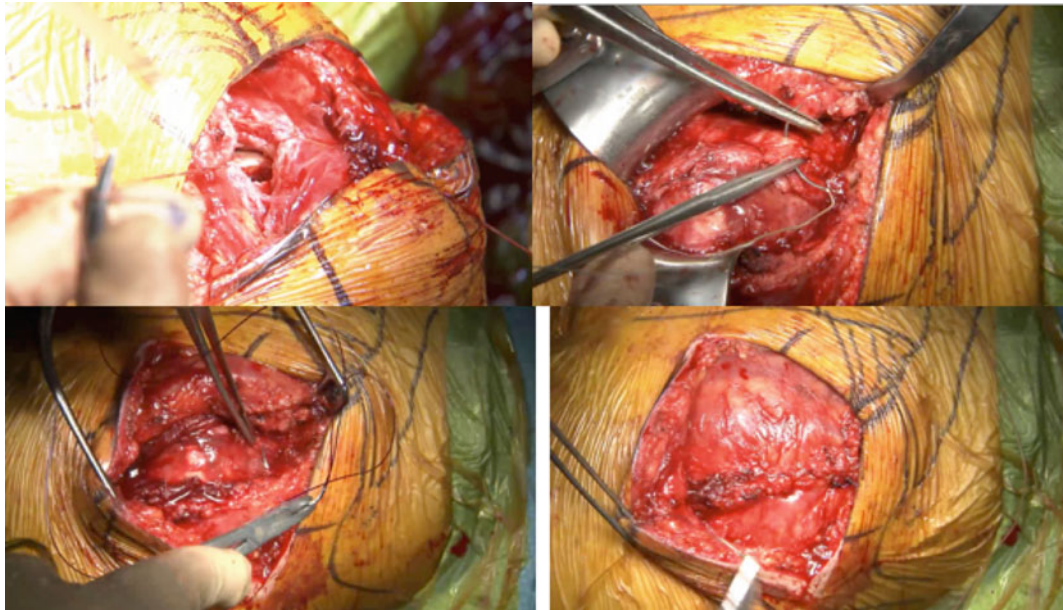
Fig. 5.37 The split in the rotator cuff is then repaired with side to side sutures. The hole in the humeral head is just visible below the split with the nail well below the surface. The acromial osteotomy and deltoid split are then repaired and the skin closed

Table 5.2 Clinical outcomes

	Two part	Three part	Four part
AAE (°)	146 [100–180]	129 [60–170]	127 [80–160]
ER1 (°)	45 [20–90]	40 [20–70]	41 [0–90]
IR1	L3 [but-T7]	L3 [but-T7]	L5 [GT-T12]

Table 5.3 Functional outcomes

	Two part	Three part	Four part
Pain	13.5 [8; 15]	12.2 [6; 15]	13 [10; 15]
Constant score	72 [47; 94]	63 [24; 87]	68 [42; 89]
Adjusted constant	86 [66; 104]	80 [26; 117]	55 [82; 111]
SSV (%)	80 [55; 100]	73 [40; 100]	66 [50; 85]

Fig. 5.38 Example of four-part fracture and the result at 6 months

and in two nails the distal screw did not pass through the distal locking nail hole.

Conclusion

The device and technique presented here represent a valuable treatment option for two-, three-, and four-part fractures of the proximal humerus. This is confirmed by our clinical experience. Our observations demonstrate favorable clinical, functional, and radiographic outcomes for treatment of patients with even the most technically challenging fracture patterns.

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