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Review

New trends in fixation of proximal humeral fractures: A review

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ABSTRACT

Surgical treatment of proximal humeral fractures continues to be a challenge especially in osteoporotic patients. Locking plates and intramedullary nails have been used with satisfactory results but the previous reported complications have not been substantially reduced. Most of the existing studies involve a small number of patients followed up for a rather short period of time. Since proximal humeral fractures constitute a heterogenous group of complex fractures in an even more heterogenous population, no single fixation method is a panacea. Choice of implant and method of fixation should be selected according to individual patient and fracture pattern characteristics based on clearly defined indications and contraindications. Based on the findings of the existing clinical studies the authors propose a treatment algorithm.

Contents

Introduction

Proximal humeral fractures account for 5–9% of all fractures in the human skeleton, mostly affecting elderly, osteoporotic patients.[18,102] Since osteoporosis-related fractures are expected to increase sharply in the near future, the effective management of these injuries becomes a matter of paramount socioeconomic importance.

Although most authors agree that displaced or unstable proximal humeral fractures should be treated operatively, until now the treatment of choice remains a matter of controversy, since no single method has been able to impose itself as the "gold standard" of treatment.[61,114] A great variety of options is available for the fixation of these fractures.[61] However, all of them suffer from a persistently substantial rate of mechanical failure as well as a number of other complications.[3,8,24,43,44,61,76,94,114]

A major issue that challenges the efficacy of all the proposed fixation methods is adequate implant anchorage, especially in osteoporotic patients. In an effort to successfully address this issue, two different design philosophies have been proposed in recently

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developed implants.[64] "Rigid" implants aim to provide maximum stability in patients with good bone quality. On the other hand, "semi-rigid" implants are designed to allow some inter-fragmentary motion and thereby decrease the forces acting upon the bone–metal interface during strain providing a semi-rigid ("elastic") fixation. They are thought to be more suitable for patients with inferior bone quality. In such cases a rigid implant might fail due to insufficiency in the bone–metal interface, whereas a semi-rigid implant might reduce the strain on the interface by allowing micro-motion, thus absorbing part of the energy.[64] If, however, macro-motion occurs at the fracture site throughout the healing process, non-union may develop. Consequently, the "ideal" implant should be elastic enough to preserve the bone–implant interface under load peaks and still rigid enough to reduce fracture movements in order to allow bone healing.

The recently introduced locking plating systems increase the stiffness and improve fatigue behaviour of plate osteosynthesis for the proximal humeral region. Therefore, the use of locking plates appears to allow earlier and safer motion thus enabling early restoration of joint function, particularly in complex cases. Additionally, when stable fixation is achieved, the vascularity of the humeral head is preserved, thus reducing the potential requirement for joint replacement.[96]

It is recognised that unreduced or mal-reduced fractures may result in severe shoulder deformity and functional disability.[98,88] The greater tuberosity may retract into the subacromial space and could cause severe shoulder impingement and dysfunction. The severely rotated articular fragment may further exacerbate the rotator cuff injury and result in shoulder joint osteoarthritis or humeral neck non-union.[98,88] Anatomic reduction and rigid fixation allowing early joint motion are the goals of treatment and are preferred to primary prosthetic replacement, especially in younger patients.

In this study we aim to evaluate the current literature in order to document all recent advances made in fracture fixation of proximal humeral fractures. We wish to shed light in the complex questions associated with the effective management of these fractures.

Materials and methods

Three different types of fracture fixation formed the basis of this study: plating (conventional and/or locking), intramedullary nailing (IM nailing) and external fixation. In addition other techniques were examined such as helix wire, trans-osseous suturing and percutaneous pinning.

The words "proximal humeral fractures or proximal humerus fractures" were used for initial manuscript screening on Pubmed. Moreover the following filters were applied: Papers should have appeared online from 01.01.2001 to 09.08.2010, should be published in English and should be reporting on human, adult patients (over 18 years). This search initially resulted in 1139 articles. Summaries of these papers were reviewed by the authors for relevance. Papers dealing with shoulder prosthesis, pseudarthrosis, delayed or non-union were excluded from the study. Relevant biomechanical studies were also included in this review.

After application of the inclusion/exclusion criteria the following papers were selected and formed the basis of this review.

Results

In total 109 papers met the inclusion criteria.[1–17,19–23,25–42,45–60,62,63–101,103–113,115,116] There were 44 papers relevant to plate fixation,[3,6,7,10,11,14,15,17,25,26,31,32,35,39–42,46,52,55,56,60,62,67,69–71,74,76,77,80,82,87,88,90,91,94,97–99,103,105,106,110] 22 papers were dealing with IM nailing,[1,2,8,34,37,38,48,54,65,66,72,73,81,83,85,89,100,101,104,108,115,116] 3 reported on the use of external fixation,[19,22,68] 21 papers described the other techniques of fracture fixation[4,9,12,13,16,20,21,27,33,36,49–51,59,78,79,84,86,93,107,112] and finally 19 papers were biomechanical studies.[5,23,28–30,45,47,53,57,58,63,64,75,92,95,96,109,111,113]

Plating

Plant-Tan plate

One of the first internal fixators introduced for specifically dealing with displaced proximal humeral fractures was the Plant-Tan plate.[67,94] This is a plate that locks two humeral head cancellous screws to the plate itself in order to achieve both angular and rotational stability (Fig. 1).

The initial discouraging results reporting an implant failure rate of up to 100% in elderly patients with osteoporotic bone[15,94] were verified by a larger prospective study that followed 62 patients for a mean of 19 months. The authors reported that the bulk of the implant, the unacceptable infection rate and the high rate of fixation failure in elderly osteoporotic patients had forced them to discontinue the use of this implant.[67]

However, a recent study presented relatively improved results with the use of the Plant-Tan plate, mainly in terms of infection and fixation failure.[97] The use of this implant has been nowadays abandoned in favour of newer plates with advanced design characteristics, such as lower implant profile and the option for multiple locking screws in the head fragment.

Locking plates

Locking plate technology differs from traditional compression plating in several important ways. Locking plates function as a locked internal fixator and do not need to be compressed for stability, allowing preservation of periosteal vascularity; additionally they provide greater angular stability and better screw anchorage in osteoporotic bone. The use of locking plates has been

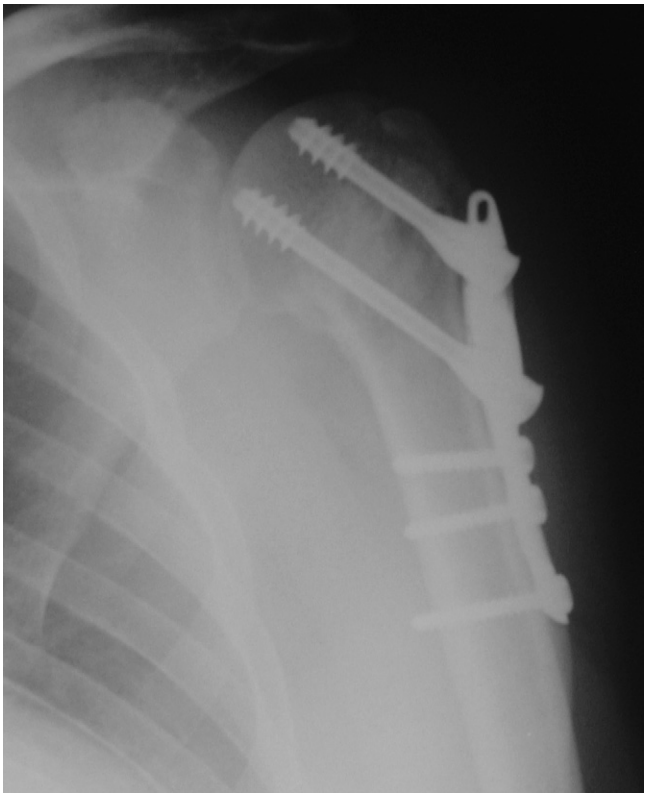

Fig. 1. Two-part proximal humeral fracture treated with Plant-Tan plate (6 months post-op).

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recently introduced in the treatment of proximal humeral fractures, in an effort to successfully address the problems encountered with previously used fixation methods,[70] especially in elderly osteoporotic patients (Fig. 2a and b). In theory they provide more stable osteosynthesis, leading to lower rates of implant failure or loss of fixation, thus allowing earlier mobilisation.[64,105]

Locking plates were found to provide better torsional fatigue resistance and stiffness than the blade plates,[113] as well as significantly greater holding power of the humeral head, when compared to standard plates.[111]

They also may have demonstrated a slightly inferior biomechanical behaviour in bending and rotational forces as compared to IM nails, in a two-part proximal humeral fracture model, but, unlike nails, they were shown to have no interfragmentary motion (toggle) at zero load.[23,29,45,95,111] Therefore, by allowing only minimal motion at the fracture site, they may offer an advantageous biomechanical environment for early and at the same time safe mobilisation. In a resent cadaveric study, locking plates demonstrated superior biomechanical properties under high rotational loads than locked intramedullary nails.[28] However, in the clinical setting, proximal humeral nails and locking plates have not shown any difference with regard to the overall functional outcome.[38]

Several clinical series coming from a number of trauma centres have recently been published, recording the outcome from the use of various specially designed locking plates in the treatment of proximal humeral fractures. Results have been very encouraging as most authors report a very high union rate combined with satisfactory functional results.[10,11,14,17,25,26,31,32,40,56,69,74,76,77,80,82,90,91,103,106] Additive fiber-cerclages may be necessary in locking plate osteosynthesis of multiple-fractured greater tuberosities or lesser tuberosity fractures that cannot be fixed sufficiently by the plate. If however an unstable proximal humeral fracture is reduced and stabilised anatomically with a locking plate, additive fiber-cerclages do not reduce interfragmentary motion.[109] Despite the overall satisfactory results, serious concerns have recently been raised as a result of the significant complication rates recorded in some published series. It should be noted though that almost half of the primary complications reported were surgical technique-related and could therefore have been avoided.[14,55,82,103,106] Implementation of this fixation method by experienced trauma or shoulder surgeons that are well versed with the technique, adhere to it and have adequate assistance appears to be of paramount importance.[55,103] During and immediately after completion of the osteosynthesis, accurate fracture reduction and correct screw placement in the humeral head should be confirmed fluoroscopically in both AP and lateral planes with rotation of the humeral head.[77,87,103] This way, the rate of complications such as primary screw perforation, implant related impingement, implant malpositioning and inadequate fracture reduction could be minimised.

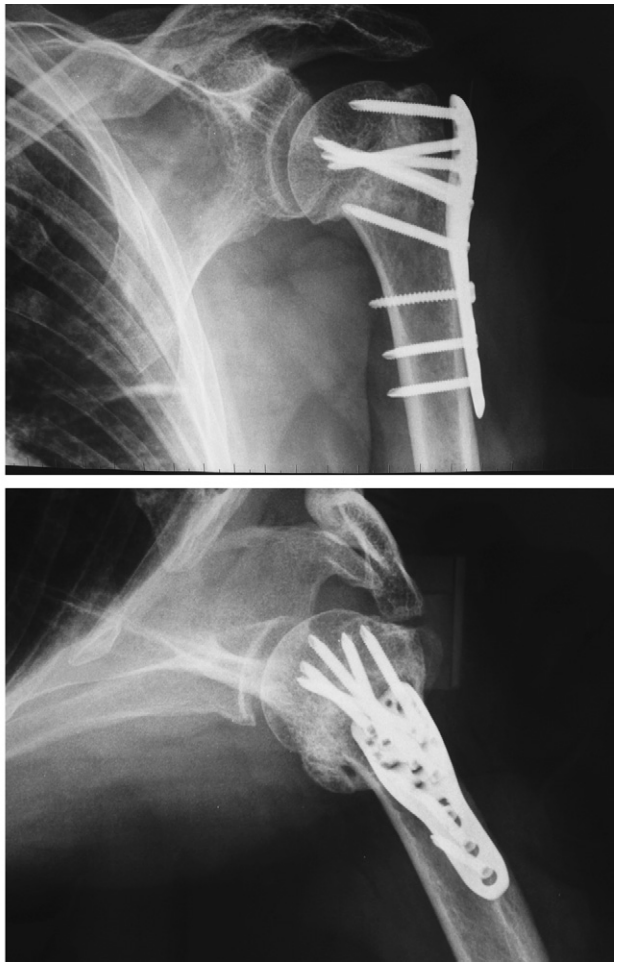

Fig. 2. (a) AP X-ray of three-part fracture treated with Philos plate (18 months post-op). (b) Lateral X-ray of three-part fracture treated with Philos plate (18 months post-op).

It appears that the overall rate of loss of fixation has significantly decreased following the replacement of traditional plates by locking plates in the treatment of proximal humeral fractures.[40,77] The low rate of early loss of fixation achieved, when locking plates are used, can be partly attributed to the "different mode of failure" of these plates. Traditional non-locking screws and plates rely on friction between the plate and bone for stability. In osteoporotic bone, this construct is more prone to failure because of bone resorption underneath the plate and high rotational forces. Additionally, the screws may not obtain sufficient purchase in the cancellous and osteoporotic humeral head, leading to high failure rates. Since locking plates rely on an angular-stable interface between the screw head and plate, the "classic" failure of screw back-out or screw-breakage at the screw head/plate interface is far less common.[3,64] Should locking plates fail, they fail catastrophically as a complete "monoblock" by pulling out of the humeral head or shaft.[3]

Furthermore, the use of locking plates in the treatment of proximal humeral fractures has been correlated with a rather low incidence of, especially total, avascular humeral head necrosis (4.5–16%).[3,11,25,40,56,74,77,82] It has been recently suggested though that the early AVN rate recorded at 12 months, more than doubles at a mean follow up of almost 4 years, with patients older than 65 with a 3- or 4-part fracture being at more risk.[39] AVN is initiated by the fracture pattern itself that almost unavoidably damages the delicate blood supply of the humeral head.[6,44] However, humeral head vascularity may be further endangered if rather extensive soft tissue dissection is required in order to achieve adequate fracture reduction and subsequent fixation with conventional plates. In that respect the use of locking plates requires considerably less soft tissue stripping and therefore, further iatrogenic damage to the blood supply of the humeral head is minimised.

Paralleling the development of locked plates was the concept of minimally invasive plating. Less invasive and more direct approaches, such as the anterolateral acromial approach to the proximal humerus which has been specifically described for reduction and fixation of proximal humeral fractures, are focused around biology and minimal soft tissue dissection. This approach uses the plane of the avascular anterior deltoid raphe with subsequent exposure and protection of the axillary nerve, allowing

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direct access to the lateral fracture planes and the plating zone without dissection of the critical blood supply of the humeral head thus offering a stable construct with reduced surgical morbidity.[31,32,35] Percutaneous plating using two minimal incisions with a lateral deltoid split and a more distal shaft incision has also been described.[60]

It appears that the choice of approach for the exposure of the proximal humerus region may influence the overall functional outcome. Stable osteosynthesis is important, but the clinical outcome following operative treatment equally depends on soft tissue management. Recent reports suggest that the deltoid-splitting approach provides a better functional outcome and less pain during the early follow-up period, but the deltopectoral approach is correlated with better mid-term results.[42] One should also point out that the reported AVN rates are significantly lower (range from 0 to 2.6%) when a minimally invasive deltoid-splitting approach is used.[32,42]

However, even if AVN occurs, leading to humeral head collapse, the screws of the locking screw construct may ''cut-through'' and eventually ''cut-out'' through the collapsing humeral head. This may in turn lead to secondary perforation of the head screws into the glenohumeral joint.[14,26,41,77,103,106] It has been suggested that when the stable fixation initially provided is preserved, fracture healing and even revascularisation of the humeral head may be achieved with an end-result that does not necessarily correlate well with the severity of the radiological findings.[6,77,114]

Recent efforts have been directed towards recognising the technical details during implant insertion together with the exact fracture parametres and patient factors that may positively or negatively affect the final outcome. It has been suggested that fractures with a disrupted medial hinge and with the humeral head fracture line located in the anatomical neck (AO/ASIF types 1.1 C1 and C2) bear a higher risk for AVN, humeral head collapse and screw perforation and may therefore not be suitable for internal fixation with the Philos plate.[77] The significance of the medial periosteal hinge has been further underlined in a recent cadaveric study.[58] Malreduction, loss of medial support, and negligence of tension band sutures on the tuberosities have been recognised as possible risk factors for early failure of the locking compression plate in osteoporotic proximal humerus fractures.[71] Aiming for an anatomic or slightly impacted stable reduction, as well as meticulously placing a minimum of five equally distributed divergent fixed-angle plate screws in the humeral head and at least one superiorly directed oblique locked screw in the inferomedial region of the proximal fragment is recommended in order to achieve more stable medial column support and maintain reduction until bone healing.[31,46] These oblique superiorly directed screws may act as ''triangulation screws'' that were found to increase the construct stiffness in a recent biomechanical study.[63] It is thought that the above, as well as leaving the screws at least 5–10 mm below the subcortical bone, increase the construct stability and decrease the probability of screw ''cut-through'' and eventual ''cut-out'', should some degree of head collapse occur.[5,77]

It appears that initial varus angulation of the humeral head is associated with a significantly worse clinical outcome and higher complication rate than similar fracture patterns with initial valgus angulation[98,99] despite the fact that a recent study calls this into question.[88] Further factors having significant influence on the final outcome in these fracture patterns are patient age[80] and the length of the intact metaphyseal segment attached to the articular fragment.[77,98] Metaphyseal segment length of less than 2 mm is predictive of developing avascular necrosis.[98] Smoking, osteoporosis as well as medical and psychiatric co-morbidities have also been associated with an increased risk of non-union in such fractures.[43,90,98] Finally, the presence of metaphyseal comminution or fracture line extension distally leading to defective medial support increases the risk for both implant and fixation failure.[14,17]

The absence of comorbidities and the restoration of the medial metaphysis were the most reliable predictors for a successful clinical outcome following locking-plate fixation of unstable proximal humeral fractures.[62]

Implant removal is often required, especially in young patients, either due to complications or on patient's request. Recent studies suggest that functional parametres as well as quality of life improves significantly following implant removal in patients with hardware related subacromial impingement, persistent rotation deficit or merely requesting hardware removal following fracture healing.[52] Recently, even arthroscopically assisted proximal humeral plate removal has been successfully attempted.[110]

Locked plates in general do not appear to be a panacea for these fractures and are unable to support the humeral head alone from a lateral tension-band position. In an effort to provide increased mechanical support to the medial column, an allograft has been placed either endosteally or even across the medial column and incorporated into the locking construct.[33,88]

However, there are several factors that are in the surgeon's control that may improve the mechanical environment. Osteosynthesis with preservation of the humeral head is worth considering when adequate reduction and stable conditions for revascularisation can be obtained. In patients with osteopenic bone and/or comminuted fractures, hemiarthroplasty is a viable alternative.[7] However, further experimental and long term clinical studies are required in order to recognise the patient factors, the fracture characteristics and the technical details during implant insertion that may positively or negatively affect the final outcome. This way one could set more exact indications and contra-indications for the use locking plate systems in the treatment of proximal humeral fractures.

External fixation

External fixators have been used in the treatment of proximal humeral fractures in an effort to overcome the disadvantages of open reduction and internal fixation. Closed reduction and percutaneous pin placement minimise the risk of infection and prevent further damage to the humeral head vascularity.

Martin et al. retrospectively evaluated 62 patients with 2 and 3 part fractures that were treated with percutaneous placement of 5 mm Ex-Fix screws, followed by the application of an external fixator. The two proximal screws were placed in the upper lateral part of the humeral head parallel to each other in the transverse plane, in order to avoid penetration of the joint cartilage. Good reduction was achieved in 50 of 62 cases and the functional result was satisfactory in 79% of patients, while no early complications or cases of humeral head necrosis were recorded.[68]

In a further retrospective study of 64 patients, excellent or good functional results were reported in 82% of patients.[22] The authors point out that the use of smaller diameter pins in a mini external fixator which allows application of pins in more than one plane provides better rotational stability of the fracture, with a lower risk of soft tissue or vascular injury.

In a recent report the Ilizarov apparatus was used in 3 polytrauma patients where displaced surgical neck humeral fractures were initially stabilised with unilateral external fixators and subsequent loss of fixation occurred. The authors advocate the use of the Ilizarov apparatus in the conversion mode or even primarily in order to achieve a better fracture reduction.[19]

The use of external fixators appears attractive, especially in polytrauma patients as the procedure can be performed in the supine position and avoid additional blood loss and further soft tissue damage.

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Other techniques

Helix-wire

The use of an intramedullary titanium helix wire has initially been proposed almost 10 years ago as a minimally invasive technique for the treatment of displaced proximal humeral fractures.[107] This method consists of the percutaneous insertion of an appropriately sized dynamic intramedullary helix wire into the humeral diaphysis, which is then rotated into the head fragment. Stability is provided by a self-locking three-point fixation including the lateral drill hole, the opposite cortex and the cancellous bone of the humeral head.

Initial results were encouraging with 85.3% of patients, especially those with 2 part fractures, having a very good, good and satisfactory functional outcome after 1 year.[36] The reported complication rate was 11.6% with the most important among them being 3 cases of dislocation requiring reoperation and 5 cases (5.3%) of avascular head necrosis (3 partial and 2 total AVN) all leading to hemiarthroplasty.[36]

However, in further studies, where patients with 2-, 3- and 4-part fractures of the proximal humerus that were treated by closed reduction and intramedullary helix wire placement, the complication rate rise significantly and ranged at 1 year from 23.1% to 47%.[50,59,84] Complications occurred predominantly in patients with 4-part fractures, were mostly seen early after the index procedure and were associated with a high revision or re-operation rate. They included non-union, avascular head necrosis, secondary loss of fixation with consecutive projection of the helix wires into the subacromial joint space, biceps tendon rupture and broken helix wire. Interestingly, no further complications or progressive posttraumatic arthritis were reported at the 6-year-follow-up, while the average Constant–Murley score also remained unchanged (70.3 at 1 year, 70.7 at 6 years).[59]

Because of its unacceptably high complication rate, this fixation method is no longer used in the treatment of proximal humeral fractures.

Trans-osseous suturing

In the last years a trend towards less invasive techniques has been noticed, in an endeavour to minimize soft tissue detachment and vascular impairment in the treatment of proximal humeral fractures. These include trans-osseous suturing of displaced proximal humeral fractures.

In a recent study, reviewing 188 patients with 2-, 3-, and 4-part proximal humeral fractures with valgus impaction, treated with non-absorbable trans-osseous sutures, very satisfactory results and a low complication rate were reported after a mean follow up of 5.4 years.[21] The authors advocate this technique specifically for the above mentioned fracture types, while 2-part surgical neck fractures should be rather treated with plate-and-screw osteosynthesis.[20,21] These findings were in accordance with previous studies, where non-absorbable rotator cuff incorporating sutures were used for treating both greater tuberosity and surgical neck 2-part fractures as well as 3-part fractures.[51,79] The authors concluded that some residual deformity did not preclude an excellent outcome, when using minimally invasive fixation techniques. Internal fixation using a double-row of suture-anchors was described for addressing the problem of comminuted, displaced fractures of the greater tuberosity.[9]

Other authors combined tension-band suture fixation with intramedullary nailing, in an effort to further improve the construct stability and to achieve better results especially in elderly patients.[51,78]

Percutaneous pinning

Percutaneous pinning represents a minimally invasive technique that avoids wide exposure and extensive soft-tissue stripping during open reduction and internal fixation of proximal humeral fractures. Although the risk of damaging vital neurovascular structures was highlighted in a number of cadaveric studies,[47,92] the low incidence of such complications in most clinical studies did not support the above concerns.[86]

Two-part fractures treated with closed reduction and percutaneous K-wire fixation do significantly better than three-part fractures, where loss of reduction was reported in 27% of cases. It has also been suggested that the use of threaded pins appears to be advantageous, while age and osteoporosis significantly contribute to the fixation failure.[27]

Watford et al. advocate closed reduction and percutaneous cannulated screw fixation of certain types of 2-part proximal humeral fractures in carefully selected patients.[112] Blonna et al. assessed the outcome of K-wire osteosynthesis of varus displaced proximal humeral fractures in patients over 65 years old, compared to a control group treated non-operatively, and concluded that the treatment of such fractures with K-wire osteosynthesis yields good results that are superior to those treated non-operatively.[12] Russo et al. described a new technique for the reconstruction of the proximal humerus around a triangular-shaped bone block positioned inside the head and the metaphysis. The fragments are stabilised with minimal osteosynthesis by Kirschner wires, screws, or sutures.[93]

Migration of at least one Kirschner-wire was reported to be the most common complication occurring in up to 36% of patients whose fractures were treated with closed reduction and percutaneous pinning.[16] Clinical results appear to be correlated with the quality of reduction obtained. Elderly patients, however, may constitute an exception, since in this patient group even an incomplete reduction could yield satisfactory clinical results.[16]

A recent multicenter study attempted to further clarify the indications for percutaneous treatment of proximal humeral fractures. Their indications included good bone quality, sufficient for pin fixation, lack of comminution in the proximal humeral metaphysis or the medial aspect of the anatomical neck, stability after reduction and fixation under fluoroscopy and sufficient patient compliance. In cases where these criteria were met, all valgus impacted 3- and 4-part fractures were treated with percutaneous K-wire fixation with satisfactory results. On the other hand, the authors advised against this the use of this method in fractures with severe tuberosity displacement or comminution, when stable reduction could not be achieved percutaneously and when significant osteopenia was present.[49]

Bogner et al. proposed percutaneous reduction and minimally invasive fixation as a satisfactory treatment option for elderly patients, where the primary treatment goal is rather to provide an adequate painless range of motion rather than to restore muscle power.[13]

The Humerusblock system (HB) was introduced to confront the issues of K-wire loosening and migrating in osteoporotic bone by stabilizing the K-wires onto the cortex. A recent biomechanical study showed that the Humerusblock system (HB), although less stiff than specially designed locking compression plates, still demonstrates significant stiffness that may be adequate in a clinical setting to maintain fracture reduction. This did not seem to be the case with IMC (Intra-Medullary Claw), an intramedullary elastic device that demonstrated very low stiffness and was thus thought to be very unlikely to maintain adequate fracture reduction until healing occurred.[57]

In a clinical study reporting the results of percutaneous treatment of 200 patients with AO type A2, A3, B1, B2 and C1, C2 the authors advocated the use of Humerusblock with concomitant fixation of the tuberosities with cannulated screws, in order to prevent Kirschner-wire migration.[4]

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Overall, percutaneous treatment of specific types of proximal humeral fractures appears to be a safe treatment alternative with satisfactory results and low complication rates, particularly when some reasonable inclusion criteria are taken into account and the issue of K-wire loosening and migration is addressed.

Intramedullary nailing

Intramedullary nailing has been traditionally reserved for diaphyseal fractures of the humerus, its anatomical boundaries lying in the proximal and distal metaphysis.[34,89] Attempts to treat proximal humeral fractures with traditional nail designs as well as early attempts with specially designed nails have led to high failure and complication rates.[8,81] Recently, a number of specially designed intramedullary nails with multiple proximal interlocking screws have been introduced and techniques have been refined in an effort to re-establish intramedullary nailing as a viable option for the treatment of proximal humeral as well as segmental humeral fractures in which one of the fracture lines lies well proximal (Fig. 3).

Intramedullary nails are load-sharing devices and demonstrate higher stiffness values, thus generating greater primary stability, than extra-medullary load carriers. This has been long proven in diaphyseal fractures, but has been lately shown to be true in the metaphyseal region as well. Recent research has suggested that intramedullary nails specially designed for the proximal humerus may have a superior biomechanical behaviour especially in bending and rotational forces as compared to plates, results though under cyclic loading are not equivocal.[23,29,30,45] Nails on the other hand, unlike locked plates have demonstrated a degree of interfragmentary motion (toggle) at zero load, which in the clinical setting may prove to be a problem in early pain-free rehabilitation of proximal humeral fractures.[95] It must be pointed out though that most biomechanical studies have been preformed in two-part fracture models and may therefore underestimate potential problems arising from multi-fragmentary configurations in more complex three- and four-part proximal humeral fractures.

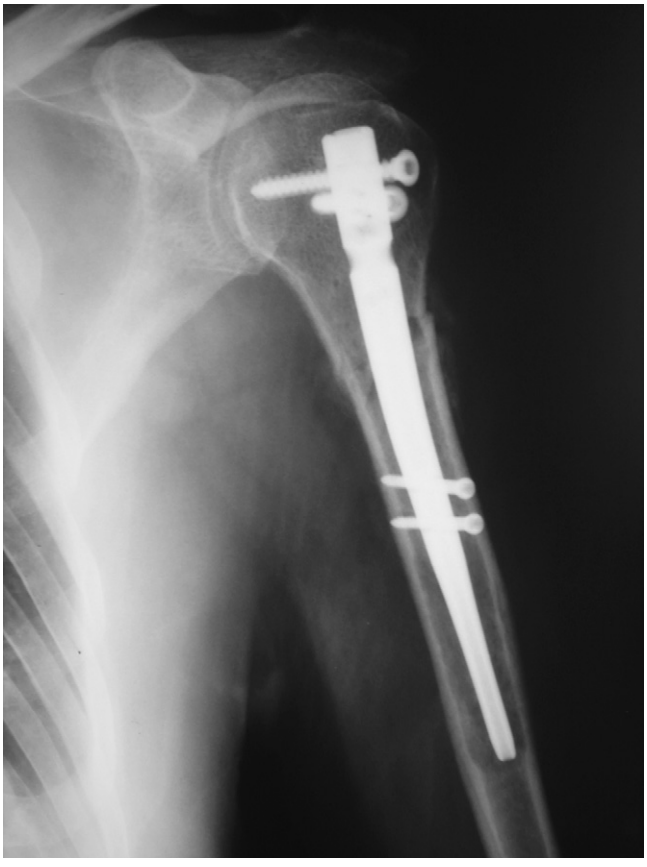

Fig. 3. Two-part proximal humeral fracture treated with Polarus nail (3 months post-op).

A number of, mostly small, clinical series have been published lately presenting the experience of different surgical teams from the use of a number of specially designed nails for the treatment of proximal humeral fractures.[1,37,48,54,65,66,72,73,83,85,100,101,104,115,116] Results have been encouraging as most authors report a very high union rate and a satisfactory functional outcome. Furthermore, IM nailing appears to be an excellent solution in complex cases of proximal humeral fractures with concomitant shaft involvement.[37,73,83,115]

Age and a multi-fragmentary fracture pattern though appear to be factors negatively affecting the final clinical outcome.[37,48] Although not supported by all studies,[66] it has been shown that 2-part fractures lead in a generally better clinical outcome than more complex 3- or 4-part fracture patterns.[101] Moreover, patients older than 65 years of age have a significantly worse functional result and this is probably due to the underlying osteoporosis resulting in poor bone quality and reduced implant grip. Special "locking" nail designs have been introduced in order to address the problem of poor bone quality which may in turn lead to screw backing out and an increased risk of varus angulation of the humeral head or great tuberosity displacement. Namely, Kitson et al. reported a significant increase in the overall construct stiffness with a special nail design where the three proximal interlocking screws are fully threaded and lock into the nail by virtue of a screw thread in the holes of the nail.[53] Mihara et al. on the other hand tried to solve the same problem in geriatric patients with a "pin-lock" nail design. Its use in people over 70 years of age led to a satisfactory functional outcome with minimal varus angulation and no proximal pin back out.[72]

The rate of complications, even in recent series, remains rather high, necessitating a re-operation or implant removal in up to 30% of cases.[37,65,100,108] One should point out though that most re-operations have been carried out to deal with minor complications such as screw backing out or protrusion. More serious complications including varus deformity, humeral head collapse and great tuberosity displacement or malunion are far less common.[37,48,72,83,100,108] The overall rates of AVN range between 3.7% and 11.8%, but some series may underestimate the pragmatic AVN rate as only cases of complete humeral head necrosis are included by most authors. Humeral head collapse of >20% though may be present in up to 37% of cases.[65] Moreover, most studies include patients with a follow-up period of 1 year or even less, while late osteonecrosis with humeral head collapse has been recently recognised to be more common than previously thought.[6,77]

Producing an additional fracture through the entry point of the nail is a well known iatrogenic complication reported in up to 17.9% of cases especially when nails with a proximal curvature are used.[2,37,83] Straight nails use a more medial entry point in order to avoid this complication. Bent nails on the other hand are more "anatomic" and more "friendly" to the rotator cuff and humeral head cartilage, but necessitate, due to their proximal curvature, a far more lateral entry point, thus increasing the risk for an additional fracture of the larger tuberosity through the entry point. Increased proximal nail diameter may be an additional risk factor.[65]

Nijs et al. performed a cadaveric study of six different commercially available proximal humeral nails in an effort to clarify if proximal locking bolts endanger the axillary nerve or the ascending branch of the anterior circumflex artery.[75] They concluded that bent nails, especially those with oblique bolts,

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place the axillary nerve at more risk and that nails with one or more anteroposterior interlocking bolts may endanger the ascending branch of the anterior circumflex artery. As a result, they advocate blunt dissection and the use of protection sleeves during drilling and screw insertion in an effort to minimize the risk for neurovascular damage during proximal interlocking bolt insertion.

Park et al. in an effort to safely expand the indications of IM nailing of proximal humeral fractures to complex 3- and 4-part fractures described "the hot air balloon technique", which aims to minimise the risk of loss of fracture fixation and tubercle dissociation.[78] According to this technique the IM nail is used in conjunction with a combination of non-absorbable "locking sutures" placed between the greater and lesser tuberosity and "tension band sutures" placed between the rotator cuff tendon and the distal interlocking screw and offers increased stability of both the surgical neck fracture and the tuberosities. Alternatively Gradl et al. used in selected complex 3- and 4-part proximal humeral fractures a combination of IM nailing and tension band wiring.[37] Kim et al. in 2008 further refined this technique by suggesting that the "tension band sutures" be passed through a washer to prevent suture slippage and pullout from the head of the interlocking screw.[51] However, in complex 3- and 4-part fractures an open approach is often required, especially when the above mentioned technical variations are used. This may obviate some of the advantages offered by closed IM nailing, such as haematoma and soft tissue preservation.

Recent results have not justified serious concerns raised earlier, but this may reflect to some extent greater care in patient selection and improved nail design. Nowadays a number of specially designed intramedullary nails are available and appear to offer a good alternative option in the treatment of most types of proximal humeral fractures.

Conclusion

Effective surgical treatment of proximal humeral fractures still remains nowadays a matter of controversy. Various fixation methods have been proposed, in an effort to address the issues that render the management of such fractures a challenge, especially in osteoporotic patients. Some fixation methods have been abandoned, while others appear to stand the test of time. Among the latter, locking plates and intramedullary nails are widely used and are supported by encouraging reported results. Although until now no randomized control trials have been performed in this field and most study-cohorts consist of relatively small numbers of patients followed for a rather short period of time, it appears that these two treatment modalities continue to gain popularity.

Most efforts focus on determining the optimal indications for each treatment option, thus minimizing failure rates. Since proximal humeral fractures constitute a heterogenous group of complex fractures in an even more heterogenous population, no single fixation method is a panacea. The key may be to choose the most appropriate fixation method according to the exact patient and fracture characteristics based on clearly defined indications and contraindications.

In an effort to summarise the findings of existing clinical studies we would like to propose a treatment algorithm:

In 2-part fractures satisfactory results can be obtained with both locking plates and IM nails specially designed for this anatomical region.

In 3-part fractures locking plates have offered an excellent fixation option. However, IM-nailing used in conjunction with a combination of non-absorbable sutures or wires placed between the tuberosities and between the rotator cuff tendon and the distal interlocking screw, in what is described as "the hot air balloon" technique, offers another valid option in our armamentarium.

In 4-part fractures IM nailing cannot dependably provide adequate stability, thus often leading to loss of reduction and malalignment. The use of specially designed locking plates augmented with sutures anchoring the tuberosities to the plate seems more appropriate for these demanding fractures.

Moreover:

- Smoking, osteoporosis, loss of medial hinge integrity, varus angulation and the presence of metaphyseal comminution or fracture line extension distally, lead to increased risk for both implant and fixation failure following fixed angle plating of proximal humeral fractures. However, the negative impact of varus angulation may not be as detrimental as previously believed.
- External fixation should be reserved for open fractures and unstable polytrauma patients.
- Percutaneous pinning is another valid option, especially in valgus impacted 3- and 4-part fractures. In some trauma centres with significant experience with this method, it has been successfully used with extended indications.
- Stabilisation with non-absorbable trans-osseous sutures can be used in 2-, 3-, and 4-part proximal humeral fractures with valgus impaction and without severe comminution and displacement.

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