Current Concepts: Advantages of Intramedullary Nail for Proximal Humerus Fractures

Conceptos actuales: Ventajas del clavo endomedular para fracturas del húmero proximal

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Rev Chil Ortop Traumatol 2022;63(3):e205–e214.

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Abstract

Proximal humeral fractures are one of the most frequent fractures in the elderly population. Open reduction and internal fixation (ORIF) is generally indicated for young patients and older patients with high functional demands and good bone quality. No consensus has been reached regarding the ideal fixation technique. Although ORIF with plates is the most widely used technique, high re-intervention rates and global complications with locked plate fixation have been reported in the literature. Addition of augmentation techniques to locked plate fixation in complex fractures may result in longer surgical times, extensive approaches, and higher costs. Therefore, considering other options for ORIF is necessary. With a greater understanding of the mechanisms of fixation failure, intramedullary fixation has become the accepted treatment option for proximal humeral fractures considering the specific biomechanical and biological advantages. Compared with ORIF with locked plates, intramedullary fixation for proximal humeral fractures has low surgical time, intraoperative bleeding, time to bone union, and rate of infections. Intramedullary fixation is a valid option to resolve complex fractures with an implant that may largely supply all the augmentation requirements of a locked plate.

Keywords

- proximal humeral fractures
- internal fixation
- intramedullary fixation
- intramedullary nail
- elderly fractures

Resumen

Las fracturas de húmero proximal (FHP) son una de las fracturas más frecuentes en la población anciana. La reducción abierta y fijación interna (RAFI) generalmente está indicada para pacientes con una FHP desplazada en jóvenes o pacientes mayores con alta demanda funcional y buena calidad ósea. No se ha llegado a un consenso sobre la técnica de fijación ideal. La RAFI con placas ha sido la más utilizada, pero se han reportado altas tasas de reintervenciones y complicaciones globales en la literatura. La necesidad de agregar técnicas de aumentación a la RAFI con placas bloqueadas en

received
June 16, 2021
accepted
January 10, 2022

DOI https://doi.org/10.1055/s-0042-1744265.
ISSN 0716-4548.

Thieme Revinter Publicações Ltda., Rua do Matoso 170, Rio de Janeiro, RJ, CEP 20270-135, Brazil

Palabras clave
- fractura de húmero proximal
- fijación interna
- osteosíntesis endomedular
- clavo endomedular
- fracturas en ancianos

fracturas complejas puede resultar en un tiempo quirúrgico más largo, abordajes extensos y mayores costos. Debido a esto, se hace necesario considerar otras opciones para la osteosíntesis de FHP. Con una mayor comprensión de los mecanismos de falla de la osteosíntesis, la fijación intramedular se ha convertido en una opción de tratamiento aceptada para las FHP con ventajas biomecánicas y biológicas. La fijación intramedular para las FHP ha demostrado menor tiempo quirúrgico, sangrado intraoperatorio, tiempo hasta la unión ósea y menores tasas de infecciones, que las placas bloqueadas. La fijación intramedular es una opción válida para que las fracturas complejas se resuelvan con un implante que por sí solo puede satisfacer en gran medida todas las necesidades de aumento requeridas por una placa bloqueada.

Introduction

Proximal humerus fractures (PHFs) are common. Their incidence is higher in women and increases after 50 years of age.[1,2] hey account for approximately 7% to 8% of all adult fractures in the Western world, and their incidence reportedly increases with age.[3] The treatment of PHFs is controversial, and it is one of the most debated of all fracture treatments.[4] Most are stable, minimally-displaced osteoporotic fractures in elderly patients resulting from a low-energy fall.[2] Most patients with these injuries regain shoulder function without surgery. The surgical treatment is reserved for patients with displaced fractures who require maximization of shoulder function. Young patients or older subjects with high functional demands and good bone quality often undergo open reduction and internal fixation (ORIF).[5,6]

The technique of choice has been highly dependent on the surgeon's interpretation of the type of fracture, comminution, and displacement degrees, bone quality, and familiarity of the surgeon with a particular method. Although multiple types of implants have been tried over time, ORIF with plate is the most used by many surgeons. The introduction of the locking screw technology in plates for the surgical treatment of the proximal humerus led to the perception that it would be the expected solution for this type of fracture.[7,8] Unfortunately, however, the literature[9,10] has reported reoperation rates of up to 25% and overall complication rates of up to 49% after ORIF with plate, mainly from loss of reduction with varus misalignment and subsequent screw penetration.[9–11]

The intramedullary nail (IMN) became an option for the treatment of PHFs thanks to the greater understanding of the mechanisms of osteosynthesis failure and the potential preservation of the biology of the fractured site. The main objective of the present narrative review was to analyze the benefits of an IMN versus a locked plate for the surgical treatment of PHFs. The secondary goal was to show how to reduce the risk of complications associated with the surgical technique using an IMN at the proximal humerus.

Methods

The present paper is not a systematic review or a meta-analysis. The author has selected publications that, in his opinion, are relevant to understanding the advantages of a proximal humerus nail, analyzing the best available evidence from selected authors in this subspecialty and from his own experience, following the parameters defined as type-V scientific evidence.

Locked Plate Osteosynthesis: Why Do Plates Fail?

Proximal humerus plates are specially designed for fixation of the humeral head. However, the proximal humerus suffers deforming forces in the horizontal plane, which are transmitted to the tuberosities by the rotator cuff. These pairs of horizontal forces are critical for the proper centralization of the humeral head. Therefore, the position of the tuberosities is fundamental for the functional outcomes.

The principles of the Working Group for Bone Fusion Issues (Arbeitsgemeinschaft für Osteosynthesefragen, AO, in German) state that the screw must be perpendicular to the fracture line for best fixation. This is not usually achieved in tuberosities or surgical neck fractures, in which the screws are proximal and distal to the fracture line. On the other hand, the proximal humerus plate acts biomechanically as a lateral tension band, which depends on medial cortical support to be stable enough. Therefore, an anatomical reduction with good medial support is critical to avoid complications. Reconstruction of the medial support has reduced the risk of displacement and improved functional outcomes.[12,13] Gardner et al.[14] were the first to suggest the parameters defining the presence of medial support; they have considered that its presence is defined when there is: a medial column with anatomical reduction and no comminution; diaphyseal impaction towards the fractured humeral head; or a direct locked screw in the inferomedial quadrant of the humeral head 5 mm from the subchondral bone. Since medial comminution is common in complex fractures, screws for medial support are key in osteosynthesis using locked plates. The lack of good medial support and the decreased bone mineral density creates the perfect setting for the humeral head to collapse onto the screws. In addition, some authors[15,16] have proposed to increase the number of screws towards the humeral head and add a second plate to increase the rigidity of the osteosynthesis.

Locked Plates Require Augments in Complex Fractures

Problems with osteosynthesis using PHF plates required technical improvements with supplementary methods to partially solve these issues. In severe valgus impaction fractures of the humeral head, some authors have proposed calcium phosphate cement, autologous bone graft, or allograft bone chips to fill the defect after reduction. Robinson and Page[17] were the first to describe that filling the residual defect with calcium phosphate cement reduced the incidence of loss of reduction, with no avascular necrosis in a series of 29 patients with valgus impaction fractures. Subsequently, these results were reproduced by other authors[18–20] with cement or cancellous bone, reducing complications compared to groups with no defect filling. These techniques are potentially indicated to fill bone defects, especially those created after reduction of displaced valgus fractures with intact medial support.

Augmentation with polymethylmethacrylate-based cement at the tip of the screws was proposed to improve their anchorage in the humeral head. In cadaveric studies,[21,22] screw adherence improved as bone mineral density and mobility of the screw–bone interface decreased. However, in a study with 94 patients over 65 years old with displaced PHFs operated on with a locked plate, Siebenbürger et al.[23] found no difference in the overall complication rate or loss of reduction at a 2-year follow-up between groups with or without cement augmentation in screws. Although the experimental biomechanical benefits are well documented, no clinical studies support its use.

The third option to increase osteosynthesis of the proximal humerus is intramedullary structural bone grafting. Walch et al.[24] presented the first clinical report with this technique to treat two-parts PHFs non-union. The bone union rate was of 96%, with significantly improved Constant-Murley scores and no avascular necrosis. In 2016, Saltzman et al.[25] systematically reviewed 4 clinical studies reporting some benefits of this technique in the acute treatment of PHFs. Of a total of 136 patients, they reported an incidence of 3.7% of screw penetration and 4.4% of reinterventions during an average follow-up of 20 months.[25] More recent comparative studies[26,27] on displaced fractures in older patients revealed a lower rate of complications and loss of reduction in the plate plus structural graft group compared to the plate group. However, this technique requires extensive dissection of the fracture site. The successful bone union of the intramedullary graft can fill the entire medullary canal of the proximal humerus with high-density bone, hindering a future reverse prosthesis.[28,29]

Biomechanics and Advantages of Intramedullary Nails

An alternative to reduce the complications associated with locked plates in PHFs is osteosynthesis with IMN. The current IMN generation for the proximal humerus has many advantages over older designs and locked plates, which include enabling a centromedullary position and entering the highest part of the humeral head through the supraspinatus myotendinous junction, avoiding damage to its attachment. This centromedullary position provides stable subchondral support over a large area according to the size of the nail. It can partially fill defects due to disimpaction and provide the centromedullary support sought with intramedullary structural bone grafts. In addition, the number of contact points for each screw (lateral cortex, nail entry, nail exit, and subchondral bone) increases, distributing the loads over more points. By itself, it is an implant that shares loads with the bone and distributes them, potentially reducing the critical need for anatomical medial support.

The current designs enable the fixation of tuberosities with perpendicular screws and a subchondral fixation of the humeral head. Some designs incorporate locking screws and screws directed to the calcar. They allow impaction of the fracture site and minimally-invasive surgery. Even though the IMN of the proximal humerus is not synonymous with minimally-invasive surgery, and some cases require an increased incision size to reduce complex fractures, it will not go beyond the fracture site; in addition, the incision is often smaller compared to that of an ORIF with a plate through a deltopectoral approach.

In biomechanical studies, Füchtmeier et al.[30] demonstrated greater angular and torsional stiffness with an IMN compared with a PHILOS plate (DePuy Synthes, West Chester, PA, US) in a cadaveric model of a two-part PHF. Kitson et al.[31] observed greater torsional stiffness and load in valgus failure with IMN compared with locked plates in a cadaveric model of a three-part PHF. Clavert et al.[32] obtained a higher failure load in regular and osteoporotic bone models, in addition to greater stiffness in an osteoporotic bone model using a locked plate. The analysis of these results must be careful. It is not clear how much load would be enough for an implant in a torsional or angular plane, and it is not clear whether greater rigidity translates into better outcomes. Most biomechanical studies[30–32] use cadaveric models with two-part fractures, not considering more complex fracture patterns or randomization per bone mineral density.

The locked plates used in a deltopectoral approach may expose terminal and ascending branches from circumflex vessels, placing them at direct risk during surgery and while positioning the plate at the lateral cortex of the proximal humerus. In contrast, IMN placement requires a limited dissection, sparing the vascular supply of the humeral head, the tuberosities, and the fracture site.[29,33]

Prognostic Factors for Proximal Humerus Osteosynthesis

The poor prognostic factors for proximal humerus osteosynthesis are well known. Hertel et al.[34] proposed that fractures with less than 8 mm in metaphyseal extension, more than 2 mm in medial hinge displacement, as well as anatomical neck fractures have a high risk of humeral head ischemia. Agudelo et al.[35] proposed that poor reduction in varus with a cervico-diaphyseal angle (CDA) lower than 120° was the main risk factor for loss of reduction when using locked plates. Osterhoff et al.[36] reported that fractures with calcar comminution presented a higher risk of poor functional outcomes with a locked plate. Using a multivariable regression, Jung et al.[13] demonstrated that osteoporosis ($p = 0.015$),

displaced varus fracture (CDA lower than 110°; $p = 0.025$), medial comminution ($p = 0.018$), and insufficient medial support ($p = 0.001$) were independent risk factors for reduction loss in ORIF using locked plates. For Spross et al.,[6] the deltoid tuberosity index (DTI; > 1.4) and a metaphyseal extension longer than 8 mm were the most significant preoperative predictors to achieve an acceptable reduction with a locked plate. A DTI higher than 1.4 ($p = 0.036$), age lower than 65 years ($p = 0.02$), and a good reduction ($p = 0.001$) were independent factors in reducing the risk of screw penetration.[6]

The literature specifically analyzing the prognostic factors for IMN osteosynthesis in PHFs is scarce; moreover, it is not clear if these factors are the same as the ones for a locked plate. López et al.[37] reported 24 patients with 2-part fractures, aged between 60 and 94 years, mostly (82%) with a DTI lower than 1.4 and treated with a straight IMN. Poor prognostic factors included fixation with residual varus, incorrect rotator cuff entry point or one that damages it, and inadequate axial alignment.[37]

Nevertheless, despite a large amount of published research, specific comparative analyses based on preoperative radiological parameters of locked plates and the IMN are scarce. Gadea et al.[38] published a retrospective, nonrandomized, observational, multicenter study with 107 patients treated with a locked plate or IMN in four parts PHF. In the entire study population, the following radiological parameters significantly affected functional outcomes: humeral head reduction ($p = 0.02$), preoperative medial hinge compromise ($p = 0.004$), postoperative medial hinge reduction ($p = 0.003$), tuberosity reduction ($p = 0.001$), development of avascular necrosis ($p = 0.005$), or complications ($p < 0.001$). The functional impact of these factors did not differ between groups, except for the integrity of the preoperative medial hinge, which favored plates. The authors[38] attributed this to the reduction technique, which depends on the surgeon. In the entire population, there were two radiological risk factors for avascular necrosis: preoperative calcar comminution ($p = 0.05$) and poor tuberosity reduction ($p = 0.006$). There was a trend toward worse outcomes with curved nails compared with straight nails, potentially influencing the global results for IMN.[38]

Several studies[6,13,34,36] available in the literature have reproduced the limits to indicate an isolated locked plate in proximal humerus osteosynthesis. This is possible because the implant has been used for many years and has not undergone critical design changes over time. However, better evidence regarding prognostic factors for IMN with straight implants, multidirectional proximal screws, locked screws, and calcar screws remains lacking. Therefore, decide the limits in age, bone mineral density and complexity of the fracture for these newer implants.

Clinical Outcomes

The clinical studies comparing locked plates and IMN for PHF are heterogeneous and susceptible to bias. Most studies include a lower proportion of complex fractures (in three or four parts) and older patients. Therefore, the objective assessment of this particular group of patients is a challenge.

Sun et al.[39] conducted a systematic review including 13 studies with 958 patients. Locked plates had a significantly increased risk of screw penetration (relative risk [RR] = 1.75; 95% confidence interval [95%CI]: 1.11–2.77; $p = 0.02$). Screw penetration was attributed mainly to medial instability, which was closely related to varus collapse.[39] In a meta-analysis of 20 studies with 1,384 patients with Neer type-II, -III, and -IV PHFs, Li et al.[40] showed that IMNs required a shorter incision length (odds ratio [OR] = -3.51; 95%CI: -5.30–-1.72), and resulted in lower levels of perioperative bleeding (OR = -2.85; 95%CI: -3.73–-1.97), lower surgical time (OR = -1.59; 95%CI: -1.94–-1.24), and shorter bone union time (OR = -1.44; 95%CI: -2.46–-0.42). Shi et al.[41] published a systematic review including 38 studies with 2,699 patients with Neer type-II, -III and -IV PHFs. Their results were consistent with those of |some previous publications.[39,40] The IMN led to lower levels of intraoperative bleeding (OR = -0.67; 95% CI: -3.36–-1.98), shorter surgical time (OR = -0.59; 95%CI: -1.97–-1.20), shorter time until union (OR = -0.68; 95%CI: -1.07–-0.28), and fewer postoperative complications (OR = 0.75; 95%CI: 0.57–0.97), with a lower risk of infection. No differences were found regarding the Constant-Murley score, the CDA, avascular necrosis, reinterventions, union delay, and osteosynthesis failure.[41] Future studies must include the latest generation of IMNs in the analysis and compare it with locked plate plus augmentation, especially with intramedullary structural grafts.

Technical Considerations for an IMN at the Proximal Humerus

The IMN technique for PHF requires a training curve. It is relevant to consider that this does not mean having to perform a percutaneous technique, and that several reduction maneuvers are similar to those that should be used with a locked plate. Start practicing this technique with surgical neck fractures in two parts in young patients. These injuries require fewer reduction maneuvers, and their bone fragments are easier to handle. Begin with an approach sufficient to view the supraspinatus muscle; split this muscle under direct visualization and position the initial reamer under direct visualization and fluoroscopic control. With more experience, it is possible to treat this type of fracture percutaneously.

The proximal humerus IMN is also suitable for two-part fractures with medial support comminution in older patients (►**Figure 1**), three-part fractures (►**Figure 2**), and four-part fractures (►**Figure 3**).

- Some general recommendations from the technical point of view are as follows:
- Perform an approach from the anterior border of the acromioclavicular joint that enables good access to the highest point of the humeral head.

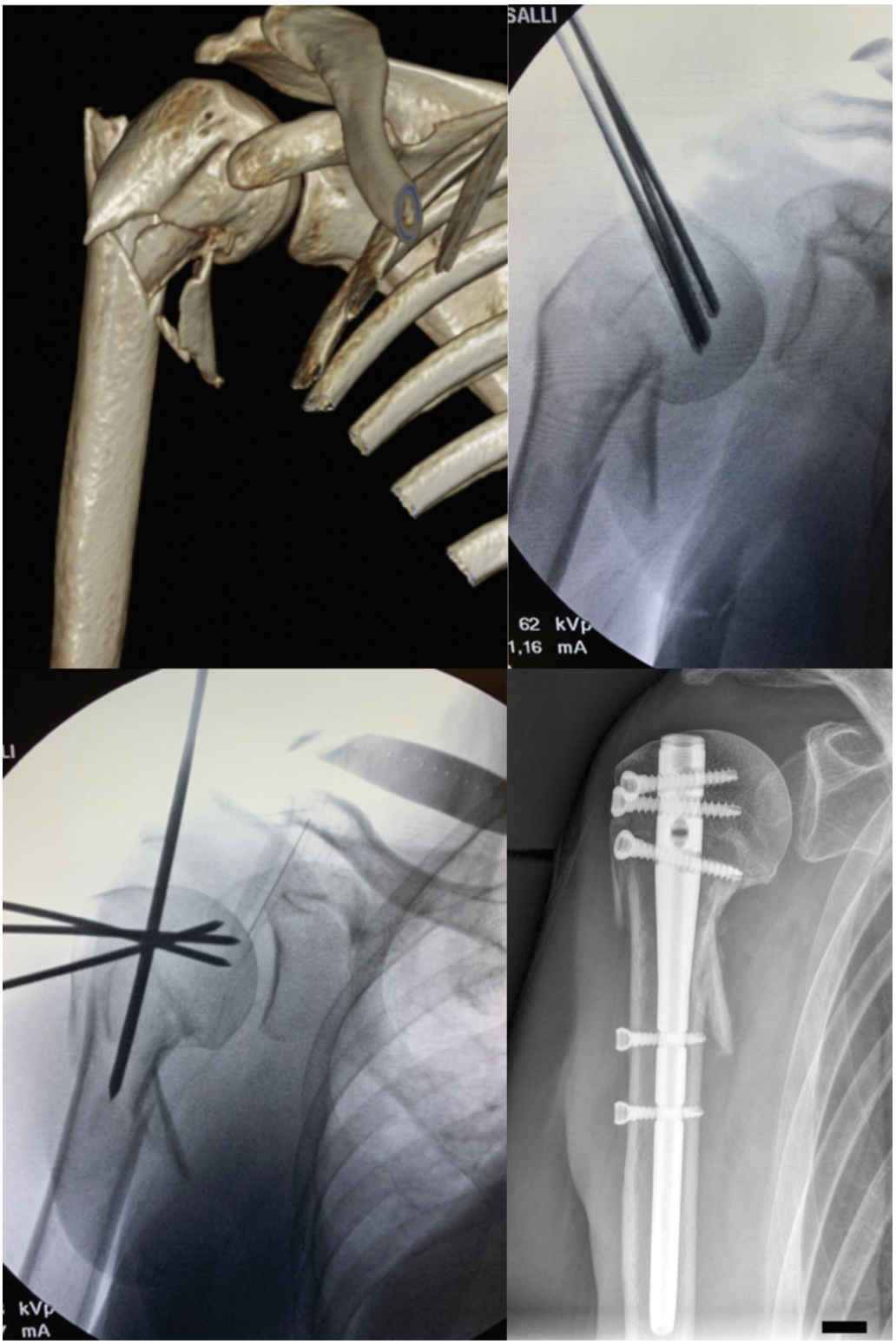

Fig. 1 A two-part proximal humerus fracture with calcar comminution submitted to reduction and osteosynthesis with an intramedullary nail with no approach to the injury site.

- The patient's position can range from supine to a tilt of approximately 30°.
- Put a forearm support on the table but allow shoulder extension. This enables the surgeon to expose and reach the highest central point of the humeral head for IMN insertion.
- Extend the approach as needed if you are not familiar with percutaneous reduction maneuvers, or if a more complex

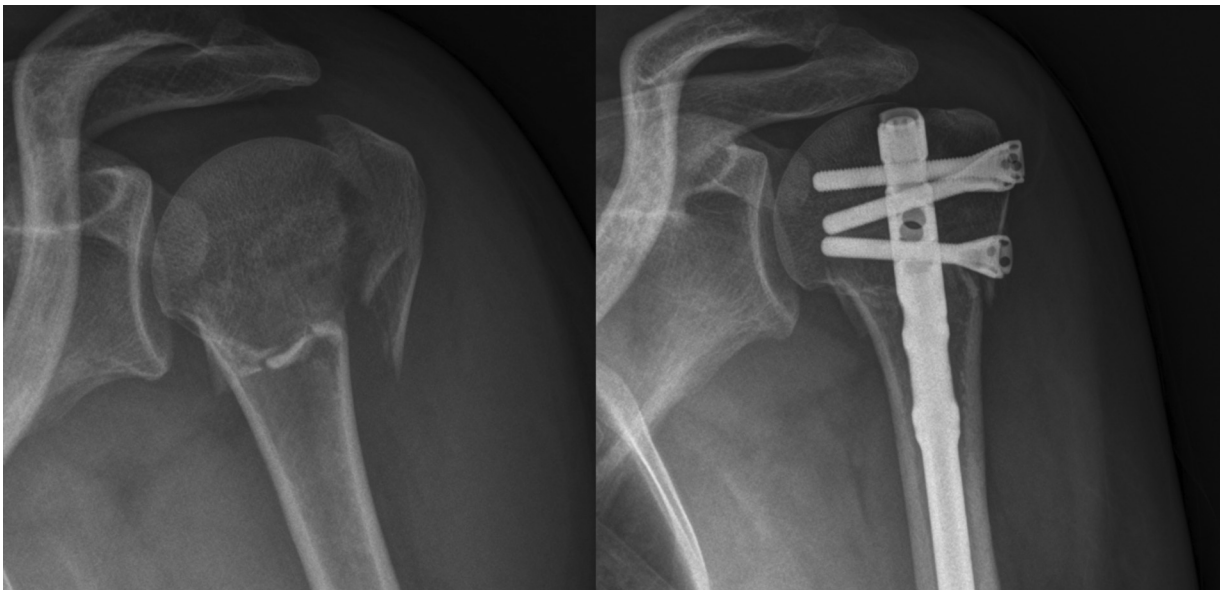

Fig. 2 A three-part proximal humerus fracture with valgus impaction submitted to reduction and osteosynthesis with an intramedullary nail.

reduction maneuver is required. There is no need to exceed the fracture line distally to achieve good reduction under direct visualization.[42]

- Good x-rays control are essential during reduction and osteosynthesis. I recommend placing the c-arm equipment from the contralateral side of the fracture.[29] For a sagittal x-ray view, an axillary projection can be obtained with correction of the c-arm axis and slight shoulder abduction (►**Figure 4**).

- In cases without good x-ray view at the sagittal plane, use the bicipital groove as an anatomical landmark. It allows to control the rotational axis and the posterior tilt of the humeral head under direct anterior visualization.
- It is highly recommended to reduce the humeral head using needles, elevators, or sutures for the tuberosities before IMN insertion. This will make it easier to find the right entry point in line with the medullary canal.[43]
- Ideal anteroposterior (AP) shoulder radioscopy is essential to achieve the correct IMN height. The idea is to provide subchondral support in the upper part of the humeral head for best mechanical support, but no protrusion outwards. The main error is tilting the c-arm upwards or downwards, which may make us misinterpret the height of the IMN. To know if the radioscopy is perpendicular to the IMN for correct height assessment, use as a reference the visualization of the anterior nail hole in a perfect circumferential manner. This ensures that the c-arm is not tilted.
- Consider orienting IMN rotation from the moment of its insertion so that the proximal screws face towards the fracture lines at the tuberosities. Take care to avoid the bicipital groove. In case of a potential conflict between a screw and the bicipital groove, check the bicipital tendon under direct visualization.
- When fixing the proximal screws, ensure that the guide is well supported against the cortical bone, and orient the radioscope perpendicular to the guide of the screw in use for accurate measurement of the screw length.
- Due to the size of the humeral head in some shorter patients, the most inferior screw in the humeral head may be distal to the fracture line. If it is essential to add another screw to provide increased support to the humeral head, use the anterior IMN screw, which is usually higher.
- Pay attention to the width of the medullary canal. In some smaller patients, the isthmus of the humeral medullary canal can be less than 160 mm away from the upper edge of the humeral head. Most of the short IMNs available are 160 mm in length, leading to a space conflict and a diaphyseal fracture. This can be planned preoperatively using radiographs. When in doubt, it is better to use systems that include drilling of the medullary canal from 6 mm upwards.

Final Summary

The best available evidence[39–41] states that the IMN reduces intraoperative bleeding, surgical time, bone union time, and the rate of postoperative infection compared with locked plate osteosynthesis for the treatment of PHFs. The author believes that the IMN is the best option for PHF osteosynthesis because its biomechanical advantages enable the management of complex fractures with a method providing all the augmentation needs required by a locked plate. This decreases surgical time, approach size, and the devitalization of the fracture site. State-of-the-art IMNs may expand the indication for proximal humerus osteosynthesis not

Fig. 3 A four-part proximal humerus fracture submitted to reduction and osteosynthesis with an intramedullary nail.

requiring augmentation to complex fractures in older patients. However, there is a potential bias because the quality of the literature is diverse. Future studies must analyze the prognostic factors for IMN use with straight implants, multidirectional proximal screws, locking screws, and calcar screws. More rigorous and objective evidence requires multicenter, randomized, double-blinded clinical trials with large samples and higher quality.

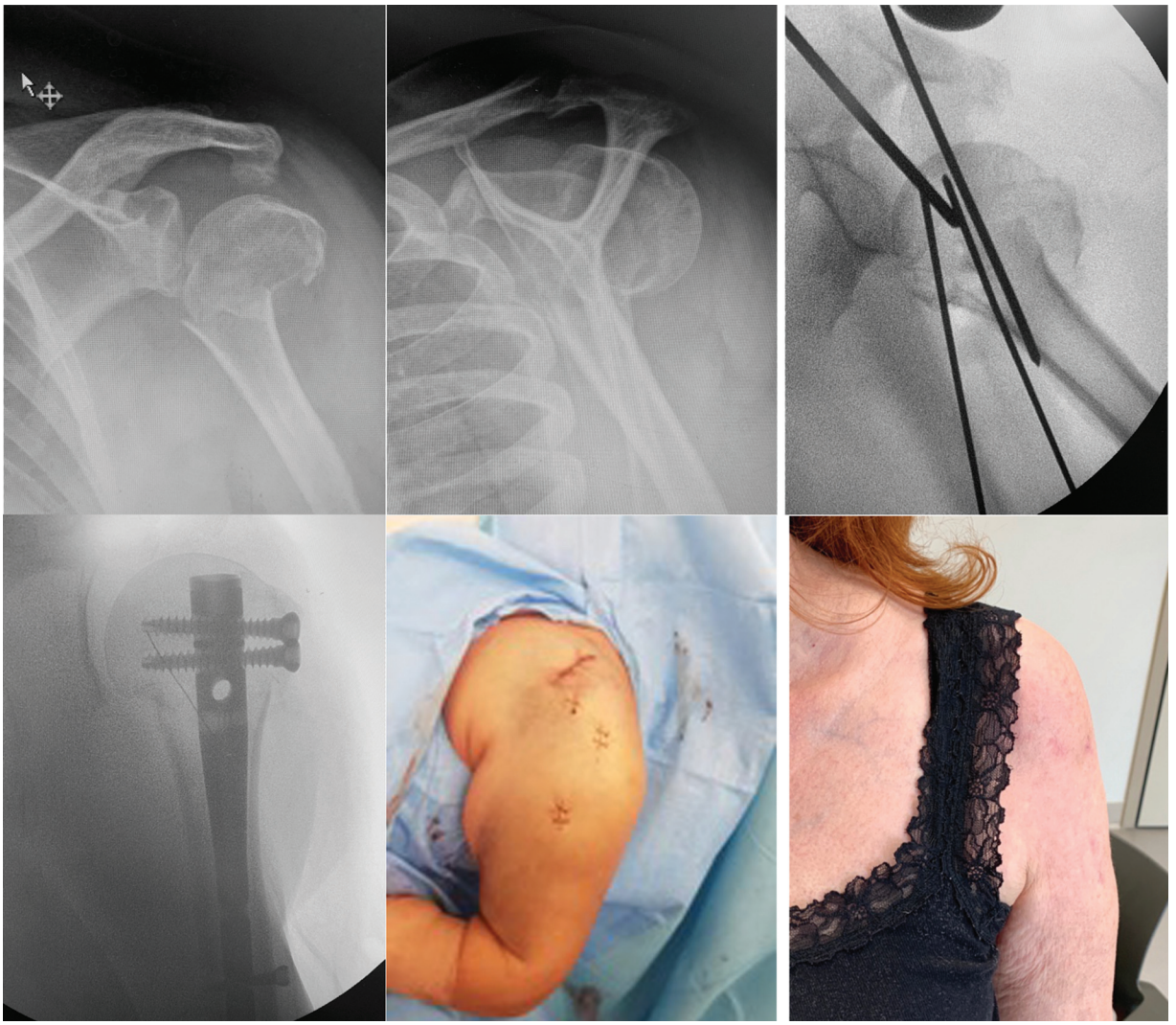

Fig. 4 Reduction and osteosynthesis of a proximal humerus fracture with an intramedullary nail. Reduction with posterior sagittal displacement needles under radioscopic control from an axillary view and with a minimally-invasive approach. The scar anterior to the acromioclavicular joint is hidden under clothing.

Regardless of the fixation method selected, the functional outcomes apparently depend on the quality of the reduction; the type of fixation is not as critical as mastering the surgical technique itself. Either technique can be used as long as the general rules of internal fixation for a PHF are applied: tuberosity reduction, varus correction, and restoring medial support.

Conflict of Interests

The author has no conflict of interests to declare.

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