Review Article

Minimally Invasive Plate Osteosynthesis of Humeral Shaft Fractures: Current State of the Art

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Abstract

Most closed humeral shaft fractures can be successfully managed nonsurgically. However, fractures for which closed treatment is unsuccessful are stabilized using either plates or intramedullary nails. There are shortcomings associated with each technique, including the potential complications of nonunion, infection, shoulder pain, and radial nerve injury. Minimally invasive plate osteosynthesis (MIPO), an innovative alternative treatment, is gaining in popularity. This technique is based on the anterior humeral shaft providing a relatively safe surface for plate application, and limited open exposures proximally and distally allow percutaneous insertion of the necessary implant. More than 40 articles have been published regarding MIPO, and it compares favorably to other available forms of treatment with excellent functional outcomes and a lower rate of iatrogenic radial nerve injury. Larger randomized controlled trials comparing this method with other accepted techniques, including nonsurgical management, are necessary to better define the role of MIPO in the management of humeral shaft fractures.

Humeral shaft fractures are common injuries, and most can be successfully managed with appropriate conservative care.[1,2] Established surgical indications include failed nonsurgical treatment, polytrauma, open fractures, bilateral injuries, and ipsilateral forearm fractures.[1] When necessary, these are stabilized using either open plating (open reduction and internal fixation [ORIF]) or intramedullary nails, and there are proponents of both methods. Typically, ORIF involves an extensile approach, with concomitant soft-tissue stripping and local vascular disruption. Accordingly, the reported rate of nonunion varies between 3% and 20%,[1,3] with the additional risks of infection or iatrogenic radial nerve injury.[4,5] Open plating is often performed through a posterior approach, predisposing the vulnerable radial nerve to injury during the exposure.[1] Intramedullary nailing (IMN) of the humeral shaft was introduced to limit the risks of nonunion and radial nerve injury, potentially allowing these fractures to heal more rapidly by virtue of the use of a minimally invasive approach.[6,7] Unfortunately, clinical series of fractures stabilized with antegrade humeral nails often report debilitating shoulder complications related to their insertion through or adjacent to the rotator cuff, greater radiation exposure intraoperatively, and a higher rate of revision surgery.[1,3,8] Although surgery is sometimes required to maintain a satisfactory reduction and promote union,[1] there are recognized risks associated with each

Table 1

Summary of Humeral Minimally Invasive Plate Osteosynthesis Case Series Published in 2002 Through 2016

Years	No. of Studies (No. of Countries)	No. of Procedures	Nonunion	Infection	Iatrogenic Nerve Injury
2002-2006[11,20,21,26,48]	5 (4)	41	1	2	2
2007-2011[12,13,16-18,24,27,30-32,49,50]	12 (10)	313	10	3	7
2012-2016[15,19,22,23,28,29,51]	7 (4)	227	4	4	7
TOTAL	24 (15)	581	15 (2.6%)	9 (1.5%)	16 (2.8%)

technique, including the potential complications of nonunion, infection, shoulder pain, and radial nerve injury. Direct comparisons between these two techniques reveal that both achieve comparable outcomes, yet there is still insufficient evidence to ascertain which of these two methods is preferable.[3,6-8]

An alternative method for the surgical management of humeral shaft fractures, minimally invasive plate osteosynthesis (MIPO), is rapidly gaining widespread popularity.[9-32] More than 40 articles on this technique have been published, including 5 comparative cohort studies,[9,10,14,25,33] 6 randomized controlled trials (RCTs),[34-39] and 4 meta-analyses.[40-43] Compared with either ORIF or IMN, this growing body of evidence now increasingly favors the MIPO technique as equally effective with less risk of complications.[14,34-38,40-43] Although the intent of ORIF is rigid fixation, the aim of any MIPO procedure is to achieve relative stability and secondary bone healing, using a locked plate to bridge the fracture site.[44,45] Indirect reduction of the fracture limits soft-tissue damage to preserve local vasculature and avoid disrupting early callus, resulting in a more biologically compatible form of plating.[44-46] The anterior surface of the humeral shaft provides a safe location for plate application,[47] using small incisions proximally and distally for percutaneous insertion of the necessary implant. Mounting evidence demonstrates that the use of this less invasive technique results in a high rate of rapid union with a decreased incidence of iatrogenic radial nerve injury.[14,40-43] This technique incorporates the benefits of minimally invasive stabilization, as with an intramedullary nail, yet avoids the associated shoulder complications, while simultaneously minimizing the risk of the other complications associated with open plating.

Early Reports, Case Series, and the Evolution of the Technique

Twenty-four clinical case series have been published on MIPO humeral plating over the past 15 years, collectively reporting on the results of >500 patients from 15 countries (Table 1). The pooled data reflect the favorable results consistently reported, with an aggregate nonunion rate of 2.6%, an infection rate of 1.5%, and an iatrogenic radial nerve injury rate of 2.8%. This compares very favorably to the complication rates reported for either ORIF or IMN, for which the risk of iatrogenic radial nerve palsy alone is reportedly as high as 10% to 20%.[4]

MIPO humeral plating first appeared as a natural extension of the minimally invasive approach to fracture fixation that already has demonstrated benefits in other anatomic sites.[44,45] For humeral fracture fixation, the method has gradually evolved to incorporate different implants and to reflect better appreciation of the subtleties of local anatomy. This technique was first reported by Dell'Oca,[48] who described two cases in a series of fractures treated with percutaneous helical plates. Livani and Belangero[20] published their initial experience in 2004 in a small series using conventional straight dynamic compression plates (DCPs) inserted percutaneously using an anterior approach. In their report on 15 cases, they noted only 1 nonunion, with that patient having a high-energy grade III open fracture.

MIPO humeral plating progressed further when Jiang et al[17] first recommended the use of a locking compression plate (LCP) in 2007 while reporting on 21 cases, 19 of which went on to unite. Schwarz et al[27] also suggested using an LCP, and although rapid primary union was achieved in 9 of the 11 patients treated, 1 patient experienced delayed union, and 1 patient experienced nonunion. In the only report to date from the United States, Ziran et al[32] subsequently reviewed 31 patients with 32 fractures who were treated with an LCP using the MIPO technique. They reported only one nonunion and observed no iatrogenic radial nerve injuries.

This move toward using LCPs instead of DCPs reinforced the principle of relative stability for this minimally invasive approach, providing a flexible yet stable mechanical construct. As such, the plate can be thought of an as internal fixator, and in spanning the fracture, it promotes

callus formation by allowing controlled micromotion.[44,45] Although the LCP theoretically enhances stability, when Shen et al[28] compared their results in 26 cases performed with a DCP to 17 cases completed with an LCP, no clinically meaningful differences in outcomes were reported.

The largest single series of cases was reported by López-Arévalo et al,[49] with a total of 86 patients. There were three nonunions (3.5%) and three transient radial nerve palsies (3.5%) that resolved spontaneously. In this study, MIPO was associated with no cases of shoulder pain and an almost complete restitution of strength and range of motion of both the shoulder and elbow. Within 6 months, 96% of these patients had returned to their normal activities. Apivatthakakul et al[11] were also early advocates of the technique, performing a cadaver study to investigate the relationship of nerves at risk to the approaches necessary to create the anterior submuscular tunnel. They emphasized protecting the radial nerve from the distal end of the anterior plate by maintaining the forearm in supination during the surgical procedure.

The minimally invasive approach to humeral plating seems to be advantageous with regard to improved shoulder and elbow ROM postoperatively. When Kobayashi et al[18] reported a prospective series of 14 patients, they specifically investigated the time to full recovery of shoulder and elbow ROM, which was on average 19 and 60 days, respectively. Livani and Belangero[20] noted that shoulder ROM was normal in all patients, with only one having limitation of elbow flexion secondary to plate malposition. In a retrospective series, Mahajan et al[22] assessed the suitability of MIPO for humeral shaft fractures in athletes and laborers and documented that 94% were able to return to their original occupation or activity. In contrast, Kobayashi et al[18] attributed slower time to recovery of full elbow motion to either plate impingement or the process of splitting the brachialis on the approach. Plate impingement can be avoided by ensuring that the distal end of the plate is at or above the coronoid fossa.

Comparative Studies

Over the past several years, five separate comparative trials have been conducted, as summarized in Table 2. Oh et al[25] retrospectively compared 29 MIPO cases to 30 ORIF cases, and the mean surigcal time in the MIPO group (110 minutes) was shorter than in the ORIF group (169 minutes). They concluded that MIPO can achieve equivalent radiologic and functional results with less surgical time, while reducing the risk of certain complications compared with ORIF. Davies et al[14] compared MIPO to IMN in a retrospective case-match controlled study, with 15 patients in each group. They combined the results for three major complications (ie, infection, nonunion, iatrogenic radial nerve palsy) and observed that the pooled risk was more than seven times greater after IMN. They concluded that MIPO is a safe and effective technique for the management of displaced humeral shaft fractures, with a markedly reduced risk of major complications compared with IMN.

Remarkably, six different studies have been published from a single institution in China.[9,10,17,28,31,46] Two of these were case series,[17,31] two were direct comparisons to other techniques,[9,10] one compared results using either an LCP or a DCP,[28] and the last was a cadaver study to assess vascular disruption related to either ORIF or the MIPO approach.[46] The perfusion studies confirmed, as expected, that MIPO was superior to ORIF in maintaining local vascular integrity and would promote periosteal filling at the fracture site.[46] In 2010, An et al[10] compared MIPO with ORIF, with union in all cases and similar functional outcomes at 1 year. More importantly, they documented a notable difference in the rate of iatrogenic radial nerve palsies, with none in the MIPO group and 5 of 16 (31.3%) in the ORIF group. In 2012, An et al[9] compared MIPO with IMN and again noted that all fractures united in both groups, with a single delayed union in the MIPO arm. Shoulder function at final review was better in the MIPO group than the IMN group, but this difference was not clinically meaningful. However, the authors noted that MIPO was technically more demanding and required 23 minutes of additional surgical time ($P < 0.05$).

Finally, Wang et al[33] again compared MIPO with ORIF, obtaining CT scans on all 48 patients to assess rotational alignment postoperatively. They also documented a decreased rate of radial nerve palsy and nonunion when using this less invasive technique. However, they observed a high prevalence of rotational malreduction (exceeding 20° in 39% of patients) after MIPO, which has not been reported previously by any other group of surgeons.

Randomized Controlled Trials

Six RCTs have been completed to date, and the results are summarized in Table 3. Lian et al[38] published the first RCT comparing humeral shaft MIPO to both antegrade and retrograde IMN. They randomized 47 humerus fractures to either MIPO (n = 24) or IMN (n = 23) and reported comparable results for most outcomes. They noted one nonunion after MIPO and two nonunions after IMN and reported one angular malunion in both groups. There

Table 2

Results of Humeral MIPO Comparative Studies

Study	No. of Procedures (Type [No.])	Nonunion (No.)	Infection (No.)	Iatrogenic Nerve Injury (No.)	Functional Outcome
An et al[10]	33 (MIPO [17], ORIF [16])	0	0	ORIF (5)	Mean UCLA score: MIPO, 34.8; ORIF, 34.4
	—	—	—	—	Mean MEPS: MIPO, 99.4; ORIF, 99.7
Oh et al[25]	59 (MIPO [29], ORIF [30])	MIPO (1), ORIF (3)	ORIF (1)	MIPO (1), ORIF (1)	Mean UCLA score: MIPO, 34.3; ORIF, 33.8
	—	—	—	—	Mean MEPS: MIPO, 97.6; ORIF, 97.0
An et al[9]	34 (MIPO [15], IMN [19])	0	0	0	Mean UCLA score: MIPO, 34.2; IMN, 31.8
	—	—	—	—	Mean MEPS: MIPO, 100; IMN, 97.6
Wang et al[33]	48 (MIPO [23], ORIF [25])	MIPO (1), ORIF (2)	0	MIPO (1), ORIF (3)	Mean constant score: MIPO, 93.5; ORIF, 95.3
	—	—	—	—	Mean ASES: MIPO, 94.9; ORIF, 96.9
Davies et al[14]	30 (MIPO [15], IMN [15])	MIPO (1), IMN (4)	IMN (1)	IMN (3)	—

ASES = American Shoulder and Elbow Surgeons score, IMN = intramedullary nailing, MEPS = Mayo Elbow Performance Score, MIPO = minimally invasive plate osteosynthesis, ORIF = open reduction and internal fixation, UCLA = University of California Los Angeles Shoulder Rating Scale

were no deep infections in either group, but there was one iatrogenic radial nerve injury after MIPO and three after IMN. The surgical time was shorter with MIPO, and shoulder function was also markedly better after MIPO. They concluded that humeral shaft fractures can be effectively managed with either MIPO or IMN, but they feel that MIPO is the better option for complex fractures, whereas IMN remains a good option for relatively simple fractures. Benegas et al[34] randomized 40 humeral shaft fractures to either MIPO (n = 21) or IMN (n = 19) and found that all fractures healed, with the exception of one nonunion after IMN. Malunions were not observed, and there were no differences in shoulder or elbow function. The surgical time was equivalent between the two groups, but there was markedly more use of fluoroscopy with IMN compared with MIPO. They concluded that humeral shaft MIPO is a safe and effective technique that resulted in less radiation exposure for the surgeon, with comparable shoulder function achieved using either method.

Kim et al[37] conducted a multicenter RCT on 68 patients in which MIPO (n = 36) was compared with ORIF (n = 32). Union was achieved by 20 weeks in all but one patient after ORIF (31 of 32) and in all 36 patients after MIPO ($P = 0.471$); the one delayed union after ORIF healed spontaneously. In all 68 patients, the fractures healed with $<10°$ of angular deformity and <1 cm of shortening. No postoperative infections were noted in either group, and postoperative radial nerve palsy was noted in only one ORIF patient (3%). The surgical time was longer with ORIF compared with MIPO, although this was not markedly different. The authors reported comparable functional outcomes for both the shoulder and elbow and concluded that MIPO is equivalent to ORIF as a safe and effective technique for the management of humeral shaft fractures when performed by surgeons familiar with the technique. Hadhoud et al[36] completed a RCT comparing MIPO with ORIF for humeral shaft fractures in 30 patients. Union was achieved in all 15 MIPO patients and in 14 of 15 ORIF patients, and the mean time to union was similar between groups. Again, the mean surgical time for the MIPO group was shorter than the ORIF group ($P < 0.0001$). There was one postoperative radial nerve palsy after

Table 3

Results of Humeral MIPO Randomized Controlled Trials

Study	No. of Procedures (Type [No.])	Nonunion (No.)	Infection (No.)	Iatrogenic Nerve Injury (No.)	Functional Outcome
Lian et al[38]	47 (MIPO [24], IMN [23])	MIPO (1), IMN (2)	0	MIPO (1), IMN (3)	Mean ASES: MIPO, 98.2; IMN, 93.5
	—	—	—	—	Mean MEPS: MIPO, 97.6; IMN, 94.1
Benegas et al[34]	40 (MIPO [21], IMN [19])	IMN (1)	MIPO (1), IMN (1)	0	Mean UCLA score: MIPO, 31.4; IMN, 31.2
	—	—	—	—	Mean Broberg-Morrey score: MIPO, 94.8; IMN, 94.1
Kim et al[37]	68 (MIPO [36], ORIF [32])	0	0	ORIF (1)	Mean UCLA score: MIPO, 33.1; ORIF, 33.9
	—	—	—	—	Mean MEPS: MIPO, 96.4; ORIF, 98.9
Esmailiejah et al[35]	65 (MIPO [32], ORIF [33])	MIPO (1), ORIF (3)	ORIF (2)	MIPO (1), ORIF (4)	Mean UCLA score: MIPO, 33.1; ORIF, 32.8
	—	—	—	—	Mean MEPS: MIPO, 96.6; ORIF, 96.9
Hadhoud et al[36]	30 (MIPO [15], ORIF [15])	ORIF (1)	ORIF (1)	MIPO (1), ORIF (2)	Mean UCLA score: MIPO, 32.2; ORIF, 30.9
	—	—	—	—	Mean MEPS: MIPO, 90.3; ORIF, 97.7
Matsunaga et al[39]	110 (MIPO [58], FB [52])	FB (7)	MIPO (1)	MIPO (1)	Mean DASH score: MIPO, 10.9; FB, 16.9
	—	—	—	—	Mean Constant-Murley score: MIPO, 87.3; FB, 80.0

ASES = American Shoulder and Elbow Surgeons score; DASH = Disabilities of the Arm, Shoulder and Hand; FB = functional bracing; IMN = intramedullary nailing; MEPS = Mayo Elbow Performance Score; MIPO = minimally invasive plate osteosynthesis; ORIF = open reduction and internal fixation; UCLA = University of California Los Angeles Shoulder Rating Scale

MIPO and two after ORIF. The MIPO technique achieved comparable results to ORIF, with reduced perioperative complications and a decreased surgical time. Esmailiejah et al[35] conducted a prospective randomized study comparing MIPO with ORIF in 65 patients. The median time to union was shorter with MIPO compared with ORIF, whereas the time of surgery, as well as functional outcomes for the shoulder and elbow, was no different. The incidence of infection, nonunion, and iatrogenic radial nerve injury was lower with MIPO, but this difference was not significant. In their opinion, the decreased time to union, the trend toward fewer complications, and the comparable clinical outcomes made MIPO a more attractive alternative to ORIF for fractures of the mid-distal humerus.

Most recently, Matsunaga et al[39] completed the first RCT comparing MIPO stabilization versus functional bracing for the management of humeral shaft fractures. Rather than evaluating the potential benefit of MIPO with respect to other surgical alternatives, this landmark study is the first RCT to compare surgical and nonsurgical management of humeral shaft fractures. In an attempt to minimize observer bias, additional measures were taken to attempt to conceal the treatment from the assessors. Patients treated with MIPO stabilization had a lower nonunion rate (zero) than those treated nonsurgically in a brace (15%). In addition, the authors observed less radiographic deformity in the coronal plane in those treated by MIPO, as well as a statistically significant advantage over functional bracing in terms of the self-reported Disabilities of the Arm, Shoulder and Hand score

at 6 months. However, the Disabilities of the Arm, Shoulder and Hand score was just six points better, and only the nonunion rate is likely to be clinically meaningful.

Systematic Reviews and Meta-analyses

Four systematic reviews and meta-analyses regarding MIPO for humeral shaft fractures have been published. Yu et al[43] conducted a meta-analysis comparing humeral shaft MIPO with ORIF, although they found only a limited number of high-quality studies (ie, two RCTs, three non-RCTs) that met their inclusion criteria. There was a markedly lower incidence of iatrogenic radial nerve palsy in patients treated with MIPO. No significant difference was observed in the risk of developing nonunion, delayed union, malunion, implant failure, or infection between the groups. Similarly, no difference was observed in the surgical time or functional outcome scores. They concluded that MIPO is a safe and effective technique for the stabilization of humeral shaft fractures, with a decreased risk of iatrogenic radial nerve palsy compared with ORIF.

Hohmann et al[40] also completed a systematic review and meta-analysis of MIPO compared with either ORIF or IMN for the management of humeral shaft fractures. In their analysis, eight studies met the inclusion criteria, and again, the paucity of high-quality studies was recognized. In this study, the pooled estimate for clinical outcomes demonstrated that MIPO resulted in markedly better function. Similarly, they demonstrated that the ORIF/IMN group had a significantly higher complication rate (odds ratio, 0.507; $P = 0.02$). Specifically, a significantly higher number of nerve injuries was noted after ORIF/IMN (odds ratio, 0.302; $P = 0.02$). Their analysis of the literature demonstrated that MIPO results in better clinical outcomes with a lower rate of complications compared with alternative surgical techniques and is a safe and effective technique for the management of humeral shaft fractures, while being comparable, if not superior, to the other available methods.

Hu et al[41] performed a meta-analysis comparing MIPO with alternative forms of surgical stabilization of displaced humeral shaft fractures. They analyzed eight studies, including four RCTs, two prospective trials, and two retrospective cohort trials. They identified no notable difference between MIPO and either ORIF or IMN with regard to the surgical time, union rate, or time to union. However, MIPO had a reduced rate of complications, including iatrogenic radial nerve palsy, compared with ORIF and better adjacent joint motion compared with IMN.

Most recently, Qiu et al[42] published their Bayesian meta-analysis comparing MIPO, ORIF, and IMN of humeral shaft fractures. This is the most comprehensive meta-analysis to date, incorporating 17 RCTs or prospective studies. The pooled results showed that the rates of radial nerve injury were lowest for MIPO, intermediate for ORIF, and highest for IMN. They also demonstrated that the risk of nonunion was lowest for MIPO, intermediate for ORIF, and highest for IMN. They concluded that the current evidence demonstrates that MIPO is the optimum choice for the management of humeral shaft fractures and that ORIF is superior to IMN.

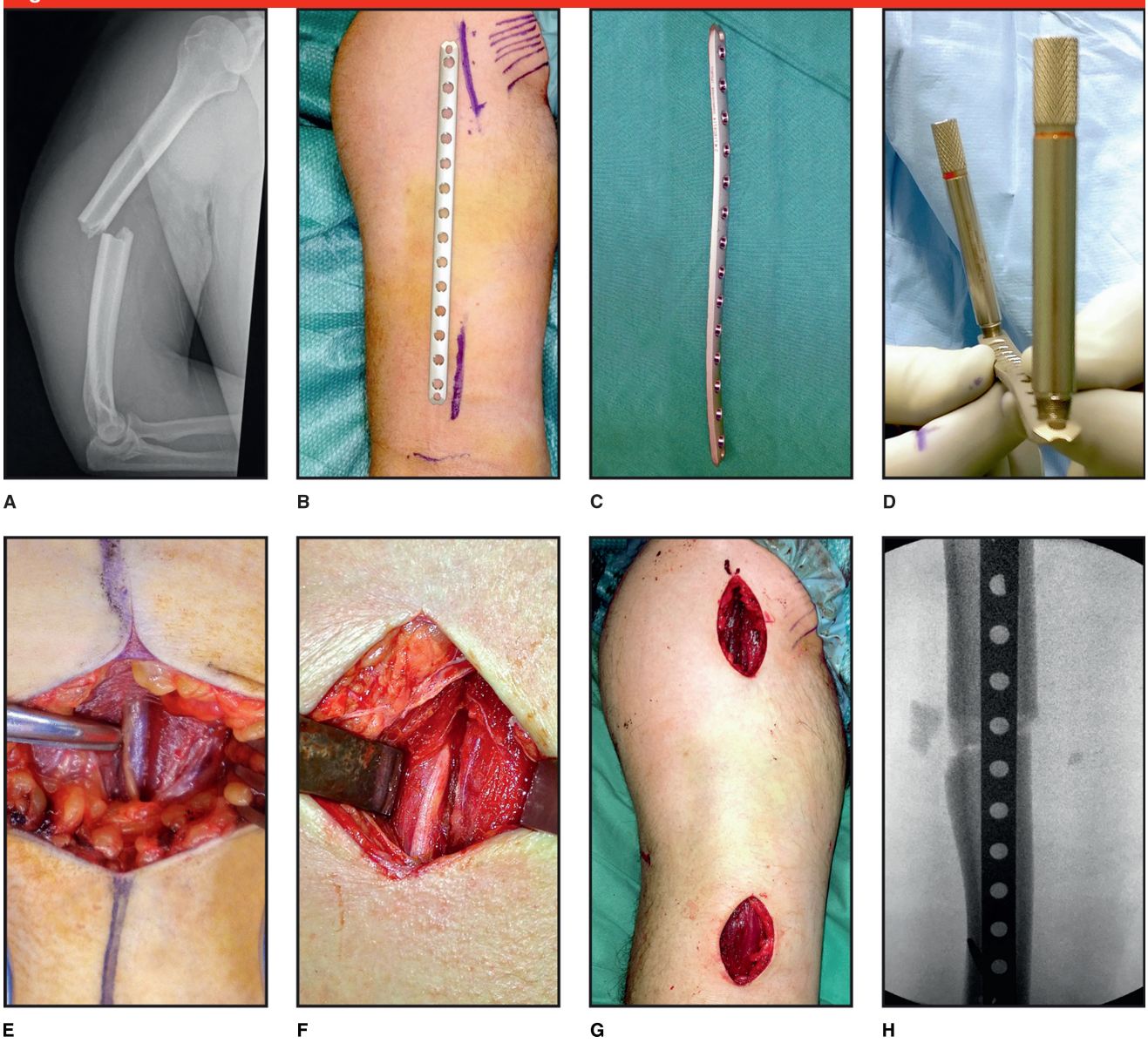
Indications and Contraindications

As with other techniques of surgical stabilization, the indications for MIPO of humeral shaft fractures include failed nonsurgical treatment, polytrauma, certain open fractures, bilateral injuries, floating shoulders, and ipsilateral forearm fractures.[1] Contraindications include pathologic fractures, advanced osteoporosis, associated vascular injuries, severe soft-tissue compromise, active local infection, and radial nerve palsy after a penetrating injury. Anterior humeral MIPO can be equally applied to transverse fractures, spiral fractures, segmental fractures, and comminuted fractures, recognizing that some fractures would inevitably be more difficult to control by any method. With minor modifications of the implants selected and the specifics of the technique, MIPO methods can be used for fractures extending from the surgical neck of the humerus to within 10 to 12 cm of the elbow joint line. Humeral shaft fractures in the proximal third are more difficult to control, and the deltoid acts to displace the fracture site. Slight extension of the proximal approach facilitates a more anatomic reduction, and the judicious use of additional screws will augment stability. Although some surgeons still consider radial nerve palsy as an indication for surgical exploration and ORIF, the current consensus for closed fractures is an expectant policy of observation and monitoring nerve injuries unless they were the direct result of an attempted reduction maneuver.[5] MIPO humeral fracture stabilization can still be used in the presence of a preexisting radial nerve palsy, anticipating that most will resolve spontaneously over the ensuing weeks.

Surgical Technique

The surgical technique has been explained in detail in many previous publications, with the article by Apivatthakakul et al[12] providing the most complete description with extensive illustrations. Most authors

Figure 1

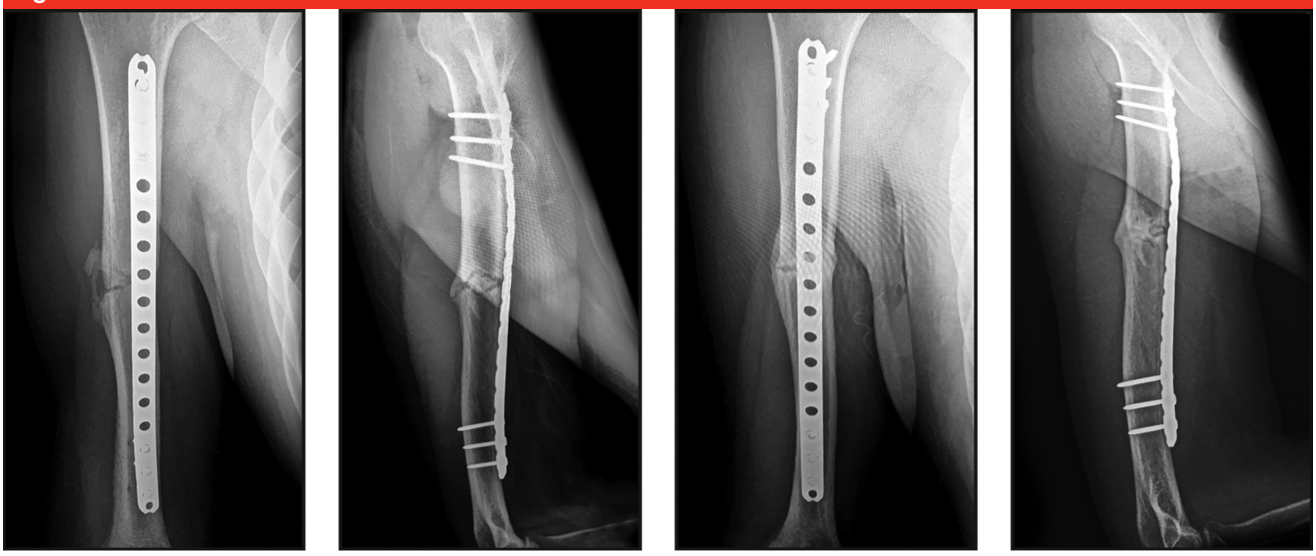


A, AP radiograph demonstrating a closed midshaft right humeral shaft fracture in a 37-year-old right-hand–dominant man who sustained polytrauma in a motorbike accident. Other trauma included a right-sided floating elbow and an ipsilateral both-bone forearm fracture. **B**, Intraoperative photograph showing a 14-hole locking compression plate with adequate length to span the fracture and provide sufficient mechanical control. **C**, Photograph showing the plate precontoured by bending the plate with subtle opposing curves proximal and distal to closely match the normal anterior humeral cortical surface and to serve as a better template for restoring anatomic alignment. **D**, Photograph showing the plate internally rotated 15° to 20° through its midportion, consistent with normal anatomy. **E**, Intraoperative photograph showing the proximal incision of 4 to 5 cm in length at the level of the pectoralis major insertion, with the cephalic vein preserved; this incision is an extension of the deltopectoral approach. **F**, Intraoperative photograph showing the distal incision of 4 to 5 cm in length just proximal to the antecubital crease; the lateral antebrachial cutaneous nerve of the forearm was identified beneath the biceps before bluntly splitting the brachialis. **G**, Intraoperative photograph showing the two incisions on the anterior arm, connected by a submuscular extraperiosteal tunnel. **H**, Fluoroscopic image demonstrating provisional reduction and alignment after insertion of the plate.

consistently follow a common set of principles,[10,12-14,17-20,22,23,25-29,31-35,49-51] with minor variations based on individual experience (Figures 1 and 2).

The patient is positioned supine, with the fractured extremity on a radiolucent table and the elbow supported in mild flexion to relax the biceps. This positioning facilitates reduction and increases the exposure possible through the limited incisions, especially distally. MIPO

Figure 2



A, AP radiograph obtained 8 weeks postoperatively demonstrating early callus formation, with minor varus alignment (<3°). **B**, Lateral radiograph obtained 8 weeks postoperatively demonstrating near-anatomic alignment. **C**, AP radiograph obtained 1 year postoperatively demonstrating mature bridging callus. **D**, Lateral radiograph obtained 1 year postoperatively confirming solid union.

humeral plating requires only two 4- to 5-cm incisions proximally and distally on the anterior aspect of the arm (Figure 1, B and G). The proximal incision is the inferior portion of the deltopectoral approach, using the biceps groove and pectoralis tendon as landmarks and exposing the proximal diaphysis immediately lateral to the biceps tendon (Figure 1, E). The distal incision begins 1 to 2 cm proximal to the antecubital crease and extends proximally for 4 to 5 cm in the midline (Figure 1, F). The interval between the biceps and brachialis is identified laterally, and the biceps is retracted medially. Care is taken to identify and protect the lateral antebrachial cutaneous nerve lying beneath. The brachialis is then split longitudinally by blunt dissection to bone, limiting dissection or retractors laterally to avoid the radial nerve at this level. It is important to keep the forearm supinated throughout the procedure to protect the radial nerve in the distal portion of the approach.[11,20,34,47]

Provisional fracture reduction is performed manually under fluoroscopic control, and a submuscular extraperiosteal tunnel is developed that connects the two incisions (Figure 1, H). Many authors recommend using a narrow 4.5-mm LCP, although our preference is for a 3.5-mm LCP. Most authors also report using a straight LCP and rely on the locking screws to maintain the reduction achieved intraoperatively.[12,17,23,31] However, to achieve the most anatomic reduction possible, the plate can be precontoured to more closely correspond to the surface of the anterior cortex of the normal humerus (Figure 1, C).

After introducing the plate, the proximal segment is aligned with the implant as anatomically as possible, and a single unlocked screw is used to reduce the plate to the anterior humeral cortex. Fixation is augmented with two additional locked screws, and the plate is then used to assist with the reduction.[29] The plate is next aligned with the distal segment as anatomically as possible, and the fracture reduction is checked fluoroscopically. Before initiating distal fixation, the reduction is assessed critically and efforts are made to correct any malalignment; recognizing rotation may be the most difficult aspect to judge correctly.[33] Manual compression of the fracture site is recommended to limit the possibility of distraction resulting in delayed union. After provisional fixation is obtained, rotation is best assessed by direct comparison with the rotational excursion of the undraped opposite limb. A single unlocked cortical screw is used to reduce the plate to the distal humerus, and distal fixation is finally augmented with two additional locked screws.

A temporary external fixator can be used intraoperatively to control the fracture in the coronal plane,[17,19,24,25,32] but most surgeons achieve satisfactory alignment using standard closed reduction techniques. When a radial nerve injury is identified preoperatively, Livani

et al,[21] have advocated formal release of the nerve through an accessory third incision. However, most authors agree that the radial nerve should not be explored routinely, and these injuries generally recover spontaneously without active intervention.

The choice of implant (ie, 3.5-mm LCP or long proximal humerus locking plate) and specifics with regard to postoperative rehabilitation can be determined based on the fracture configuration and location, as well as details with respect to the surgical indications, quality of the reduction, and the strength of screw purchase in any individual patient. Patients are generally instructed to use a sling for comfort as necessary for the first 2 weeks. Early active/assisted range of motion of the shoulder and elbow is encouraged immediately, without restrictions. Full extension of the elbow is an early priority, and activity is increased as limited by pain. Minor functional limitations are continued until solid bridging callus is visible radiographically. Return to sports and completely unrestricted activity is generally permissible within 4 to 6 months.

Summary

The focus of this review was to introduce the MIPO technique for humeral shaft fractures, while summarizing the available literature regarding the indications, contraindications, clinical outcomes, and potential benefits. More than 40 relevant articles have already been published, generally favoring MIPO compared with alternative methods of surgical stabilization (ie, ORIF, IMN), including 6 RCTs[34-38] and 4 meta-analyses.[40-43] These findings are not surprising because previous studies using MIPO for the lower limbs have also demonstrated a decreased rate of nonunion and diminished need for further surgery.[44,45] Leaving the early fracture callus undisturbed while preserving local vasculature theoretically contributes to accelerated union.[44,45] However, the greatest advantage seems to be the diminished risk of complications, particularly reducing the rate of iatrogenic radial nerve palsy.[14,40-43]

Based on the available literature, MIPO now holds genuine promise as an alternative method of humeral shaft fracture fixation. The current literature consistently favors MIPO compared with other methods of surgical stabilization, and it offers a middle ground between ORIF and IMN that incorporates some of the best aspects of each. Although many cases can be managed nonsurgically, MIPO provides another option for managing select humeral shaft fractures that may benefit from surgery. The MIPO technique compares favorably to other available forms of treatment with excellent functional outcomes, a lower rate of iatrogenic radial nerve injury, and a high rate of rapid union. However, larger RCTs comparing this method with other accepted techniques, including nonsurgical management, are necessary to better define the role of MIPO for humeral shaft fractures.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 3-6, 32-37, and 49 are level I studies. References 38-41 are level II studies. References 7, 8, 12, 23, and 31 are level III studies. References 2, 9-11, 13-22, 24-30, 45-48, 50, and 51 are level IV studies.

References printed in **bold type** are those published within the past 5 years.

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