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A practical guide for the use of contour locking plates for the repair of humeral diaphyseal fractures with proximal extension

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ABSTRACT

Introduction: The emergence of minimally invasive techniques has expanded the use of plates and improved their safety for the repair of humeral diaphyseal fractures with proximal extension. In this study, we aimed to determine the best contouring method for long locking plates in the repair of humeral fractures using this approach.
Patients and methods: Comparative observations were performed between helical and spiral modelling in plastic models to identify which shape best fits the contours of the humerus. To determine the best shape, we attempted to assess the torsion required for the plate to settle laterally in the greater tuberosity and anteriorly in the diaphyseal region of the humerus. After establishing the best approach, we transferred the method to two anatomical specimens and confirmed the viability of the method and pathways. Additionally, to confirm the clinical applicability of the method, we applied the method in ten patients.
Results: After placing the plates in the bone models, it was found that the helical plate was more distant from the bone. On the other hand, the spiral plate achieved better accommodation along the contours of the humerus. The amount of twist was tested at 50°, 70° and 90°. When the plate was twisted at 70°, it maintained contact with the greater tuberosity proximally and the anterior cortical diaphyseal region. Eight patients completed the follow-up. Radiographic consolidation and good functional outcomes were achieved in all patients.
Conclusions: Spiral modelling at 70° allows anatomical accommodation at the greater tuberosity proximally and in the diaphyseal region.

Introduction

Proximal and diaphyseal humeral fractures are usually treated conservatively; however, the nonunion rate of diaphyseal humeral fractures extending proximally has been reported to be as high as 29% owing to the action of muscular forces, which result in deviations and lack of contact between fracture fragments [1–4]. The fixation of proximal humeral fractures with plates is associated with the occurrence of many complications, especially avascular necrosis and fixation failure, with the latter likely resulting from the loss of periosteal blood supply because of extensive exposure, bone fragility secondary to advanced age and low stability, thereby reflecting a clear dissociation between metallurgy and biology [5]. Despite these problems, plate fixation remains a viable option for the repair of humeral diaphyseal fractures with proximal extension, and biological fixation has been developed to minimise the above-mentioned complications [2,4,6].

Over the past decade, researchers have developed various procedures involving the use of fixed-angle implants that are installed by minimally invasive approaches (e.g. minimally invasive percutaneous plate osteosynthesis [MIPPO]) and offer high fixation stability [6]. The use of MIPPO techniques for fracture repair requires knowledge about the involved structures in order to avoid the potential risk of injury when accessing pathways and implant fixation sites. Additionally, it is fundamental to use safe corridors to tunnel and slide the implants in place. The main structures located in the path of the implant are the proximal axillary nerve and distal radial, musculocutaneous and lateral cutaneous nerves of the forearm [7,8]. Unfortunately, few publications in the literature provide information on shaping of plates for the repair of metaphyseal

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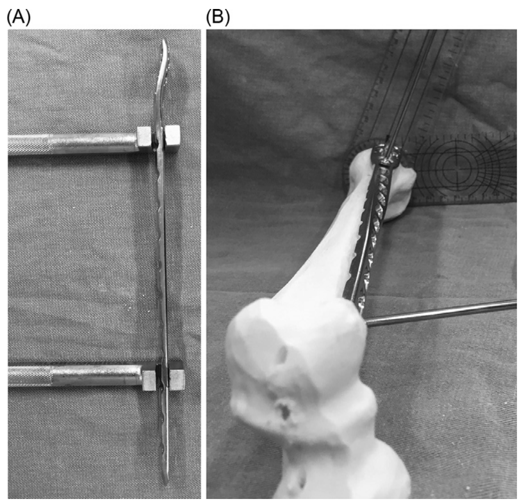

Fig. 1. (A) Location of plate contouring, with attention to avoid distortion of the head and distal holes, where the plate will be fixed to the bone. (B) The implant was tested with a twist of 70°.

or diaphyseal fractures, which translates into clinical difficulties in such situations.

In 2002, Fernández [9] described contouring of helical plates for humeral and femoral fixation and emphasised the importance of differentiating between spiral and helical contouring. In the former, the plate winds around a single point in two distinct planes, whereas in the latter, the plate follows a three-dimensional curve that lies on a cylinder while its angle remains constant to a plane perpendicular to the axis. Fernández contoured the plates to lay laterally in the proximal aspect of the humerus and anteriorly in the humeral diaphysis and used a plate with a helical contour to prevent the formation of neurological and vascular lesions during the surgical procedure [7,9].

The aim of this study was to evaluate the best contouring method for long locking plates in the repair of humeral diaphyseal fractures with proximal extension, using plastic bone models, anatomical specimens and clinical data (to confirm the clinical applicability of the method).

The study protocol was approved by the institution's ethics committee (CAAE: 49761215.9.0000.5479).

Patients and methods

This experimental study used similar, certified and intact plastic models (Synbone 5010^{TM}; Synbone AG, Malans, Switzerland). The fixation positions were determined, and the accommodation of the implant was evaluated using plates with two different contours (spiral and helical).

A long proximal humeral internal locking plate system (PHILOS, Synthes®) with 12 diaphyseal holes was used to evaluate how different plate contours can accommodate the intact plastic model. We tested and compared spiral and helical mouldings on plastic models and determined the best shape for further study. Plates with standard 50°, 70° and 90° spiral contouring were evaluated while maintaining the holes at the head of the plate and the last three diaphyseal holes (Fig. 1). We attempted to reproduce a standard surgical procedure while preventing deformation of the holes for fixed-angle screws.

In order to confirm and reproduce the results obtained with the plastic models, the twisted plates at 70° were shifted for anatomical specimens. In these specimens, we used a technique that simulates a minimally invasive procedure, where a transdeltoid approach is applied proximally and an anterior approach is applied distally to the humerus while separating the brachialis muscle along the midline [5,10,11]. The models were then analysed. The accommodation of the plate along the bone, the approach and the proximity of the plate to the axillary and radial nerves were assessed.

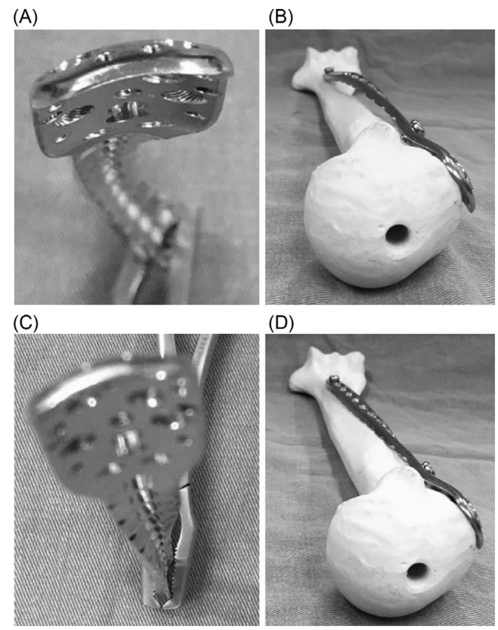

Fig. 2. (A, B) Plate with helical contouring twisted to maintain a constant distance and axis in the model. (C, D) Plate with 70° spiral contouring accommodated on the bone model, where the plate is twisted on its own axis.

In the final assessment of the applicability of the method, ten patients (aged ≥18 years; both sexes) who underwent repair of the humeral shaft with proximal extension up to the surgical neck using contoured plates twisted to 70° between August 2015 and February 2016, were followed up prospectively. The mean follow-up period was 29 (range: 25–33) months. Eight patients completed the follow-up. There were three male and five female patients, with a mean age of 53.7 (range: 24–79) years. The mean time from injury to surgery was 9.6 (range: 5–15) days, and the fractures were classified according to the AO/OTA Fracture and Dislocation Classification as 12-A (four patients), 12-B (three patients) and 12-C (one patient) [12]. None of the patients presented with injury to the radial nerve prior to treatment, although two developed neuropraxia postoperatively but completely recovered after the follow-up. The radial nerve was visualised intraoperatively in one of these patients but not in the other

Pearson's correlation analysis, confidence interval inference, the Kruskal–Wallis test and the chi-square test were used for statistical analyses. In addition, descriptive statistical analyses were conducted. All statistical analyses were performed using Statistica 8.0 (StatSoft Power Solutions, Inc., Tulsa, OH, USA) or IBM SPSS Statistics for Windows, version 20 (IBM Corp., Armonk, NY, USA).

Results

The results of the bench tests clearly showed that the contact of the implant next to the plastic model was punctiform along the distal portion and the plate was too distant in the diaphyseal region when the helicoidal model was assessed. Conversely, there was good accommodation of the implant when the spiral model was assessed (Fig. 2).

With regard to the degree of twist, when the plate was twisted at 70°, it remained in contact with the greater tuberosity proximally and the anterior cortex in the diaphyseal region. Addition-

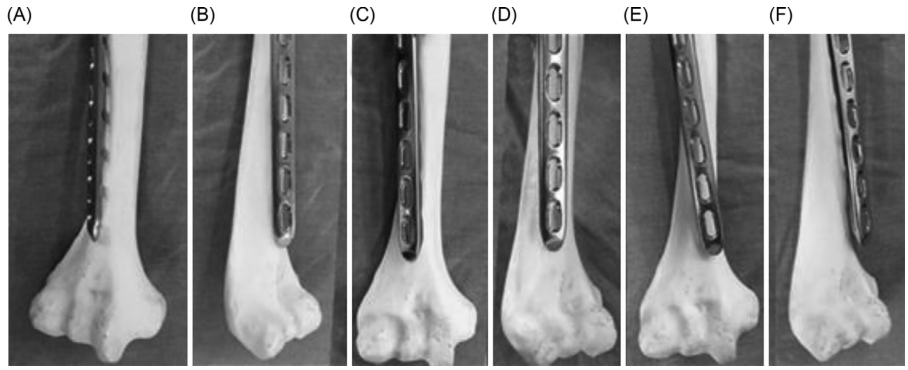

Fig. 3. (A, B) At 50°, the plate is marginal in the lateral cortex, and its distal portion loses contact with the bone. (C, D) At 70°, there is better accommodation of the implant in the anterior region of the diaphysis. (E, F) At 90°, there is overpassing of the implant beyond the diaphysis in the distal portion, which can create a problem with the use of locked screws, as the holes in the plate do not allow angulation.

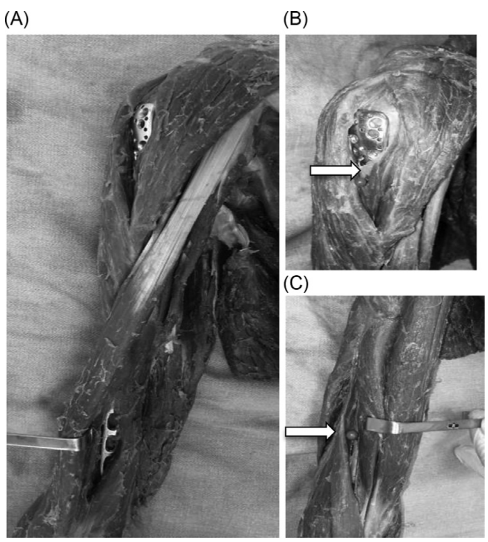

Fig. 4. (A) A 70° spiral contoured plate in an anatomical specimen, simulating a minimally invasive approach (transdeltoid proximally and anterior distally). (B) The arrow shows the axillary nerve in the proximal approach. (C) The arrow shows the radial nerve in a position lateral to that used for anterior access.

ally, at 50°, there was partial contact in the lateral cortex, and at 90°, the plate went beyond the medial cortical diaphyseal region (Fig. 3).

When testing the anatomical model with the 70° plate (Fig. 4), we had difficulty in tunnelling the plate at the lateral insertion of the deltoid muscle, and this difficulty was overcome with the use of a chisel as a facilitator instrument. In both models, the axillary nerve was identified in the proximal approach and was preserved without difficulty. The axillary nerve always rested on the plate in our approaches. Distally, the shortest distance from the lateral edge of the plate to the isolated radial nerve was 3.1 mm in one anatomical model and the longest distance was 4.3 mm.

In patients who underwent the method, the mean time from surgery to radiographic consolidation was 12 (range: 10–16) weeks. The University of California at Los Angeles (UCLA) shoulder score and Disabilities of the Arm, Shoulder and Hand (DASH) score were good to excellent [10,13], with values of 31.4 (range: 28–34) and 10.58 (range: 0.83–22.2), respectively. There were two cases with a transient complication, which was diagnosed to as postoperative radial nerve neuropraxia.

The associations among various factors are presented in Table 1. There were direct relationships between the rotations of contralateral limbs and those of operated limbs (numerically expressing the clinical results), indicating that the results were satisfactory. Additionally, there was a negative relationship between external rotation and the DASH score (as external rotation of the operated side increased, the DASH score decreased).

The confidence interval construction technique and the Kruskal–Wallis test were used for assessing the correlation of the fracture severity (according to the AO/OTA classification) because variances were not homogeneous according to analysis of variance (Tables 2 and 3).

Discussion

We attempted to identify the best contouring method for long locking plates in the repair of humeral diaphyseal fractures with proximal extension. We found that accommodation of the implant was better with the spiral model than with the helical model, and it translated into greater ease of fracture reduction in an intraoperative situation, as well as greater fixation capacity of the plate. Therefore, spiral modelling most closely approximated the principles of minimally invasive treatment for diaphyseal fractures.

Long plates with fixed angles provide stable fixation of complex fractures of the proximal humerus with diaphyseal extension.

Table 1
Matrix of Pearson's correlation coefficients of quantitative variables.

	ER operated	ER CL	IR operated	IR CL	UCLA	DASH
ER operated	1.00	0.76	0.20	0.09	0.42	−0.76
ER CL	**0.76**	1.00	−0.01	−0.04	0.35	−0.61
IR operated	0.20	−0.01	1.00	**0.87**	−0.21	0.10
IR CL	0.09	−0.04	**0.87**	1.00	−0.53	0.20
UCLA	0.42	0.35	−0.21	−0.53	1.00	**−0.75**
DASH	**−0.75**	−0.61	0.10	0.20	**−0.75**	1.00

Abbreviations: ER, external rotation; IR, internal rotation; CL, contralateral; UCLA, University of California at Los Angeles; DASH, Disabilities of the Arm, Shoulder and Hand. Values are in bold are statistically significant.

Table 2
Correlations between the fracture classification (A, B or C) and the UCLA score and functional result.

Classif	UCLA media	Standard error	Inferior 95% CI	Superior 95% CI
A	32	0.707	30.18	33.81
B	32	0.816	29.90	34.09
C	28	1.414	24.36	31.63

Abbreviations: Classif, classification; CI, confidence interval.

Table 3
Correlations between the fracture classification (A, B or C) and the DASH score and functional result.

Classif	DASH media	Standard error	Inferior 95% CI	Superior 95% CI
A	5.6	4.137	−5.01	16.25
B	13.3	4.777	1.04	25.61
C	22.2	8.274	0.92	43.47

Abbreviations: Classif, classification; CI, confidence interval.

(A) (B) (C) (D)

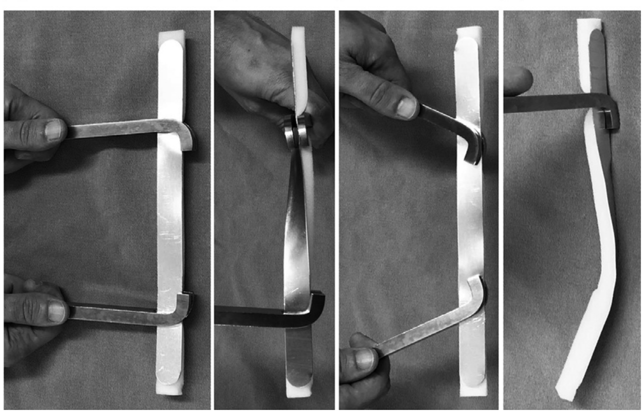

Fig. 5. Moulding of the plate with moulders parallel to each other and perpendicular to the metal model (A) creates a spiral impression (B). Plate moulding with converging moulders (C) promotes a bend associated with the twist (D).

However, deformation of plate holes during contouring, which is a well-known complication, may damage the locking mechanism and affect the fatigue property of the plate [14]. In order to avoid this complication, plate contouring should follow established parameters that help avoid damaging the threaded holes at the head of the plate and the three distal holes, maximising implant fixation.

The first step of the learning was development of the best positioning of the plate moulders. With regard to the spiral contour, the moulders should be parallel to each other and perfectly perpendicular to the plate. If there is convergence or divergence (Fig. 5), there may be flexion or extension of the implant associated with torsion.

The long head of the brachial biceps and the intertubercular groove prevent plate fixation on the anterior proximal humeral surface, whereas the insertion of the deltoid muscle limits implant fixation on the lateral aspect of the proximal humerus. Alignment causes stress between the screw holes, which may lead to new longitudinal fractures. These factors justify the continued use of the spiral plate method [6–9,11,14].

Fixation of the plate to the anterior aspect of the humeral diaphysis is an excellent solution to avoid injury to the radial nerve that surrounds the medial, posterior and lateral aspects of the humerus [7]. An anterolateral acromial surgical approach [11] coupled with helical plating is an attractive option for minimally invasive access and avoidance of the fracture site [5]. The deltopectoral approach with helical plates for fractures of the proximal third of the humerus has been reported to be associated with satisfactory clinical results [5,9]. When exploration of the radial nerve is indicated, the implant may be placed without prior contouring. The radial nerve was identified in the anatomical models, as expected, and the smallest distance between the nerve and implant occurred at an average of 12.9 (range: 12.6–13.2) cm from the lateral epicondyle. However, the specimens were not fresh, and thus, the measurement was not as precise as desired. Spiral plates implanted with the MIPPO technique may be associated with risks of injury to the axillary nerve proximally and the lateral cutaneous nerve of the forearm in the distal approach. Both the radial and musculocutaneous nerves are close to the pathway of the implant; therefore, an appropriate technique should be employed to avoid injury to these nerves. When performing such techniques, the forearm should be maintained in the supine position during the entire procedure and Hohmann retractors must be avoided. Because of the rigidity of the anatomical models, it was not possible to employ such preventive techniques when measuring the distance between the implant and radial nerve.

In the present study, plates with a helical contour were more distant from the plastic models [6,9,15]. Conversely, it was easy to slide plates with a spiral contour through the insertion of the deltoid muscle with the aid of a chisel, as it is close to the bone. Although the plate was twisted by 70° on its own axis, it had excellent fixation and accommodation in both the plastic model and anatomical specimens. Proximal accommodation of the spiral plate is achieved by tilting the plate relative to the greater tuberosity. This procedure requires not only great care, but also insertion of a short screw in the anterosuperior hole, considering the risk of articular penetration. Additionally, fixation is weak at the humeral head owing to decreased bone mineral density [16,17].

We questioned whether there could be issues with the implant length, but considering that the use of this method of fixation is indicated for the treatment of metaphyseal fractures with a diaphyseal extension, the distal region can be explored and the length of the plate can be as large as necessary till the anterior coronoid fossa region, as long as it allows fixation with three screws and maintains free flexion of the elbow joint.

Smith et al. demonstrated that locking plates could be safely adopted for the proximal humerus with minimally invasive techniques but the plate sleeve (aiming system) must be avoided [18]. The authors indicated that it is only safe to place the locking screws in the three proximal rows of the plate while maintaining a good safety margin with regard to the axillary nerve when the plate is positioned laterally.

To confirm the practical applicability of the method, we applied the technique in ten patients with diaphyseal fractures of the humerus with proximal extension (Fig. 6), and eight of these patients completed the follow-up. We noted the importance of the preliminary analysis moulding of the plates on the plastic models as facilitators of the procedure. The approach was found to be reproducible and safe. The axillary nerve in the proximal pathway invariably remains in contact with the implant, and we had no difficulty locating and protecting the nerve during the operation. The radial nerve was not assessed during the procedure, but there was a possibility of distal access interfering with the nerve, and in such

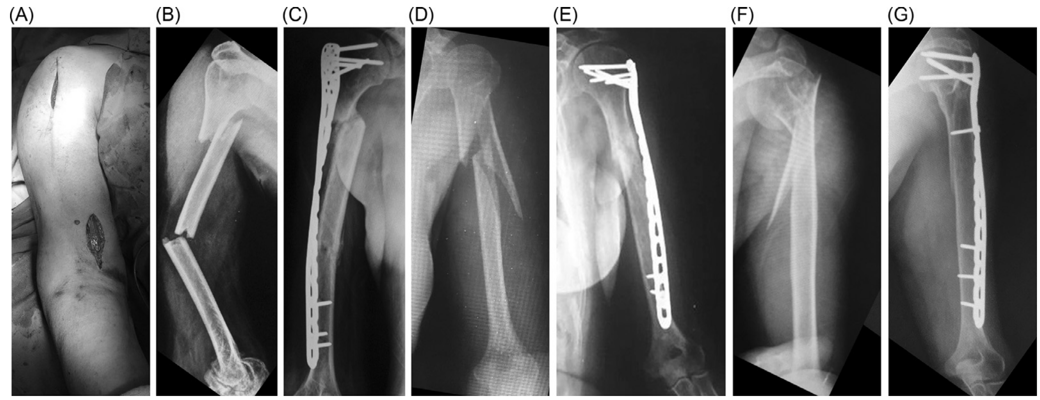

Fig. 6. (A) Approaches performed for bridging plate - proximal transdeltoid and anterior in the distal segment. (B, C) Pre and postoperative complex fracture. (D, E) Pre and postoperative fracture with a wedge. (F, G) Before and after fracture with a wedge and medial calcar comminution.

a situation, the nerve was mobilised. The radial nerve and implant are usually in different muscular planes, with the radial portion of the brachial muscle separating these structures. Two patients had postoperative neuropraxia, but they showed complete remission of the condition during follow-up. In one of these patients, the nerve had been identified and mobilised.

With regard to clinical results, all patients showed good outcomes as expected, and there were no complications, such as infection, pseudoarthrosis and implant breakage. There was a negative correlation between the results of external rotation and the DASH score (a larger external rotation was associated with better functional results). In a previous comparative study evaluating rotational deviations in minimally invasive fixation with the technique described, there were more fixations with external rotation than with internal rotation [19]. The authors attributed these results to the position of the limb on the surgical table, where the force of gravity maintains external rotation of the limb during the procedure. Considering our data, these factors may be beneficial to achieve better final functional results.

We were unable to establish a significant correlation between the energy of trauma, presumed by the AO/OTA classification and the functional results, and the extended confidence interval because of the small number of patients (UCLA score, $p = 0.293$; DASH score, $p = 0.311$).

The present study had some limitations. Plastic models and anatomical species do not represent the actual situation that depends on factors, which are sometimes unforeseeable, such as fractures and patient characteristics. Additionally, the number of included patients was small because of the specificity of the procedure indication, which limited the reliability of the statistical results, but it was sufficient to prove the practical application of the implant moulding method. The present results will pave the way for future research involving this methodology.

Conclusion

A 70° spiral model allowed for anatomical accommodation near the greater tuberosity and in the anterior diaphyseal region. Our method achieved satisfactory clinical results.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

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