Int J Clin Exp Med 2017;10(4):6489-6495
www.ijcem.com /ISSN:1940-5901/IJCEM0049548

Original Article

Tips and tricks of long helical PHILOS plating on proximal humeral diaphyseal and metaphyseal fractures using the MIPO technique in elderly patients: a cadaveric study and clinical experience

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Received January 23, 2017; Accepted February 27, 2017; Epub April 15, 2017; Published April 30, 2017

Abstract: Proximal humeral diaphyseal and metaphyseal fractures in elder patients are more likely to result in nonunion, and joint stiffness problems will appear after long-term external fixation. When a straight metaphyseal locking plate is inserted distally through a conventional approach, it is inevitable that the deltoid muscle insertion will be detached massively and there is the possibility of distal iatrogenic radial nerve injury. The purpose of this study is to identify the safety and efficacy of the long helical PHILOS plating on treating proximal humeral diaphyseal and metaphyseal fractures in elder patients with MIPO technique based on cadaveric and clinical studies. We put the 10-hole long helical PHILOS plates on the arms of six fresh elderly cadavers and the anatomic relationships were studied. After that, 16 elderly patients (>65 years old) were treated by the same technique and clinical outcomes were studied. Finally, the results of our cadaveric and clinical study showed that the radial nerve, the musculocutaneous nerve and the brachial vein are safe and at 2-year follow-up, the average Constant-Murley score and the MEPS were 77.3% and 96.7 respectively. So, proximal humeral diaphyseal and metaphyseal fractures in elderly patients can be successfully treated with a long helical PHILOS plate by the MIPO technique.

Keywords: Helical plate, humeral fractures, MIPO, neurovascular injury, anatomy

Introduction

Humeral shaft fractures account for approximately 1-3% of all fractures [1, 2], most of which can be treated conservatively. However, the union rate of fractures in the proximal third is relatively lower than those in other regions with conservative treatment, and this specific fracture is more likely to result in nonunion [3-5] with joint stiffness problems tending to appear after long-term external fixation [6]. Moreover, approximately 49.3% of proximal-third humeral shaft fractures extend into the humeral head [5, 7], which is difficult to verify on X-ray and should be treated with stable fixation. Thus, for proximal humeral diaphyseal and metaphyseal fractures, internal fixation should be considered as an alternative.

With the growth of the elderly population, most proximal humeral diaphyseal and metaphyseal fractures occur because of osteoporosis [8]. Locking plates, which are considered to be a better choice than other implants in fixing osteoporotic bone, are widely used to treat proximal humeral diaphyseal and metaphyseal fractures [6, 7, 9, 10]. Use of the minimally-invasive plate osteosynthesis (MIPO) technique should reduce soft tissue injury and preserve the blood supply of the fragments. However, when a straight metaphyseal locking plate is inserted distally through a conventional approach, it is inevitable that the deltoid muscle insertion will be detached massively and there is the possibility of distal iatrogenic radial nerve injury [11-14]. Thus, the helical plating technique is recommended.

Helical plating was first reportedly used in proximal third humeral shaft nonunion in 1999 [15]. This technique was developed and successfully used for the internal fixation of proximal humer-

Figure 1. A 10-hole long helical PHILOS plate was precontoured on synbone, then placed on the right arm of a fresh elderly cadaver using the minimally-invasive plate osteosynthesis (MIPO) technique.

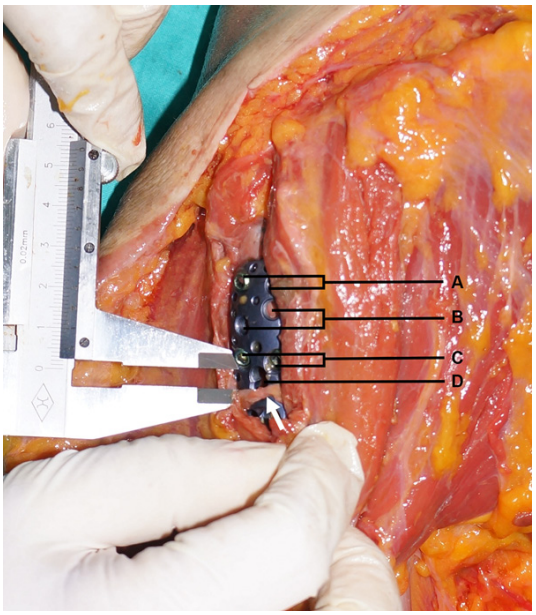

Figure 2. The proximal holes of the PHILOS plate are marked as (A-D), while the white arrow indicates the axillary nerve which just passes across the plate below hole (D). This was considered to be the "safe zone" for screwing above the (D) hole.

al shaft fractures [12, 13, 16-19]. The locking plate is twisted about 90° to lie on the lateral aspect of the greater tuberosity proximally and the anterior or anteromedial aspect of the humeral shaft distally, so theoretically, most of the deltoid muscle attachment can be preserved and the radial nerve should not be entrapped in the distal approach. However, the limited number of proximal locking screws may not provide adequate stability for fixation of proximal humeral diaphyseal and metaphyseal fractures with a metaphyseal locking plate, especially in a geriatric patient with osteoporosis, which may lead to a high rate of implant failure after surgery. Furthermore, if the diaphyseal humeral fracture extends to the humeral head, the metaphyseal locking plates will not provide sufficient stability for fracture fixation. Thus, we hypothesized that the helical long PHILOS plating technique would be a better choice.

The purpose of this study was to identify the safety of the helical long PHILOS plate fitted by the MIPO technique based on cadaveric anatomy, and then to present retrospective clinical outcomes of proximal humeral diaphyseal and metaphyseal fractures fixed with the helical long PHILOS plates percutaneously in elderly patients. In addition, some recommended tips and tricks during the operation are provided.

Materials and methods

Before the procedure, a 10-hole long PHILOS plate (DePuy Synthes, Zuchwil, Switzerland) was precontoured on a Synbone (Synbone AG, Malans, Switzerland) model of the right humerus (**Figure 1**). The plate was twisted at about 90 degrees (began at the superior part of humeral deltoid tuberosity), as the proximal part of the plate was located on the lateral side of the greater tubercle, and the distal part on the anterior side of the distal humerus. All data are presented as means ± standard deviation. The clinical trial was given approval by the local research ethics committee.

Cadaveric study

Six fresh-frozen human cadaveric right upper limbs from different adult donors were obtained. These comprised four females and two males, with a mean age of 73.7 years (range 66-86). All the specimens included the entire scapula, clavicle and intact associated soft tissues. Gross examination was performed and clinical histories were reviewed to exclude any history of pathological diseases.

With the elbow flexed at 70 degrees and the forearm in full supination, the standard anterolateral acromial approach (ALA) was performed with a 5 cm skin incision proximally, and the

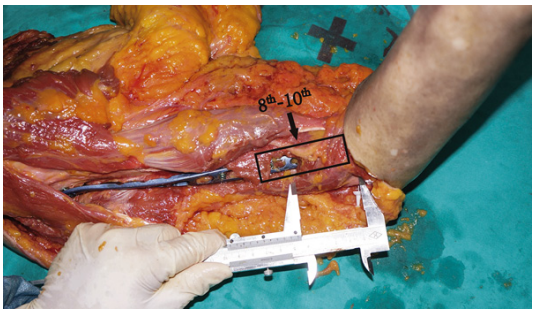

Figure 3. The intersection of the musculocutaneous nerve and plate across the screw insertion at the 8th to 10th hole, which was considered the "danger zone".

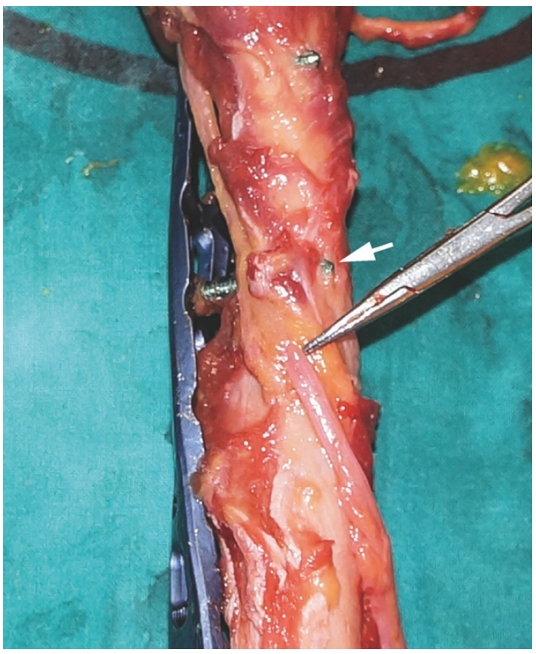

Figure 4. At the mid-point of the posterior humerus, the 6th screw's tip was safe for the radial nerve. The white arrow indicates the tip of the 6th screw and the tip of the needle holder indicates the radial nerve.

anterior approach was performed with a 5 cm skin incision distally by splitting the brachialis longitudinally just along the lateral side of the biceps brachii. During the distal anterior approach, care was taken not to injure the musculocutaneous nerve, which lies between the biceps and the brachialis; the dissection through the brachialis was performed bluntly but gently, without routine nerve exposure. An extraperiosteal tunnel was made to connect with both approaches, from the lateral part of the greater tubercle proximally to the anterior part of the humerus distally. Using the MIPO technique, the precontoured helical long PHILOS plate was then inserted from the proximal approach, passed through the tunnel distally and fixed on the humerus with locking screws through the ALA approach proximally. The distal 8th and 10th holes were screwed through the distal anterior approach, and the distal 6th hole through a stab incision (**Figure 1**).

To identify the anatomic relationships between the implant and neurovascular bundles, a deep dissection was then made by joining the proximal and distal incisions. The course of the radial nerve was traced from the spiral groove in the posterior aspect at the middle third of the humerus to the elbow distally, and the musculocutaneous nerve was exposed at the middle and distal third of the humerus. With the elbow and forearm in the same position, the distance from either the lateral border of the plate or the posterior distal 6th screw tip to the radial nerve was measured and the level of the crossing musculocutaneous nerve on the humerus was also observed. At the medial side, the distance from the brachial vein to the distal medial edge of the plate was measured.

Clinical study

A retrospective review was conducted on 16 consecutive elderly patients (≥65 years old) with proximal humeral diaphyseal and metaphyseal fractures who were treated with this technique in the same institution from February 2011 to February 2013. In addition to radiography in the antero-posterior and lateral views, CT scans were routinely taken preoperatively. After general anesthesia, the patient was placed in the beach-chair position, and the operative procedure was performed similarly to that described in the cadaveric study. The screw insertion on the distal locking hole was decided based on the different working length for the different fracture type in each patient. Whether the distal 6th screw was inserted through the distal anterior approach or through another stab incision was dependent on the severity of soft tissue swelling. The patients were followed up at 1, 3, 6, 12 and 24 months postoperatively, complications and the time to fracture union were recorded, and the outcome was assessed by the Constant-Murley shoulder score and Mayo Elbow Performance Score (MEPS) at 2-year follow-up.

Table 1. Anatomical data based on cadaveric study of six arms

	Average value
Age	73.7 years
Length of the humerus	295.7 ± 4.7 mm
Distance	
The axillary nerve to the great tuberosity tip	40.4 ± 2.7 mm
The radial nerve to the great tuberosity tip	110.6 ± 2.1 mm
The intersection of musculocutaneous nerve and plate to the lateral epicondylar	51.4 ± 4.9 mm
The radial nerve to the distal lateral part of the plate	5.1 ± 0.26 mm
The brachial vein to the distal medial part of the plate	4.7 ± 0.63 mm
The screw at 6th hole to the lateral intermuscular septum	11.0 ± 0.51 mm
The screw tip at 6th hole to the radial groove transversely	8.3 ± 0.72 mm

Table 2. Demographic details and outcomes of patient cohort

Number/ Sex/Age, y	Mechanism of injury	AO/OTA classification	Co-morbidities	Proximal humeral involved	Fellow-up (mo)	Union time, (wk)	Complication	C-M score (%)	MEPS score
1/M/73	Ground-level fall	12C1		N	24	15		77	95
2/F/76	Ground-level fall	12C1	Hypertension	Y	28	12		87	100
3/F/70	Ground-level fall	12C3	Diabetes	Y	24	18		87	100
4/F/78	Ground-level fall	12C1	Stroke	Y	3				
5/F/76	Ground-level fall	12C1	Diabetes, Hypertension	Y	28	12		80	100
6/F/71	Ground-level fall	12C1	Hypertension	Y	28	24	Shoulder impingement	64	95
7/F/73	Ground-level fall	12A1		Y	26	11		83	100
8/F/69	Ground-level fall	12C1	Diabetes, Hypertension	N	24	18		69	95
9/F/67	Ground-level fall	12C1		N	28	11		64	90
10/F/65	Ground-level fall	12A1	Rib fracture	Y	24	13		83	100
11/F/66	Car accident	12C1		Y	36	18		77	95
12/F/75	Car accident	12B1	Diabetes, Hypertension	N	30	24		82	90
13/M/66	Ground-level fall	12A1		Y	24	13		82	100
14/F/69	Ground-level fall	12C2	Pulmonary contusion	Y	28	18		77	100
15/M/67	Ground-level fall	12C1		Y	30	20		69	95
16/M/76	Ground-level fall	12B1	Hypertension	N	3				

M, Male; F, Female; C-M, Constant-Murley; MEPS, Mayo Elbow Performance Score.

Results

Cadavers

The helical long PHILOS plates were inserted just above the periosteum in all six specimens. The plate was laid on the surface of the humerus without nerve entrapment in any case and the main part of the deltoid muscle insertion was protected. The proximal four locking screws were placed in the A holes and D holes, which were both in the "safe zone" because the axillary nerve was passed just below the D holes (**Figure 2**). The distance from the axillary nerve to the tip of the great tuberosity was 40.4 ± 2.7 mm. The musculocutaneous nerve passed across the distal plate at 51.4 ± 4.9 mm on average from the lateral epicondyle. The intersection of the musculocutaneous nerve and the plate was considered as a "danger zone", which covers the screw insertions in the 8th to 10th holes (**Figure 3**). The distance from the radial nerve to the distal lateral part of the plate was 5.1 ± 0.26 mm. The tip of the 6th locking screw was in the posterior side of the humerus, which was 8.3 ± 0.72 mm on average away from the radial nerve in the posterior groove (**Figure 4**). The distance between the distal medial edge of the plate and the brachial vein was 4.7 ± 0.63 mm. All the metrical data are shown in **Table 1**.

Clinical cases

A cohort of 16 patients was retrospectively reviewed. Patients comprised four males and 12 females, with a mean age of 71.1 (range 65-78) years. None of the patients had nerve

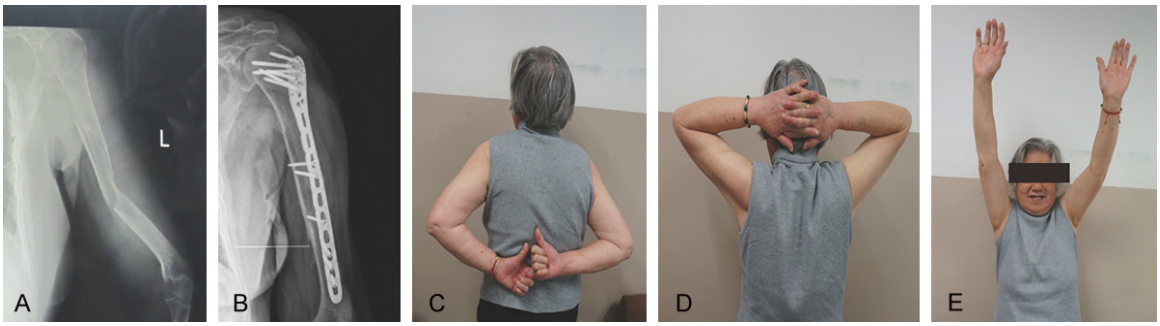

Figure 5. Radiological and functional outcomes in an elderly female patient, who suffered a proximal humeral diaphyseal and metaphyseal fracture of her left arm from a simple fall. A: The fracture type was classified as 12C1. B: Fracture union at 12 weeks after operation with a long helical PHILOS plate. C-E: Satisfactory outcomes of shoulder and elbow function.

palsy before the operation, all fracture types are detailed in **Table 2**. Except for two patients who dropped out, 14 patients were followed up over 27.3 months on average (range 24-36 months). All the fractures healed in 16.2 weeks on average (range 11-24). One patient, who was lost to follow-up, died from a stroke 5 months after operation, and another refused to return to the hospital because they were satisfied with the recovery, as stated in a phone-call follow-up at 3 months after operation. There were no instances of iatrogenic radial nerve injury intraoperatively. No patient suffered superficial or deep infection. In addition, no major complication was observed except for one patient who suffered shoulder impingement. The Constant-Murley shoulder score on the fracture side was 77.2% (range 64%-87%) on average compared with the contralateral side; the MEPS was 96.8 on average (range 90-100). **Figure 5** shows the radiological and functional outcomes of one patient. All clinical data are shown in **Table 2**.

Discussion

Humeral shaft fractures frequently occur in elderly patents after a low-energy injury. Although they can be treated conservatively, this results in a high rate of non-union and joint stiffness, especially with proximal humeral diaphyseal and metaphyseal fractures. Papasoulis *et al.* reported a review of clinical studies into functional bracing treatment of humeral shaft fractures. They found that there was a higher non-union rate with proximal-third humeral fractures, and that age was an important factor which affected the final functional outcome [20]. Thus, early internal fixation should be considered in elderly patients.

When using a locking plate, lateral plating is safe for proximal screw insertion, but there is a danger of iatrogenic injury to the radial nerve distally. In addition, it would also violate the deltoid muscle insertion. As to anterior plating, Jiang *et al.* reported poor shoulder function in two out of three patients in whom the plate was fixed higher than the lesser tubercle, most probably due to rotator cuff impingement or biceps tendon interference [21]. The helical plating technique used in our study is described as inserting the plate twisted at about 90 degrees, so the proximal part of the plate is located on the lateral side of the greater tubercle and the distal part on the anterior side of the distal humerus, which minimizes the drawbacks of either lateral plating or anterior plating.

Yang *el al.* previously reported a satisfactory outcome of the use of a pre-contoured helical long narrow plate to treat comminuted fractures of the proximal and middle one-third of the humerus [18]. Previous biomechanical studies [16, 22] have shown that the helical plating technique exhibited higher stiffness compared to a straight plate under torsional loading, which would provide a better biomechanical environment for healing of humeral shaft fractures. However, long narrow metaphyseal locking plates may not provide adequate stability of the humeral head, especially in elderly patients with osteoporosis, due to its unique design and limited number of locking screws. We believe the locking screws in the proximal part of the PHILOS plate can provide angular stability in different directions, resulting in better purchase and stability, so it might be the better choice for proximal diaphyseal and metaphyseal humeral fracture fixa-

tion, especially in cases in which the fracture line extends into the humeral head.

In our cadaveric study, the proximal "safe zone" was identified. Consequently, the locking screws should not be inserted below the D holes so as not to injure the axillary nerve. This opinion is almost the same as reported by Stecco *et al.* [23], who advised that the two distal screws of the proximal part should be avoided to protect the axillary nerve through the deltoid-split anterolateral approach. The distal "danger zone" was also identified where the musculocutaneous nerve passes across the plate, about 51.4 ± 4.9 mm on average from the lateral epicondyle. Because of these danger points, screw insertion between the 8th and 10th hole of the long helical PHLIOS plate should be undertaken cautiously by the distal approach. Gardner *et al.* [17] mentioned a similar "danger zone" for musculocutaneous nerve injury in the helical locking reconstruction plating technique, which was approximately 12.2-14.8 cm from the greater tuberosity. When the MIPO technique is used via the distal approach, we believe that it will be more feasible to identify both the distance from the lateral epicondyle and the area of the screw hole in the plate.

Apivatthakakul *et al.* [24] fixed humeral shaft fractures with a straight locking plate by the MIPO technique anteriorly, and found that the radial nerve was away from the lateral edge of the plate when using the distal approach. With helical long PHILOS plating, we found that the radial nerve was also at a safe distance from the distal lateral part of the plate, at 5.1 ± 0.26 mm. The average distance between the tip of the 6th screw and the radial nerve was measured to confirm the safety of the radial nerve on the posterior side of the middle humerus, while in another study it was thought that there was a danger of the radial nerve at the middle humerus suffering screw tip irritation [25]. We also assessed the safety of the medial side of the plate, and found that it was safe for the brachial vein, with a distance of 4.7 ± 0.63 mm on average, thus the medial neurovascular bundle, which consists of brachial vein, brachial artery and median nerve, was considered safe.

Besides the results of the cadaveric study, our clinical cases also showed a satisfactory outcome, with all fractures healing and no patients suffering iatrogenic neurovascular injury. Our findings were similar to those of other studies, for example in a study by Arumilli *et al.,* two of five patients with straight long PHILOS fixation suffered radial nerve palsy after surgery but this did not arise in the contoured PHILOS fixation group [11]. Another study by Moon *et al.* reported satisfactory results of the MIPO technique using a helical plate [12]. The mean age of the patients in our study was 71.1, which was much older than in the study by Moon *et al.* (average, 58.8), while the Constant-Murley scores were much lower than in their study (77.2 vs. 88.6). This could be explained by the fact that in elderly patients, humeral fracture might be combined with rotator cuff degeneration.

This study is the first to present data from an Asian population. However, there are some limitations to our study. The first is that all the metrical data were measured in six Asian cadavers, consequently the measurements may be a little different from those of other researchers because of differences between human populations as well as individual variation, but the clinical outcome was encouraging based on the tips and tricks. Secondly, the retrospective design limits the level of evidence. Finally, the small number of patients in our cohort will hide some rare complications and the two patients lost to follow-up may influence the final functional outcomes.

In conclusion, long helical PHILOS plating is safe and effective for the treatment of proximal humeral diaphyseal and metaphyseal fractures in elderly patients by the MIPO technique. During surgery, the proximal locking screws should be placed in the "safe zone" and the distal 6th hole has proven to be safe for the radial nerve, while the "danger zone" should be noted to protect the musculocutaneous nerve.

Acknowledgements

The authors would like to thank the Medical-engineering cross foundation of Shanghai Jiao Tong University for the funding support.

Disclosure of conflict of interest

None.

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