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Modified use of a proximal humeral internal locking system (PHILOS) plate in extra-articular distal-third diaphyseal humeral fractures

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ABSTRACT

Background: Surgical treatment of extra-articular distal-third diaphyseal humeral fractures is controversial in terms of surgical approach and position of implant. The aim of this study is to evaluate the clinical and radiological outcomes of a modified application of the proximal humeral internal locking system (PHILOS) plate in extra-articular distal-third diaphyseal humeral fractures.
Materials and methods: A total of 23 patients with extra-articular distal humerus fractures were treated using either open plating or the minimally invasive plate osteosynthesis (MIPO) technique with upside down application of the PHILOS plate. Fracture configuration, number of screws in the distal fragment, and time to union were analysed. Elbow range of motion, Mayo Elbow Performance Score (MEPS), and complications were evaluated at the final follow-up.
Results: Fracture union was obtained in all patients at a mean postoperative time of 20.8 ± 2.9 weeks. The mean shortest and longest cortical lengths were 50.7 ± 14.0 mm and 85.2 ± 12.4 mm, respectively. The average number of screws in the distal humeral fragment was 5.6 ± 0.7. No statistically significant correlation was observed between the shortest cortical length and number of screws in the distal fragment ($p = 0.224$) or between the longest cortical length and the number of screws in the distal humeral fragment ($p = 0.956$). The average MEPS was 97.6 (range, 75–100). No postoperative complications that required reoperation were occured.
Conclusion: A modified anterior application of the PHILOS plate in extra-articular distal-third diaphyseal humeral fracture showed satisfactory outcomes, so it is an alternative when considering the ability to increase plate-screw density with locking screw fixation in a distal humeral fragment.
Level of evidence: Therapeutic level IV, case series.

Introduction

Most extra-articular distal-third diaphyseal humeral fractures are treated conservatively using a functional brace or above-elbow cast, which results in a high rate of bony union and relatively satisfactory functional outcomes [1–3]. Nevertheless, surgical treatment is advocated due to several limitations of conservative treatment including difficulty controlling distal humeral fragments, elbow stiffness caused by long-term immobilization, and possibility of radial nerve injury during bracing [1,4].

Surgical treatment of extra-articular distal-third diaphyseal humeral fractures is challenging because the distal fragment is generally too small to stabilize with a sufficient number of screws through the plate holes, particularly in the anterior aspect of the humerus. Therefore, several different plating positions including posterior, anterolateral, and double-plating were introduced with individual features [5–8]. Posterior plating encounters the anatomical course of the radial nerve proximally, which may result in iatrogenic radial nerve injury during plate fixation due to the limitation of nerve mobility [9,10]. Bending of the anterolateral plating is necessary to provide a flare extending distally beside the coronoid fossa due to the unique morphology of the distal humerus.

The proximal humeral internal locking system (PHILOS, Synthes, Paoli, PA) plate was originally designed for proximal humerus fractures, and it follows the anatomical contour of the proximal humerus. The plate has 9 holes for locking head screws in the proximal part, and the locking holes allow different angles of screw trajectory. Interestingly, the proximal part of the PHILOS plate is suitable to stabilize the flare distal humeral fragment because the contour and anterior angulation of the distal humerus

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are matched to the shape of the plate's proximal part. Therefore, we applied the proximal part of the plate distally on the anterior side of the humerus in extra-articular distal-third diaphyseal humeral fractures to provide more secure fixation of the distal humerus with a sufficient number of screws,.

The present study evaluated the clinical and radiographic outcomes in patients with extra-articular distal humerus fractures treated with upside-down application of the PHILOS plate on the anterior aspect of the humerus. Our hypothesis was that modified use of the PHILOS plate, as an alternative to many different surgical methods in extra-articular distal-third diaphyseal humeral fractures, would result in satisfactory outcomes.

Materials and methods

From March 2012 to June 2016, a total of 25 consecutive patients with extra-articular distal-third diaphyseal humeral fractures were treated with the modified use of the PHILOS plate in our department. The patients were enrolled prospectively for this surgical treatment and the data were analysed retrospectively. Two of these patients were lost to follow-up before bony union, and the remaining 23 patients constituted our study. The indication for surgery was acute displaced extra-articular distal-third diaphyseal humeral fractures classified to 12A(c), 12B(c), or 12C(c) according to the AO/OTA classification system. Patients with an open fracture, a pathological fracture, a history of any injury on the same humerus, a fracture that extended to the articular surface, an extra-articular distal humeral fracture classified to 13A, or a floating elbow injury were excluded. At the beginning of this study, we performed the open reduction and internal fixation in the first consecutive 15 patients because the modified application of the PHILOS into the extra-articular distal-third diaphyseal humeral fractures was the first attempt in our experience. Ten subsequent patients with extra-articular distal-third diaphyseal humeral fractures underwent osteosynthesis using the MIPO technique. The institutional review board approved the study protocol, and informed consent was obtained from all participants.

Clinical and radiographic assessments

Clinical outcomes were assessed at the final follow-up using the Mayo Elbow Performance Score (MEPS) and range of motion of the elbow joint. Analysis of the fracture configuration using cortical length from the upper margin of the coronoid fossa in the distal fragment was performed on preoperative radiographs. The longest cortical length was defined as the distance from the upper border of the coronoid fossa to the most proximal end of the distal humeral fragment. The shortest cortical length was defined as the shortest distance from the upper margin of the coronoid fossa to the most distal end of the fracture line in the distal humeral fragment (Fig. 1). The numbers of locking head screws and conventional screws in the distal humeral fragment were also evaluated on postoperative radiographs. Plate-screw density was defined as the quotient formed by the number of screws inserted and the number of plate holes in this study. Radiographic assessments for bony union were performed routinely at 2 weeks, 1 month, and every month thereafter until fracture healing was obtained in the humerus anteroposterior (AP), lateral, and both oblique views. Non-union was defined as no evidence of the healing process in radiographs over a three-month period. Malunion was defined as a greater than 10° angle between two longitudinal axis lines on each proximal and distal humeral shaft fragment in both AP and lateral views.

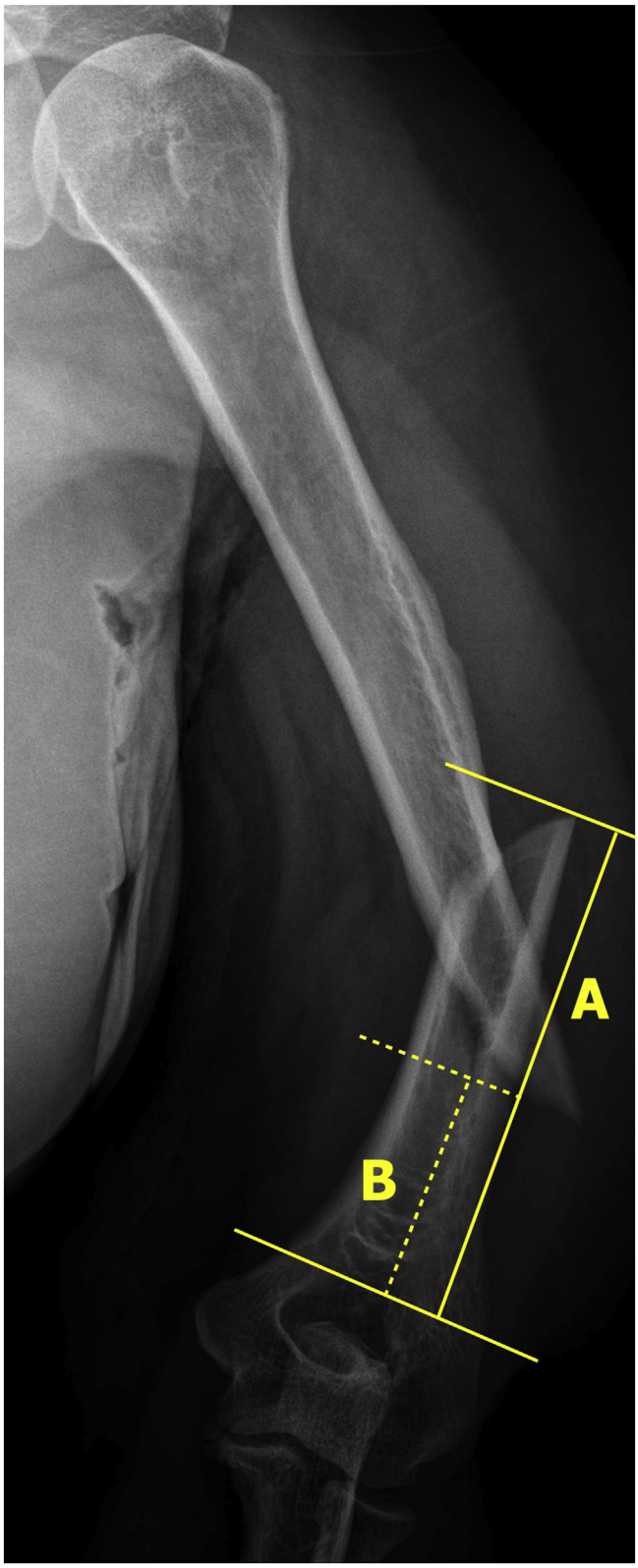

Fig. 1. Anteroposterior view of an extra-articular distal-third diaphyseal humeral fracture. The longest cortical length (A) was defined as the distance from the upper margin of the coronoid fossa to the most proximal end of the distal humeral fragment. The shortest cortical length (B) was defined as the shortest distance from the upper margin of the coronoid fossa to the most distal end of the fracture line in the distal humeral fragment.

Operative technique

The patient was placed on a radiolucent table in the supine position, and the affected arm was draped in a sterile manner to allow free manipulation. The PHILOS plate was used for both surgical modalities in all patients. Open reduction and plating were performed via the conventional anterolateral approach, and dissection was carried down along the lateral border of the biceps brachialis muscle. The biceps brachialis muscle was retracted medially, and the brachialis muscle was dissected longitudinally along the midline. Exploration of the radial nerve was not routinely performed unless concomitant preoperative radial nerve palsy occurred because the nerve is anatomically located between the brachialis and brachioradialis muscles, and the lateral half of the brachialis muscle protects the nerve. After exposing the fracture site, the fracture was reduced with a clamp and stabilized using an independent conventional lag screw based on the fracture configuration. The plate was applied in the upside-down configuration. The position of the plate was determined under an image intensifier and direct vision of the superior margin of the coronoid fossa. The screws were placed in near and far fashion to obtain a construct with maximal working length. Because the holes for the locking head screws in the first and third rows of the proximal part of the plate have a divergent angle, careful drilling and depth measuring were necessary (Fig. 2).

For the MIPO technique, the distal window with a 5-cm longitudinal skin incision was made first. The muscle was dissected in the same manner as the anterolateral approach in open plating without exposure of the radial nerve. After accessing the distal humeral fragment, a submuscular extraperiosteal tunnel was prepared using a periosteal elevator. For indirect reduction of the distal humeral fragment, the temporary Schanz pin fixation was one option via insertion of the pin to the lateral condyle of the humerus to facilitate realignment of the varus/valgus deformity (Fig. 3A). The proximal part of the plate was placed on the distal humerus fragment and centered under an image intensifier. A 2.8-mm locking drill bit was placed in one of the proximal locking holes to temporarily stabilize the plate on the distal humeral fragment. A 3.5-mm cortical screw was inserted into the combi-hole (fourth row hole) to reduce axial alignment in the lateral view via pulling the distal fragment towards the plate (Fig. 3B). A 2.4-mm K-wire was used to correct the rotational alignment of the proximal humeral fragment and verify the neutral rotation of the proximal humerus head (Fig. 3C) [11]. After confirming alignment of the humerus based on the AP view on the image intensifier, the placement of a 3.5-mm cortical screw with temporary fixation of a locking drill bit was used to reduce the axial alignment in the lateral view in the same manner as fixation of the distal humerus. Three to four 3.5-mm cortical screws were placed in the proximal fragment to follow the principle of plate-screw density in the clinical use of a locking plate [12]. The distal humeral fragment was stabilized with as many additional locking screws as possible (Fig. 4). The patient's arm was supported in a sling for four weeks postoperatively. Gentle passive and active range of motion of the shoulder and elbow joint was permitted immediately after surgery when the pain was tolerable.

Statistical analysis of the fracture configuration was performed using Spearman's correlation test in SPSS Version 20.0 (SPSS, Inc., Chicago, IL, USA), and 95% confidence intervals of the means of all parameters were calculated.

Results

The present study included 18 males and five females, with a mean age of 41.9 years (range, 17–69 years). (Table 1) The right shoulder was involved in 10 patients and the left in 13. Patients underwent surgery within a mean time of 3.5 days after injury (range, 0–11 days). The mean follow-up time was 18.13 months (range, 12–41 months). All fractures were classified according to the AO/OTA classification: nine 12A(c), twelve 12B(c), and two 12C (c). Preoperative radial nerve injury was not observed in any patient.

The initial radiographs revealed that the mean shortest cortical length and the mean longest cortical length were 50.7 ± 14.0 mm (range, 13.2–68.9 mm) and 85.2 ± 12.4 mm (range, 54.8–105.5 mm), respectively. The average number of screw fixations

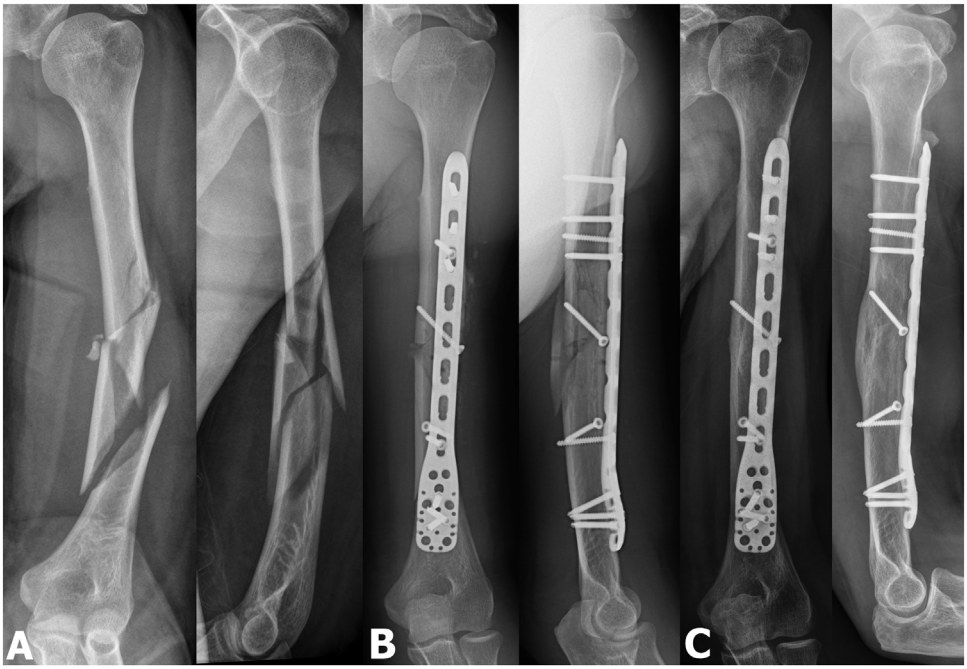

Fig. 2. Extra-articular distal-third diaphyseal humeral fracture treated with open plating and modified use of the PHILOS plate. (A) A 42-year-old male with a 12C3(c) fracture. (B) Immediate postoperative radiographs. (C) Radiographs 24 months after surgery.

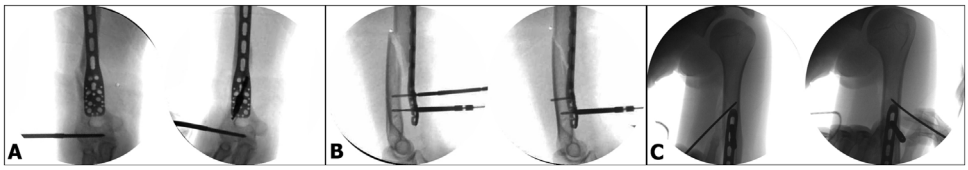

Fig. 3. MIPO technique with modified use of the PHILOS plate. (A) Schanz pin fixation was used as one option to reduce varus/valgus alignment. (B) A 3.5-mm cortical screw was used to reduce axial alignment with temporary fixation of the locking drill bit. **(C)** A 2.4-mm K-wire was used to correct the rotational alignment of the proximal humeral fragment. Greater tuberosity and lesser tuberosity showed neutral rotation after derotation of the proximal humerus.

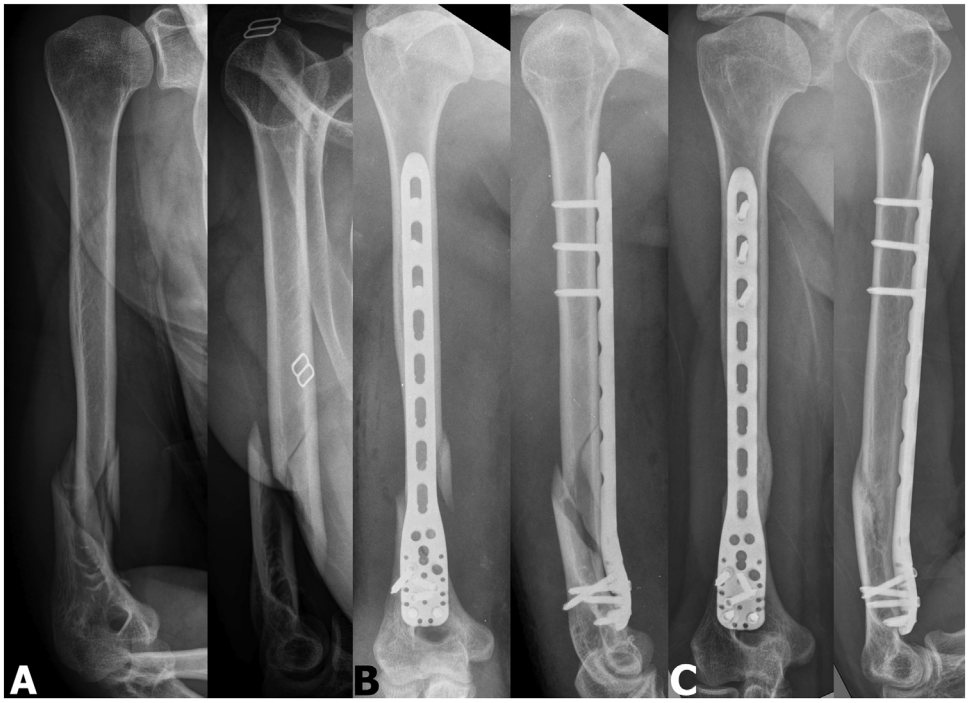

Fig. 4. Extra-articular distal-third diaphyseal humeral fracture treated with the MIPO technique with modified use of the PHILOS plate. (A) A 47-year-old female with a 12B2 (c) fracture. (B) Immediate postoperative radiographs. (C) Radiographs 28 months after surgery showed bridging callus formation and solid bony union.

in the distal humeral fragment was 5.6 ± 0.7 (range, 4–7), and the mean plate-screw density in the distal humerus was 0.6 (5.6 screws/9 holes). No significant correlation was observed between the shortest cortical length and number of screws in the distal fragment ($p = 0.224$) or between the longest cortical length and number of screws in the distal humeral fragment ($p = 0.956$). Fracture union was obtained in all patients at a mean of 20.8 ± 2.9 weeks (range, 17–28 weeks). Neither malalignment nor loss of fixation was observed in any patient.

At the final follow-up, the mean range of elbow motion was 3.3° of flexion contracture (range, 0° - 15°) and 130.4° of further flexion (range, 120° - 140°) (Table 2). The average MEPS was 97.6 (range, 75–100). Postoperative complications that required reoperation such as plate breakage, infection, pull-out of the screws, or neurovascular compromise did not occur. No patient complained of discomfort due to plate irritation during elbow joint motion. Plate removal was performed in 3 patients (13%) upon patient request. No complications after plate removal such as neurovascular compromise, scar pain, or refracture occurred in these three patients.

Discussion

The present study treated acute displaced extra-articular distal-third diaphyseal humeral fractures using a modified anterior application of the PHILOS plate in open plating or MIPO and showed satisfactory clinical and radiological outcomes.

Surgical treatment of extra-articular distal humerus fractures is challenging due to the anatomical characteristics of the distal humerus and proximity of the fracture line to the distal humeral joint. Extra-articular distal-third diaphyseal humeral fractures have a unique configuration because the fracture line traverses a proximal-lateral to distal-medial direction. This specific pattern of fracture is often related to radial nerve injury and leads to a debate on the adequate number of screw fixations for distal fragment and appropriate plate position [13]. Although some authors advocated MIPO for extra-articular distal-third diaphyseal humeral fractures with 4 cortical point fixations on each fragment, a minimum of six cortical point fixations on each fragment is essential to achieve stable fixation for union [14]. However, surgeons often encounter difficulty in achieving a minimum of 3 cortical fixations in the distal fragment, especially when the fracture extends far and distally close to the elbow joint. Based on clinical studies of anterolateral plating, surgeons could not place more than 4 screws in the distal fragment with 3.1 being the mean number of distal screws [5,15]. The mean number of screws in the distal humeral fragment in the present study was 5.6. Modified use of the PHILOS plate allowed the insertion of more screws, which may increase the mechanical stability of the distal humeral fragment compared to the results reported in previous studies using anterolateral plating.

Table 1
Details of patients demographics.

Patient number	AO/OTA classification	Fracture configuration		The number of screw in distal fragment	Length of PHILOS (Shaft holes)
		Shortest distance from coronoid fossa (mm)	Longest distance from coronoid fossa (mm)		
1	12B2(c)	39.33	103.35	5	8
2	12A1(c)	38.01	104.77	6	8
3	12B2(c)	56.69	61.24	6	9
4	12B2(c)	67.15	80.84	4	8
5	12A2(c)	49.73	78.56	6	7
6	12B2(c)	60.23	100.12	6	9
7	12B3(c)	64.69	98.12	7	8
8	12B2(c)	40.74	68.07	6	9
9	12B2(c)	38.65	89.56	6	7
10	12B2(c)	44.75	85.01	5	6
11	12A1(c)	42.82	82,45	6	7
12	12C3(c)	41.51	90.32	7	8
13	12A1(c)	33.01	87.32	6	8
14	12B3(c)	13.23	54.77	5	8
15	12A2(c)	68.93	87.81	6	8
16	12A1(c)	47.98	105.51	5	8
17	12B2(c)	64.98	79.31	6	9
18	12B2(c)	51.08	83.71	5	8
19	12A1(c)	56.75	83.44	5	7
20	12A2(c)	68.45	74.22	5	8
21	12A1(c)	65.92	94.36	5	8
22	12C3(c)	47.54	76.35	6	7
23	12B2(c)	63.29	87.65	5	8

Table 2
Radiographic and clinical outcomes.

Union time (weeks)	20.8 ± 2.9 (range, 17 – 28)
Axial alignment	
AP	1.4 ± 1.1 (range, 0.3 to 3.6)
Lateral	1.2 ± 2.0 (range, 0.23 to 10.2)
ROM of the elbow joint (^{0})	
Flexion contracture	3.3 ± 5.1 (range, 0 – 15)
Further flexion	130.4 ± 6.6 (range, 120 – 140)
MEPS	97.6 ± 6.5 (range, 75 – 100)

VAS visual analogue scale, ROM range of motion, MEPS Mayo Elbow Performance Score.

However, biomechanical studies regarding optimal number of screw and fixation point in the distal fragment for stable fixation would be needed afterward.

Traditionally, posterior plating has several advantages over anterior plating in the treatment of extra-articular distal-third diaphyseal humeral fractures. The posterior side of the distal humerus provides a flat surface that is suitable for plating, and the posterior approach allows direct visualization of the radial nerve and provides the option of double plating [6]. Levy et al. reported satisfactory clinical outcomes of distal humerus fractures treated with the posterior plate fixation extending distally with modified use of the lateral tibial head buttress plate [6]. A recent commercially available anatomical extra-articular distal humerus plate, which is placed on the lateral column of the distal humerus, has been widely used, and good outcomes were reported [8,16,17]. However, the main disadvantage of posterior plating is that an iatrogenic radial nerve may be injured because the radial nerve limits mobility, and the plate must be placed underneath a radial nerve. Based on a cadaveric study, the radial nerve traversed 12.7–15.8 cm from the lateral epicondyle [18]. Therefore, the radial nerve was always in the way of the posterior plating in our experience due to the proper plate span ratio and the appropriate number of cortical screw insertion in the proximal humeral fragment. Postoperative radial nerve palsy occurred in up to 11.5% of patients in several studies on posterior plating in extra-articular distal-third diaphyseal humeral fractures [8,16,19]. In a previous comparative study on lateral and posterior approaches, a significant difference in overall complications was observed; 3 iatrogenic radial nerve palsy and 1 triceps muscle rupture in the posterior approach group [8]. The complication rates in these studies on the posterior plate were considerably high. This high rate is one of the reasons we preferred anterior placement of the plate for extra-articular distal third humeral fractures. No postoperative radial nerve palsy occurred in the present study. Because the radial nerve is anatomically placed between the brachialis and brachioradialis muscles and safely protected by these muscles, we do not routinely explore the radial nerve unless preoperative radial nerve compromise is noted. Furthermore, the anatomical characteristics of the radial nerve position provide an opportunity to safely apply the MIPO technique.

When the conventional plate is applied anteriorly for extra-articular distal third humeral fracture, there are several technical and mechanical issues for stabilization of the distal fragment due to the proximity to the coronoid fossa. Anterolateral plating has slightly more space to secure as many screws as possible in the distal humeral fragment by placing the plate distally closer to the coronoid fossa [5,8,15]. Based on several studies of anterolateral plating, the cortical length of the lateral column was longer than the medial column in 90.3% of patients [8]. The results from these studies also demonstrated that the anterolateral plate provided 6-point cortical fixation to achieve stability in the distal humeral fragment. However, a mechanically weak point remains because of the relatively short working length in the distal fragment. Considering that the length of the distal three holes is approximately 50 mm in a 4.5-mm limited bone contact dynamic compression plate (LC-DCP) or a 4.5/5.0-mm locking compression plate (LC-LCP), 3-screw cortical fixation is not always amenable, particularly in a far distal extra-articular humerus fracture. The PHILOS plate has 9 holes for locking head screws in the proximal part, and the 9 locking holes are located within 4.5 cm of the margin of the plate. The

mean shortest cortical length in the present study was 50.7 ± 14.0 mm, which provides adequate space for sufficient screw fixations (9 locking head screws) using the PHILOS plate in the distal humeral fragment. The plate also allows different angles of screw trajectory in every locking hole. Therefore, we consider these characteristics an advantage of the modified use of the PHILOS plate in treating extra-articular distal-third diaphyseal humeral fractures.

However, a concern in the present study was the mechanical property of cortical fixation because the diameters of the cortical and locking head screws for the PHILOS plate are 3.5 mm. Traditionally, 4.5-mm LC-DCP or LC-LCP is recommended with 6–8 cortices of purchase on either side of the fracture [14]. At least four screw holes in the proximal and distal fragments is recommended to improve the stability of plate fixation when a plate thickness of greater than 3.5-mm is used. A 3.7-mm-thick PHILOS plate satisfies the mechanical property recommendation. However, the mechanical weakness of 3.5-mm screws should be considered. Therefore, increasing the plate-screw density in the distal humeral fragment is a plausible solution. Increasing the plate-screw density with a fixed angle device in far distal or far proximal fractures is a reasonable and effective method considering how periarticular fractures including the distal radius, olecranon, distal femur, and distal tibia are stabilized with the anatomical periarticular locking plates.

The present study has several limitations. First, the number of patients was relatively small to clarify the effectiveness of modified use of the PHILOS plate in extra-articular distal-third diaphyseal humeral fractures. However, satisfactory outcomes in 23 patients with modified use of the plate showed the effectiveness of the PHILOS plate in clinical applications considering the low incidence of extra-articular distal humerus fracture. Second, the heterogeneity of surgical methods with open plating and MIPO may have influenced the outcomes. For instance, comminuted fracture type was treated using MIPO in the present study, however simple type distal humerus fracture was treated with the open plating and a lag screw to obtain absolute stability. Finally, a biomechanical study to justify the use of the proximal humerus plate in extra-articular distal-third diaphyseal humeral fractures is needed to compare small diameter 3.5-mm to traditional 4.5-mm screw fixations. Further randomized controlled trials with longer follow-up and larger sample sizes are needed to clarify the efficacy of the modified use of the proximal humerus plate in extra-articular distal humerus shaft fractures.

Conclusion

A modified anterior application of the PHILOS plate in extra-articular distal-third diaphyseal humeral fracture showed satisfactory clinical and radiological outcomes. Use of an upside-down application of the PHILOS plate in extra-articular distal humerus fracture may be an alternative method considering its ability to increase plate-screw density with locking screw fixations in a distal humeral fragment.

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