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Minimally invasive plate osteosynthesis (MIPO) of the humeral shaft fracture Is it possible? A cadaveric study and preliminary report

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Radial nerve injury

Summary Minimally Invasive Plate Osteosynthesis (MIPO) has gained popularity with satisfactory clinical outcomes in the treatment of long bone fractures. MIPO for humeral shaft fractures, however, could be a surgically dangerous procedure because of the risk of radial nerve injury. An anatomical study was performed to evaluate the feasibility of MIPO for the humeral shaft fractures, and to study the relationship between the radial nerve and the plate with the forearm in full pronation and in supination. The study was performed on ten arms from five fresh cadavers. Two separate incisions, one proximal and one distal, were made in each arm with the forearm in full supination. A 9-hole narrow DCP was inserted into a tunnel using an anterior approach and fixed with 2 screws each on the proximal and distal humerus. The tunnel was then explored to identify the relationship between the radial nerve and the plate. No radial nerve compression or entrapment by the plate was found. The distance measured from the closest part of the plate to the radial nerve was 2.0—4.9 mm (average 3.2 mm). When the forearm was pronated, the radial nerve moved closer to the plate by a distance of 0—3 mm. The results of this study showed that it is possible to treat humeral shaft fractures by the MIPO method using an anterior approach. To reduce the risk of radial nerve injury, the forearm must be kept in full supination during plate insertion, and excessive force should be avoided during retraction of the lateral half of the brachialis muscle together with the radial nerve in the distal incision. The results of using this MIPO approach for humeral shaft fractures in 4 patients were also reviewed.

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Introduction

Most humeral shaft fractures can be successfully treated by nonoperative methods.[4,16,22] The indications for operative treatment include unacceptable alignment after closed reduction, multiple injuries, radial nerve palsy after manipulation, bilateral humeral fractures and open fractures.[1,3,6,19] Compression plate fixation, which is a widely accepted operative method,[1,6,11] gives a high union rate and allows early active motion of the joints. An interlocking intramedullary nail has been reported to produce satisfactory results with less soft tissue injury, relatively percutaneous insertion and biomechanical improvement. [3,5,21] Compression plate fixation, however, is technically demanding and requires extensive surgical dissection with risk of injury to the radial nerve. As a result of technical advancement, minimally invasive plate osteosynthesis (MIPO) has gained popularity in recent years with satisfactory clinical outcomes.[13,17,18,26] The plate is inserted by a percutaneous approach with separate proximal and distal incisions. This method requires less soft tissue disruption and preserves the fracture haematoma and blood supply to the bone fragments.

Percutaneous plate insertion in humeral shaft fractures seems to be a dangerous procedure regarding radial nerve injury. Four conventional surgical approaches to the humeral shaft have been described:[15] posterior, anterolateral, anterior and anteromedial. Open plate fixation has generally utilized two approaches: anterolateral and posterior. The anterolateral approach is suitable for proximal and middle third fractures, whereas distal third fractures are best treated using the posterior approach.[6,14,25] The anteromedial approach is less useful because of intervening neurovascular structures. The anterior approach is rarely used. However, the radial nerve does not cross the anterior aspect of the humerus, hence the anterior approach to the humerus carries the least risk of injury to the radial nerve.

The aim of the current study was to determine the feasibility of applying the MIPO technique in the treatment of humeral shaft fractures using the anterior approach, and to observe the anatomical relationship between the radial nerve and the plate during supination and pronation of the forearm so as to determine which position of the forearm is safe for the radial nerve in the distal humerus during insertion of the plate.

This MIPO method using the anterior approach was then applied in the treatment of humeral shaft fractures in four patients and the results are presented.

Materials and methods

This study was carried out on ten arms from five fresh cadavers which were obtained within 72 h after death—six were male and four female. The procedures were performed with the torso supine, the arm in 90° abduction and the forearm in full supination. First, the interval between the lateral border of the proximal part of the biceps and the medial border of the deltoid muscle was palpated; a 3 cm proximal incision was then made approximately 6 cm distal to the anterior part of the acromion process and dissection carried down to the proximal humerus (Fig. 1). Distally, a 3 cm incision was made along the lateral border of the biceps muscle approximately 5 cm proximal to the flexion crease of the elbow (Fig. 2). The interval between the biceps brachii and the brachialis was identified; the biceps was retracted medially to expose the musculocutaneous nerve lying on the brachialis. The brachialis was then split longitudinally along its midline to reach the periosteum of the anterior cortex of the distal humerus. The musculocutaneous nerve was retracted together with the medial half of the split brachialis, while the lateral half served as a cushion to protect the radial nerve, which at this point, had pierced the lateral intermuscular septum and was lying between the brachioradialis and brachialis muscles. A sub-brachialis extraperiosteal tunnel was then created by passing a tunneling instrument, a reused narrow DCP attached with the handle, deep to the brachialis from the distal to the proximal incision (Fig. 3). Some difficulty maybe encountered during the passage of the tunneling instrument at the proximal part of the tunnel due to the intimate blending of the fibres of the brachialis and deltoid muscles along the lateral aspect of the tunnel at this point. Incision of these

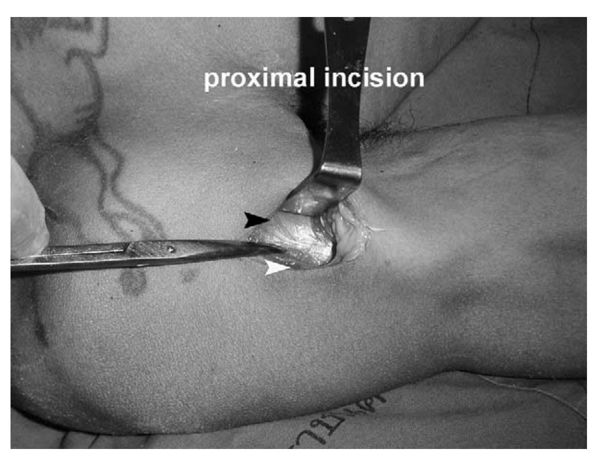

Figure 1 The proximal incision—deep dissection between the lateral border of biceps muscle (black arrow) and medial border of deltoid muscle (white arrow).

Figure 2 The distal incision—the biceps muscle, medial portion of brachialis muscle and musculocutaneous nerve were retracted by the medial retractor (white arrow). The lateral portion of brachialis muscle served as a cushion for the radial nerve that was retracted by the lateral retractor (black arrow).

Figure 4 The intimately blended fibres of the brachialis and deltoid were incised to allow the passage of the tunneling instrument through to the proximal incision.

muscle fibres at the tip of the tunneling instrument will allow its passage through to the proximal incision (Fig. 4). To avoid injury to the radial nerve at the lateral aspect of the distal humerus, the tunneling instrument should be passed along the anterior or slightly anteromedial aspect of the humerus. After preparation of the anterior sub-brachialis tunnel, a nine-hole narrow DCP was tied to the tip of the tunneling instrument and introduced from the proximal to the distal incisions following the track of the tunneling instrument. The plate was then fixed to the proximal humerus with one screw. After positioning the plate on the centre of the anterior surface of the distal humerus, two distal screws were inserted. Finally, the second proximal screw was inserted to complete the fixation.

To identify the relationship between the radial nerve and the plate in the sub-brachialis tunnel, a separate longitudinal lateral incision was made from the posterior acromion to the lateral epicondyle of the humerus (Fig. 5). A deep dissection was made at the same time to identify the axillary nerve by splitting the deltoid. The course of the radial nerve was traced from the spiral groove in the posterior aspect of the middle third of the humerus distally to the elbow. The MIPO tunnel was then exposed by joining the proximal and distal incisions and the dissection carried down to the plate (Fig. 6). The closest distance from lateral border of the plate to the radial nerve was measured (Fig. 7). The forearm was then pronated to identify the medial movement of the radial nerve and the distance between the radial nerve and the plate remeasured (Fig. 8).

Four patients with five humeral fractures were treated with this technique. The indications for surgery included bilateral humeral fractures, ipsi-

Figure 3 The tunneling instrument was beneath the brachialis muscle toward the proximal incision.

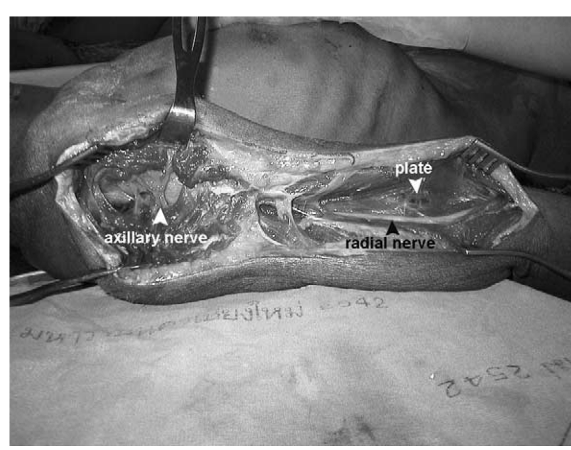

Figure 5 A longitudinal incision from the posterior part of the acromion process to the lateral epicondyle was made to identify the axillary nerve (white arrow on the left), radial nerve (black arrow) and plate (white arrow on the right).

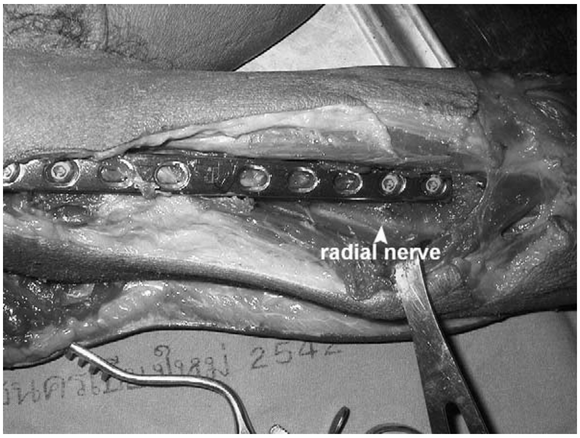

Figure 6 Joining the MIPO incisions and dissecting deeply to the plate in order to identify the radial nerve (white arrow).

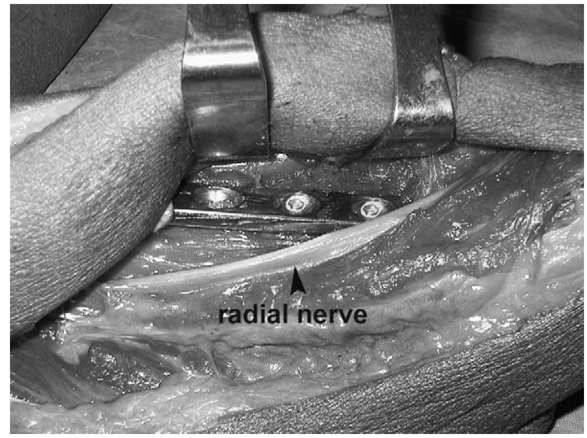

Figure 8 The relationship between the radial nerve (black arrow) and the plate with the forearm in pronation.

lateral humeral and distal radius fractures, humeral fracture associated with thoracolumbar fracture and failed closed reduction. The following data were collected for each patient; operative time, time to union, secondary procedures and complications.

Results

In all 10 specimens, the plates were inserted extraperiosteal beneath the brachialis. The plate was laid on the anterior surface of the humerus with a thin layer of muscle deep to it. The brachialis muscle trauma was limited only to the tunnel created by the tunneling instrument. The axillary nerve ran from the posterior to the lateral aspect of the proximal humerus and injury by the plate was not possible when using the anterior approach through the proximal incision. There was no radial nerve entrapment by the plate in any case. The radial nerve ran close to the bone in the spiral groove on the posterior surface of the middle third of the humerus. After piercing the lateral intermuscular septum, the radial nerve was separated by a thin layer of muscle from the lateral cortex of the distal humerus. The closest distance measured between the lateral border of the plate and the radial nerve in full supination of the forearm was 2.0—4.9 mm (average 3.2 mm) (Fig. 7). When the forearm was pronated, the radial nerve was noted to move medially closer to the distal end of the plate (Fig. 8). It moved to touch the plate in 6 specimens, while in 4 specimens, there was a distance of 1.3, 1.5, 2.4 and 3 mm, respectively. The musculocutaneous nerve ran between the biceps and brachialis muscles and could be protected by the medial retractor. There was no entrapment of the musculocutaneous nerve by the plate any the specimens.

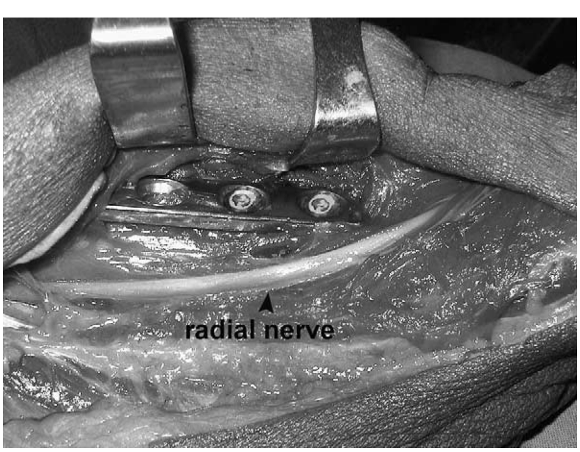

Figure 7 The relationship between the radial nerve (black arrow) and the plate with the forearm in supination.

Discussion

Minimally invasive methods for fracture treatment continue to evolve and MIPO techniques have become more popular. The first MIPO techniques were developed for subtrochanteric and distal femoral fractures.[17] Later, these methods were modified and adapted for use in other types of fractures, including those of the femoral shaft,[27] proximal and distal tibia[13,17,20] and foot.[26] MIPO of the humerus has been previously reported only once by Fernandez[7] whose method involved the use of a double approach: a deltoid split on the lateral aspect of the proximal humerus and an anterior approach to the distal humerus. A 90° helical implant was inserted from the proximal incision, deep to the axillary nerve, into the sub-brachialis space close to the bone. The plate was fixed to the lateral aspect of the proximal humerus and anterior aspect of the distal humerus. Twenty patients were operated on using this helical implant. Nonunion extending to the proximal humerus, comminuted humeral shaft fracture, three and four part proximal humeral fractures were included. Some cases were operative using the MIPO technique. The surgical results were satisfactory. There has been no previous study regarding MIPO of the humerus with a straight implant using a minimally invasive anterior approach. This cadaveric anatomical study has shown that it is possible to perform the MIPO technique for the humerus by an anterior approach. The course of the radial nerve has been well described in the literature[9] and the text.[15,10] The nerve passes through the triangular space between the long head of triceps and the shaft of humerus beneath the teres major muscle. It crosses the posterior aspect of the humerus at an average of 20.7 ± 1.2 cm proximal to the medial epicondyle, to 14.2 ± 0.6 cm proximal to the lateral epicondyle. The nerve then pierces the lateral intermuscular septum to enter the anterior compartment where it lies between the brachioradialis and brachialis muscles. In its proximal course, the radial nerve lies on the posteromedial side of the humeral shaft. The proximal incision for the anterior MIPO approach is therefore safe for the radial nerve. In the mid shaft, the nerve lies posterior to the humerus. Passing the plate through this area by the anterior approach is also safe for the radial nerve. However, at this level, screws should not be passed from an anterior to posterior direction to fix the plate to the humerus in order to avoid injury to the radial nerve in the spiral groove. The plate should thus be used as a bridge plate.[2,12] In the distal humeral shaft, the radial nerve lies laterally between the brachioradialis and brachialis. By splitting the brachialis along its midline, the lateral portion of the muscle serves as a cushion between the retractor and the nerve. A Hohmann's retractor must not be used on the lateral side of the humerus in order to avoid catching the radial nerve with its tip.

The position of the forearm has an effect on the position of the radial nerve. In our cadaveric dissections, we found a thin layer of the brachialis muscle between the radial nerve and the plate in all specimens. To study the effect of forearm rotation on the radial nerve, we had to remove this intervening muscle to measure the distance between the plate and the radial nerve. We found that pronation of the forearm made the radial nerve move more medially by a few millimeters. We therefore suggest that the forearm be placed in full supination during surgery in order to move the radial nerve more laterally. This, combined with splitting the brachialis along its middle and retracting the lateral half of the muscle together with the radial nerve will protect the latter from injury.

In the MIPO technique for the humerus described by Fernandez[7], the tunnel for the helical plate starts at the sub-deltoid space and turns 90° anteriorly to the sub-brachialis space. The axillary nerve is the structure at risk from the deltoid split. The axillary nerve may be injured if the implant is introduced lateral to it—the nerve may then be caught by the plate and subsequently compressed against the bone by the implant during screw fixation. This complication can be avoided by always sliding the implant very close to the proximal humerus deep to the axillary nerve or approaching the proximal humerus from the anterior aspect. The anterior plate on the proximal humerus may interfere with the long head of the biceps, as described by Fernandez.[7] However, in this cadaveric study the plate was laid on the lateral side of the long head of the biceps (Fig. 1) and medial to the deltoid. In this position, the plate did not interfere with the function of the biceps or compress the axillary nerve.

In this study, intact cadaveric humeri were used. However, in patients with humeral fractures, the anatomical landmarks and tissue planes are usually abnormal and distorted. In order to overcome this problem, it is recommended that the alignment of the arm be restored first by traction before surgery and during the tunneling and sliding of the plate.

From the biomechanical point of view, this plate is used as a splint on the outside of the bone as a bridge plate. Both ends of the plate are fixed to the main fragment by three to four screws. Long plates bridging an extensive zone of fragmentation with only short fixation on either end of the bone will undergo considerable deformation forces. As bending stresses are distributed over a long segment of the plate, the stress per unit area is correspondingly low, which reduces the risk of plate failure. The entire construct becomes elastic and even simple fractures can be success fully bridged.[23,24]

Although technically difficult, the MIPO approach described here is less invasive when compared to the conventional open reduction technique. This technique can be applied for the treatment of simple or comminuted humeral shaft fractures extending from the deltoid insertion down to 6 cm above the trochlea fossa which allows at least three screw fixation for each proximal and distal fragment. It can also be applied to a humerus with a

Figure 9 (A) 46-year-old male, motorcycle accident with comminuted fractures of the left humerus. (B) A 12-hole narrow DCP was inserted by the MIPO technique using a bridge plate concept and the fracture zone left undisturbed. Anatomical reduction was unnecessary. AP and lateral radiographs immediately postoperative are shown. (C) AP and lateral radiographs one year later. Healed bone, good alignment. (D) Surgical scars, good clinical result and radial nerve function.

small canal diameter that is not suitable for intramedullary nailing. In future, the newly developed locking compression plate (LCP)[8], which functions as an internal fixator, will have an important role in MIPO applications. With the advantage of the locking head screw, the plate will not press directly against the bone, but instead leaves some space between the two, making it safe for the radial nerve in the unlikely event that the nerve is trapped in between the two.

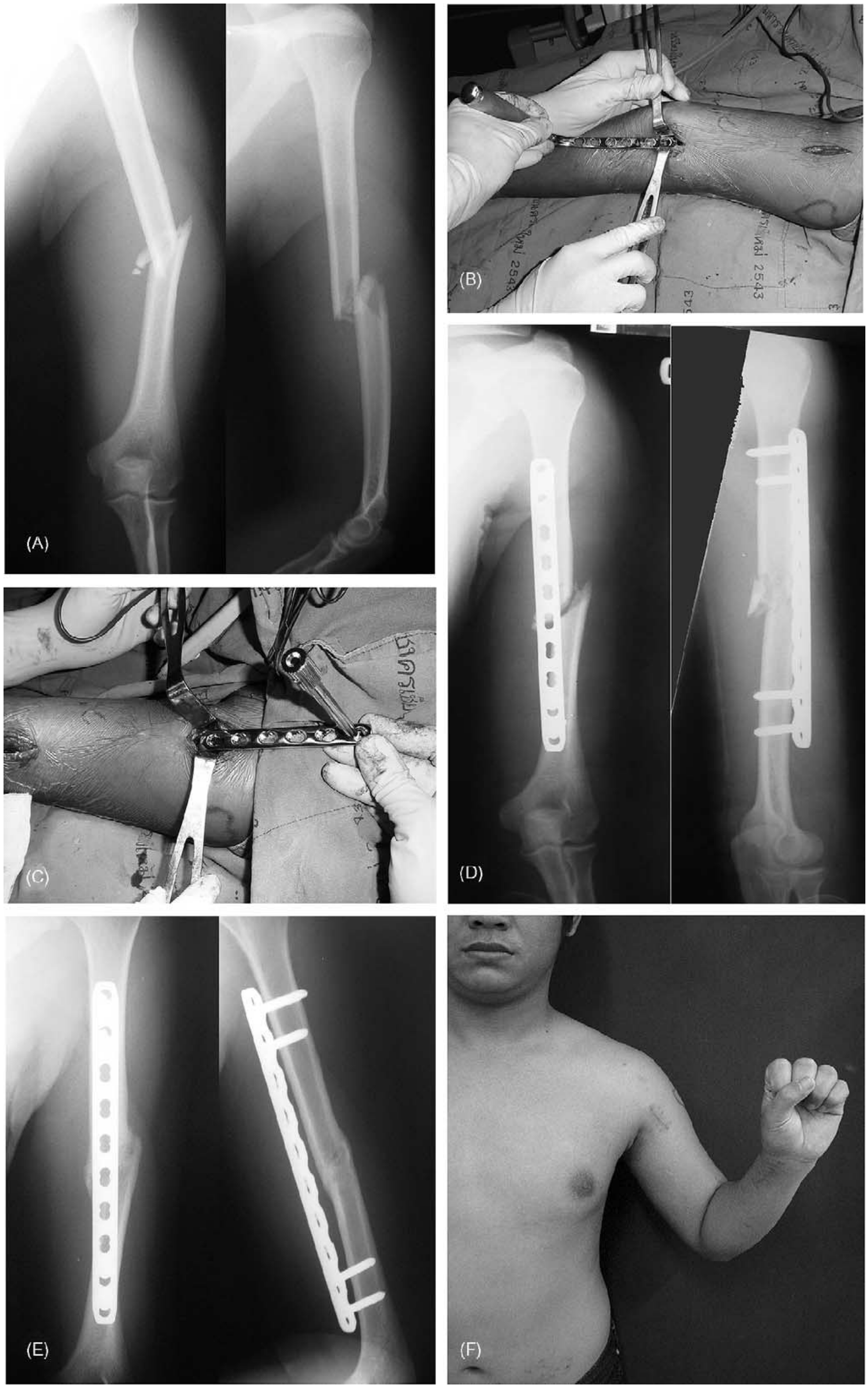

Figure 10 (A) 18-year-old male, polytraumatized patient. Among many fractures, he had ipsilateral oblique fracture of the left humerus and fracture of the distal radius. The X-ray of the humerus is shown. (B) Two small MIPO incisions were made. Preparation the tunnel from the distal incision. The medial retractor retracted the biceps and musculocutaneous nerve. The lateral retractor protected the radial nerve. (C) The LCP as it is slid in from the proximal incision. (D) AP and lateral postoperative radiographs. (E) AP and lateral radiographs after 9 months, which show complete fracture healing. (F) Clinical outcome and surgical scars, with full function of the shoulder, elbow and radial nerve.

Table 1 Clinical cases

Patient	Location	Fx. pattern	Implant	Op. Time (min)	F.U. (week)	Bridging callus (week)
1	Middle 1/3	Comminuted	Narrow DCP	70	50	18
2	Middle 1/3	Comminuted	Narrow DCP	60	50	12
3	Middle 1/3	Oblique	Narrow DCP	60	40	6
	Distal 1/3	Comminuted	Narrow DCP	55	40	6
4	Middle 1/3	Oblique	LCP	45	36	6

Conclusion

MIPO is a novel way of treating fractures that is gradually gaining acceptance. Fractures of the humerus, where indicated, can be treated by minimally invasive osteosynthesis. This study shows that MIPO of humeral fractures can be performed using an anterior approach. The advantages of the anterior approach are as follows: there is no risk of injury to the axillary nerve which is some distance away from the plate; the radial nerve is not at risk as long as the forearm is kept in supination during the procedure, and no screws are inserted into that part of the humeral shaft where the radial nerve runs along the spiral groove; a straight implant can be used without the need for excessive bending or twisting. This method was applied to treat humeral shaft fractures in four patients with satisfactory outcomes.

Clinical cases

Four patients with five humeral fractures, were treated by the MIPO technique (Table 1). Four fractures occurred in the middle third of the humerus with one extending into the distal third. All patients had intact radial nerve function before the operation. All cases were operated on using a double small approach by the MIPO technique under fluoroscopic control, as described in the cadaveric study. The plates were fixed with three to four screws in both proximal and distal fragments (Fig. 9), except in the case fixed with a LCP that used only two screws on each fragment (Fig. 10). The patients were encouraged to perform passive motion of the shoulders and elbows during the first postoperative week. Active motion was carried out from the second week without a cast or brace. The average operating time was 58 min (range: 45—70 min). The average duration of follow-up was 43.2 weeks (range: 36—50 weeks). No patient had any evidence of radial nerve dysfunction after surgery. One patient had transient hypoesthesia of the skin supply of the musculocutaneous nerve, but this completely recovered after 6 weeks. The average time when bridging callus could be seen at the fracture site was 9.6 weeks (range: 6—18 weeks). Union was achieved in all patients without bone grafting. The function and range of motion of the shoulder and elbow joints were satisfactory.

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