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Anteromedial minimally invasive plate osteosynthesis (MIPO) for distal third humeral shaft fractures – Is it possible?: A cadaveric study

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ABSTRACT

Introduction: The purpose of this study was to evaluate the feasibility of the anteromedial minimally invasive plate osteosynthesis (MIPO) approach for distal third humeral shaft fractures and identify neurovascular structures at risk with this approach.
Methods: Twenty cadaveric arms were fixed with 12-hole precontoured narrow locking compression plates (LCP) with the anteromedial approach using MIPO technique. The proximal approach was done between the biceps and deltoid muscle directly to the bone. The distal approach involved elevating the brachialis from medial intermuscular septum. The plate was inserted beneath the brachialis tunnel from distal to proximal. Three locking screws were fixed at each end through incisions and the rest of screws were inserted percutaneously. The arms were then dissected to identify damage to or direct contact between the screws and brachial artery (BA), median nerve (MN), musculocutaneous nerve (MCN), and radial nerve (RN). The distances from the screws to structures at risk, humeral length, and length of three distal screws in mediolateral (ML) direction were measured.
Results: The average humeral length was 28.97 cm. The average danger zone for the BA and MN were 20.47%–62.66% of the humeral length from the lateral epicondyle, and 20.47%-75.02% for the MCN. The ulnar nerve was not endangered by this approach as it lies posteromedially to the humerus. The danger zone for the RN averaged 27.07%–43.74%, and the most dangerous screw that either penetrated or touched the nerve was at the fifth hole, which lay at 33.14% of the humeral length. The average length of three distal screws in ML direction were 41.4, 25.0 and 22.5 mm.
Conclusions: The anteromedial MIPO approach can be performed through the internervous plane beneath the brachialis muscle without exposing any nerves or causing any muscle splitting with a 12-hole plate. Both proximal and distal screw insertion must be done with direct exposure. Insertion of percutaneous screws in the middle part of the plate between the two incisions is not possible. This approach could be an alternative for extra-articular distal third humeral shaft fractures which provides less invasive surgical dissection, allows the use of longer distal screws, and achieves better cosmesis.

Introduction

Most extra-articular distal third humeral shaft fractures can be treated conservatively [1]. However, more predictable alignment and early return to functionality can be achieved by open reduction and plate fixation [2]. As a result of surgical advancements, minimally invasive plate osteosynthesis (MIPO) of the humerus has gained popularity in recent years. MIPO of mid-distal humeral shaft fractures offers the advantage of less iatrogenic radial nerve palsy and accelerated fracture union with satisfactory clinical outcomes compared to the conventional open plating [3].

MIPO approaches for distal third diaphyseal fractures of the humerus have been described using anterior [4–7], anterolateral [8–10], and posterior [11–13] approaches, each of which has both advantages and disadvantages. To our knowledge, none has evaluated the anteromedial approach and verified the neurovascular structures at risk.

We hypothesized that the anteromedial approach for extra-articular distal third humeral shaft fractures could be safely performed by MIPO technique. The purpose of this study was to identify the anatomical relationships with nearby neurovascular structures and also compare the lengths of three distal screws

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between the mediolateral (ML) and the anteroposterior (AP) direction.

Methods

This study was conducted using ten random fresh human cadavers (20 humeri), 5 male and 5 female, obtained from the Department of Anatomy. The donors were confirmed to have had no deformity or previous surgery of the upper extremities. The average age of the cadavers was 71.6 years (range 60–87). The study protocol was approved by the Institutional Ethical Committee Board.

The procedures were performed with the torso supine, the arm in 90 degrees of shoulder abduction, and the forearm in full supination. The surgeon sat facing the cadaver's axilla, with the assistant on the opposite side of the arm. First the medial epicondyle was palpated, then a longitudinal 5 cm distal incision was made just above the medial epicondyle along the humeral shaft. The interval between the biceps brachii and the triceps brachii muscles was used for distal access. The basilic vein and the medial antebrachial cutaneous nerve were identified and protected posteriorly, then the brachial fascia was incised and the brachialis muscle was elevated from the intermuscular septum and the medial supracondylar ridge. The ulnar nerve was indirectly protected by retracting the triceps brachii muscle posteriorly, while other neurovascular structures were protected by the brachialis muscle anteriorly. The anteromedial surface of the distal humerus was then exposed (Fig. 1).

The 4.5 mm 12-hole narrow locking compression plate (LCP) (Depuy Synthes®, Oberdorf, Switzerland) was placed on the skin and a proximal incision was made at the three most proximal holes of the plate. Then, the interval between the lateral border of the proximal part of the biceps and the medial border of the deltoid muscle was palpated and dissected. The insertion of the pectoralis major tendon was identified and retracted laterally. The musculocutaneous nerve was protected by retracting the biceps medially and dissection was continued down to the medial surface of the proximal humeral diaphysis (Fig. 1).

The LCP was precontoured at the two most distal holes to fit the anteromedial supracondylar area. A sub-brachialis extraperiosteal tunnel was then created anteromedially by passing the plate with a threaded drill sleeve attached as the handle into the most distal hole as a handle for tunneling and plate insertion into the sub-brachialis from the distal to the proximal incision. During this step, the pectoralis major tendon insertion could be partially incised in cases that the plate extended above the insertion to allow adequate exposure. A second threaded drill sleeve was attached to the most proximal hole. By adjusting both drill sleeves, the distal end of the plate was aligned on the anteromedial surface of the humerus (Fig. 2a). The distal end of the plate should be placed about 1–1.5 cm proximal to the medial epicondyle. In clinical cases, we adjusted the position of the plate until the first screw could be inserted just above the coronoid fossa by using the drill sleeve as a trajectory reference under fluoroscopic control and aiming the screw toward the lateral supracondylar ridge which will permit a longer medial to lateral screw. With this screw direction, the plate will not lie completely flat on the bone. Three locking screws were subsequently fixed on each end of the plate under direct visualization. The motion of the elbow was tested to confirm that there was no impingement. After that, all screw holes between the proximal and distal incisions were fixed percutaneously using stab incisions (Fig. 2b). The position of plate and screws was shown on cadaveric bone (Fig. 2c).

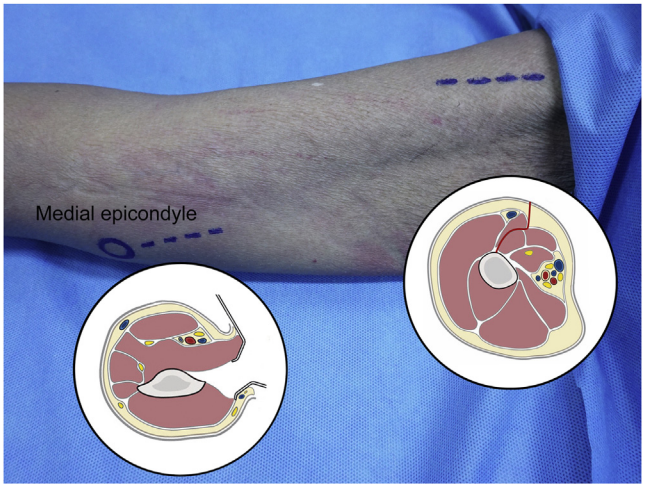

Fig. 1. Proximal and distal incisions of the right arm and diagrams of the plane of dissection.

This study used the LCP with locking screws to reduce the variability of screw direction. The long locking screws, 40–50 mm, were inserted to allow bicortical penetration with the tip of the screws penetrating 5 mm beyond the far cortex to allow observation of any radial nerve (RN) or axillary nerve (AXN) injuries. This also left the head of the screws above the skin to observe any medial neurovascular injuries.

The MIPO tunnel was exposed by joining the proximal and distal incisions, and deep dissection was carried down along the plane between the biceps and the triceps muscles to expose nearby neurovascular structures. Damage to or direct contact of the locking screws with the brachial artery (BA), median nerve (MN), or musculocutaneous nerve (MCN) were recorded, and the distances between each screw and the neurovascular structures were measured (Fig. 3). All measurements were done 2 times by the first author using a digital caliper with an accuracy of 0.01 mm and use the average.

Next, the surgeon moved to the opposite side and made a posterolateral incision along the tip of the screws. Deep dissection was performed to expose the AXN proximally and the RN from the point where it crossed the spiral groove down to the radial fossa. Damage to or direct contact with these nerves by locking screw tips was recorded, and distances were measured in the same manner (Fig. 4a,b).

The posterolateral angle of the acromion process and the lateral epicondyle were palpated and measured as the humeral length. The distance between the lateral epicondyle and each locking screw was measured; the first screw was located in the most distal hole and the twelfth screw was located in the most proximal hole. Average distances were calculated for all measurements, and are reported as a percentage of the humeral length.

Finally, to compare the ML and AP screw length, the plate and screws were removed. The three distal holes were measured using a depth gauge and recorded for ML screw length. Then, another straight narrow LCP was placed anteriorly just above the coronoid fossa. The distal three holes were drilled, the plate was removed, and the depths of the holes were also measured for AP screw length.

Results

The average humeral length was 28.97 cm (99% CI: 27.99–29.94 cm). The fixation zone of the first to the twelfth locking screw was 1.03–21.73 cm [3.56% (99% CI: 2.38–4.73) to 75.02% (99% CI: 73.69–76.36) of the humeral length] from the lateral epicondyle.

On the anteromedial aspect, the zone of BA and MN injuries averaged 5.93–18.15 cm [20.47% (99% CI: 19.43–21.52) to 62.66%

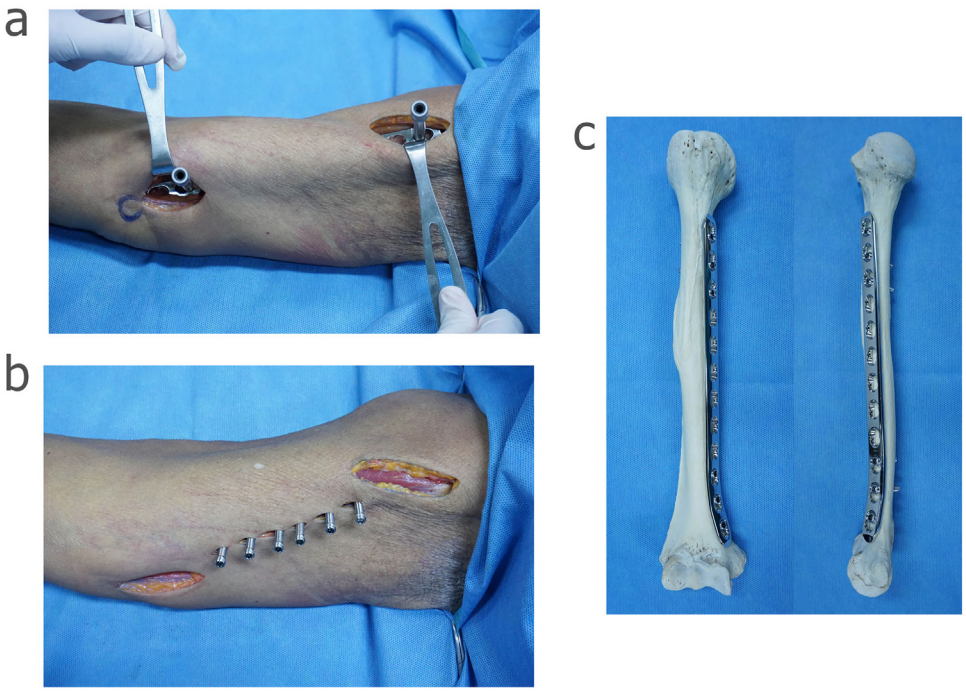

Fig. 2. a. 12-hole narrow LCP with drill sleeve inserted into the MIPO tunnel. b. Three proximal and distal screws inserted through incisions, percutaneous screws for the rest of the LCP holes. c. 12-hole narrow LCP fixed on cadaveric bone.

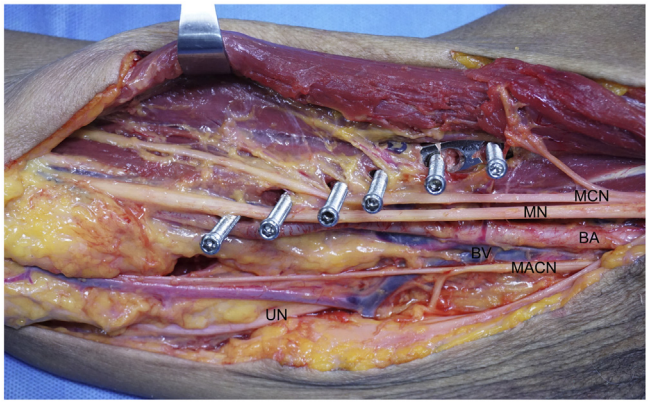

Fig. 3. MIPO tunnel exposed to identify brachial artery (BA), median nerve (MN), and musculocutaneous nerve (MCN). (UN = Ulnar nerve, BV = Brachial vein, MACN = Medial antebrachial cutaneous nerve).

(99% CI: 61.63–63.69) of the humeral length] from the lateral epicondyle, and for MCN injuries 5.93–21.73 cm [20.47% (99% CI: 19.43–21.52) to 75.02% (99% CI: 73.69–76.36) of the humeral length] (Fig. 5). The ulnar nerve was not endangered with this approach since it lies posteromedially to the humerus and traverses beneath the medial intermuscular septum before passing behind the medial epicondyle of the distal humerus.

On the posterolateral aspect, the zone of RN injuries averaged 7.84–12.67 cm [27.07% (99% CI: 26.10–28.04) to 43.74% (99% CI: 42.79–44.69) of the humeral length]. The most dangerous screw that frequently penetrated or touched the nerve, was at the fifth hole which lay 9.6 cm [33.14% (99% CI: 32.18–34.11) of the humeral length] from the lateral epicondyle. Additionally, the AXN could be injured if the most proximal screw were inserted between 21.76–23.20 cm (75.12% to 80.07% of the humeral length) from the lateral epicondyle (Fig. 5).

The distances between the screws and each of the neurovascular structures at risk were measured. The number of screws which had direct contact with nerves or arteries was also recorded and is presented as the percentage risk of injury (Table 1, Fig. 6a and b).

The average length of the three distal screws in the ML direction were 41.4 (32–56), 25.0 [22–30], and 22.5 [20–28] mm. In the AP direction, the average length of the screws were 20.1 [18–26], 21.1 [18–26], and 21.7 [18–26] mm. Comparison of screw length between the two directions using Student's *t*-test showed a statistically significant difference ($p < 0.01$) for the first and second holes (Table 2).

Discussion

Our study aimed to validate the possibility of using the anteromedial MIPO approach through the medial intermuscular plane for treating the distal third humeral shaft fractures by combining the advantages of the medial approach with the MIPO technique. We measured the humeral length and reported the danger zone of anteromedial MIPO as the percentage of the humeral length in order to facilitate application during surgery. We also described the danger zone using the lateral epicondyle which is an easily palpable bony landmark that surgeons can identify during the operation.

The distal incision with our approach is easy to perform by palpating the medial epicondyle and making the incision proximally (Fig. 1). The brachialis muscle originates on the lower half of the anterior humerus, and is loosely attached to the medial bony surface, so it is easily elevated from the bone without splitting the muscle. The anterior MIPO approach requires splitting the brachialis which has the chance of injury to the RN or MCN branches, and may denervate some parts of the muscle and result in motor weakness [14,15]. Concha et al. [16] proposed that brachialis muscle scarring and inadequate postoperative rehabilitation may be involved in limiting elbow range of motion with the

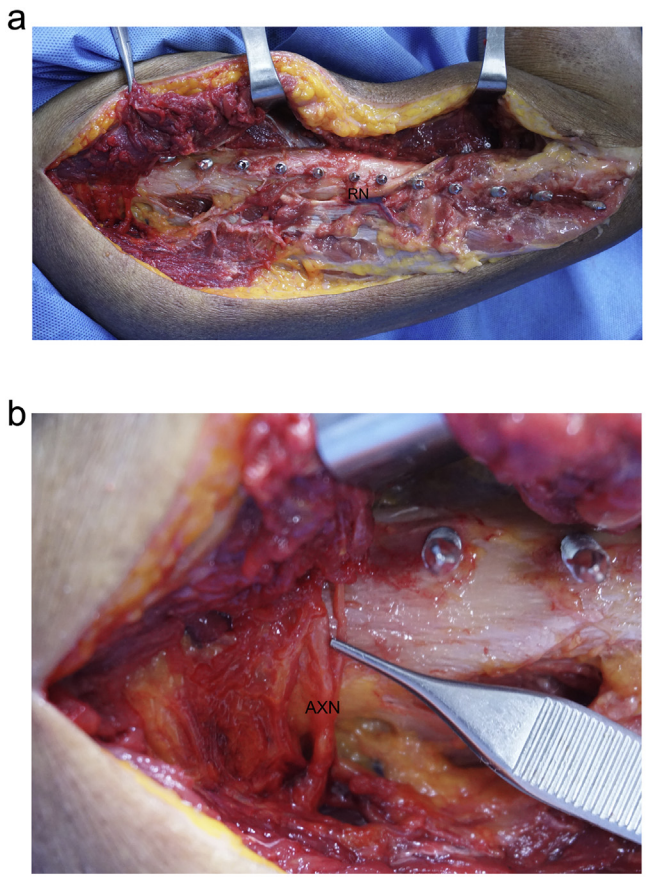

Fig. 4. Posterolateral approach from the posterior acromion to the lateral epicondyle to identify 4a. the radial nerve (RN) and 4b. the axillary nerve (AXN).

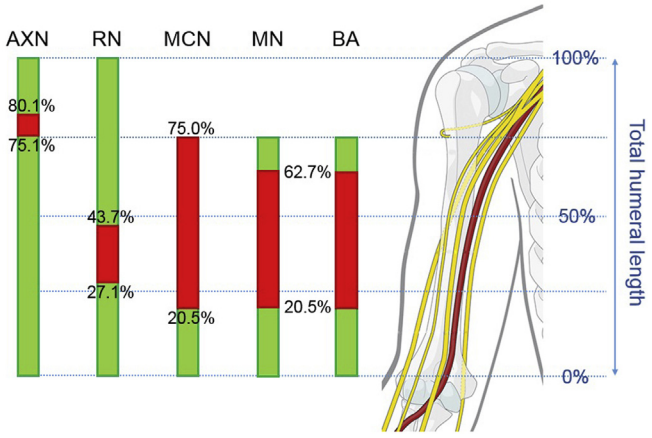

Fig. 5. Chart of the safe zone (green) and danger zone (red) of structures at risk related to the % of humeral length (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

anterior MIPO approach. On the other hand, our approach from the medial side potentially avoids these complications.

The proximal incision for our approach is at the interval between the biceps tendon or muscle and the deltoid insertion which is a simple approach. The middle part of the medial approach between the proximal and distal incision appears to be dangerous due to the presence of the MCN, MN, and BA. When using the open medial approach, all the structures at risk have to be identified and protected. However, with the anteromedial MIPO approach, the plate is placed in the sub-brachialis tunnel and all those structures are naturally protected by the brachialis muscle. The MCN crosses from proximal medial to anterior at the midshaft and lateral at the distal shaft. The greatest chance of injury occurs at the proximal incision between the 7th and the 10th plate hole (43.7% to 62.7% of the humeral length). Meticulous dissection close to the bone between the deltoid insertion and the biceps is recommended to protect the MCN from the incision. At the distal incision, the brachialis muscle is elevated from the anteromedial surface of the humerus. All the structures at risk are retracted and protected anteriorly by the brachialis muscle; screw fixation is done under direct vision. Three distal screw holes are fixed, occupying approximately 20.5% of the humeral length. Theoretically, fixation with two distal screws can provided adequate stability for the distal fragment [4,17]. It can be possible to fix a distal fragment with a length of 3.7 cm or 12.9% of the humeral length with only 2 locking screws. Combined with a long anteromedial to posterolateral screw, this fixation should be sufficiently stable and may allow early mobilization of the elbow and shoulder.

The RN crosses from posterior to anterolateral through the intermuscular septum at an average distance of 20.7 cm proximal to the medial epicondyle to 14.2 cm proximal to the lateral epicondyle [18]. The direction of the screw in our study, which ran from anteromedial to posterolateral, can potentially injure this nerve. The screws that most frequently touched or penetrated the RN in our study were at the 5th hole; the chance of injuring the nerve located at 33.1% of the humeral length was 80%. The screws at the 4th hole also had a 35% chance of injuring the nerve which is located at 27.1% of the humeral length. The screw at the 3rd hole presented no risk of injury to the RN. In cases where it is necessary to use a screw at the 4th hole, a unicortical screw is recommended.

The AXN originates from the quadrangular space and extends from posterior to anterolateral between 75.1%–80.1% of the humeral length. Most humeral shaft fracture fixations will not extend into this area, with the exception of proximal shaft fractures which require an anterolateral approach. In cases where screw fixation is needed in this area, the unicortical locking screw is recommended.

In our study, BA, MN and MCN injuries could occur between the two incisions if percutaneous screw insertion was used. The highest risk of neurovascular injuries was 60% in the 5th hole for BA, 70% in the 6th hole for MN, 60% in the 7th-8th holes for MCN, and 80% in the 5th hole for RN (Fig. 6b). Plate insertion beneath the brachialis without any screws in this zone does not endanger these neurovascular structures. The RN injuries occurred between the 4th-7th holes, so 1st-3rd distal screws should be safe for the RN. Screw length in the ML direction was significantly greater than in the AP direction at the first and second holes (Table 2). Thus, stability of distal fixation might be better with longer screw using the anteromedial MIPO approach.

For distal third humeral shaft fractures which are located close to the metaphyseal area, adequate fixation is usually difficult due to the short length of the distal fragment, its triangular shaped anatomy, and the presence of nearby neurovascular structures. To overcome these problems, most surgeons use a posterior approach for open plating on the posterior aspect which requires identification of the radial nerve. Some authors have recognized that exploration of the radial nerve is difficult and can increase the risk of iatrogenic radial nerve palsy [18,19]. In order to achieve stable fixation, the plate needs to be placed more distally on the posterolateral column of the humerus, which is difficult when using a straight plate. In addition, the most distal screw might be unicortical and subject to pullout in osteoporotic bone. Levy et al. [20] proposed an alternative method, modifying the plate to match the anatomic contour of the distal humerus so the plate does not

Table 1
Distance between screws and neurovascular structures.

Brachial artery						
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)	Number directly injured (n = 20)	% Injured
12	20.5	5.1	33.6	7.4	0	0
11	17.5	3.5	31.8	6.8	0	0
10	14.4	0.0	30.8	7.4	2	10
9	10.8	0.0	20.2	5.7	3	15
8	8.0	0.0	19.5	4.8	2	10
7	4.8	0.0	16.4	4.3	5	25
6	2.9	0.0	13.5	3.9	10	50
5	1.7	0.0	9.7	2.7	12	60
4	3.2	0.0	11.2	3.2	8	40
3	6.2	0.0	17.0	4.5	4	20
2	10.0	2.7	23.9	5.5	0	0
1	13.8	3.8	30.2	7.3	0	0
Median nerve						
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)	Number directly injured (n = 20)	% Injured
12	17.5	3.3	27.9	6.7	0	0
11	14.9	1.6	23.3	6.3	0	0
10	11.7	0.0	21.0	6.0	2	10
9	8.4	0.0	17.3	5.3	3	15
8	5.4	0.0	13.5	4.2	4	20
7	3.1	0.0	11.6	3.4	7	35
6	1.7	0.0	11.2	3.1	14	70
5	1.9	0.0	6.9	2.6	11	55
4	3.0	0.0	10.5	2.8	5	25
3	5.6	0.0	14.6	3.6	2	10
2	8.2	2.9	18.6	4.1	0	0
1	12.1	5.4	25.8	5.2	0	0
Musculocutaneous nerve						
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)	Number directly injured (n = 20)	% Injured
12	7.4	0.0	21.7	6.4	4	20
11	5.1	0.0	18.3	5.7	6	30
10	3.2	0.0	14.9	4.5	9	45
9	2.5	0.0	12.3	3.1	8	40
8	2.0	0.0	10.0	3.0	12	60
7	2.3	0.0	10.4	3.5	12	60
6	4.1	0.0	14.9	4.4	7	35
5	7.2	0.0	21.2	5.6	2	10
4	11.0	0.0	23.2	5.4	1	5
3	15.0	0.0	25.9	6.4	1	5
2	19.5	6.1	34.7	7.5	0	0
1	25.1	10.7	46.1	8.8	0	0
Radial nerve						
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)	Number directly injured (n = 20)	% Injured
12	27.8	16.8	33.6	5.6	0	0
11	21.0	9.4	28.5	5.2	0	0
10	16.7	8.4	25.6	4.4	0	0
9	12.8	8.0	21.1	3.8	0	0
8	9.4	4.9	19.2	3.7	0	0
7	5.8	0.0	16.9	3.4	1	5
6	2.4	0.0	10.2	2.9	9	45
5	0.6	0.0	4.7	1.3	16	80
4	4.1	0.0	11.3	3.6	7	35
3	10.0	3.1	17.0	4.5	0	0
2	16.4	7.2	21.7	4.2	0	0
1	27.4	17.6	37.3	4.2	0	0

impinge on the olecranon fossa. This method also provides additional length, allowing for additional distal screw holes.

An anterolateral or lateral plate is recommended for internal fixation of distal humeral shaft fractures [21,22]. Mill et al. [21] described a lateral approach which allows extensile identification of the radial nerve, exposing this area easily without muscle splitting, but plate fixation is affected proximally by the deltoid insertion. Yin P et al. [22] compared the treatment results of extra-articular distal humeral fracture fixation using a lateral and posterior approaches. They demonstrated that both approaches achieved satisfactory results with a low complication rate but the extensile surgical dissection is inevitable.

A medial approach is an alternative choice for humeral shaft fracture fixation which was first described by Judet et al. [23] in 1968. Later, Jupiter et al. [24] reported that the approach could also be used in cases of complex non-union of the humeral diaphysis. The main reason that the medial approach is not widely used is the complicated anatomy of the medial aspect of the upper arm.

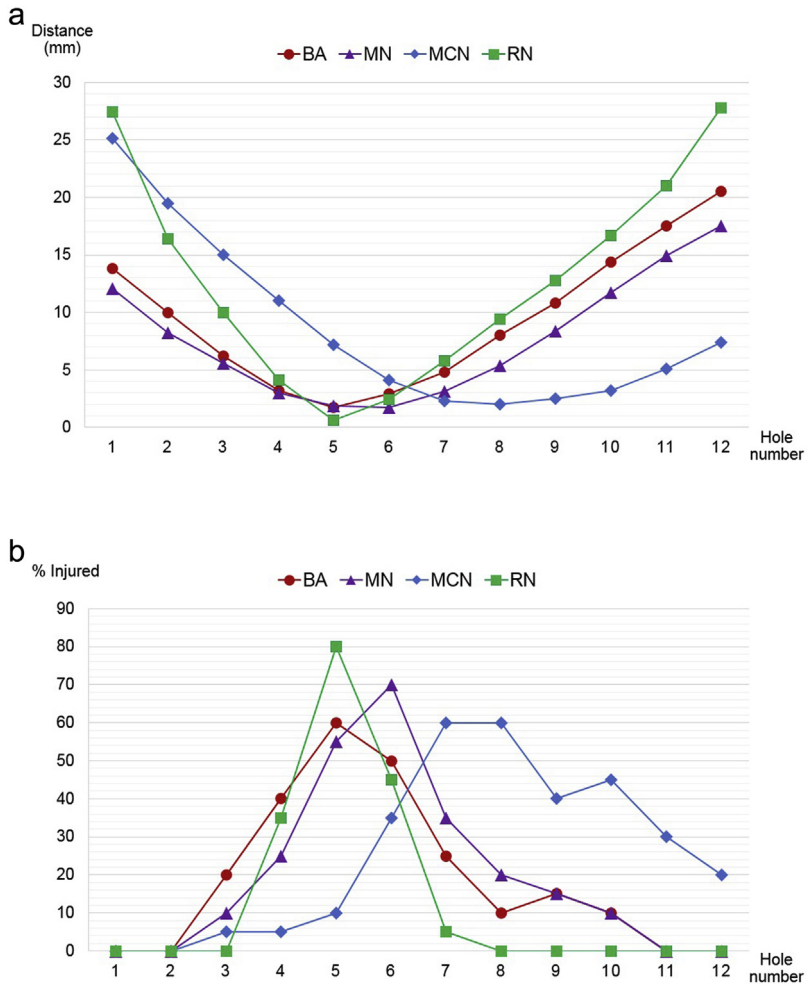

Fig. 6. a. Mean distance of structures at risk related to screw holes. b. Percentage risk of neurovascular injuries related to screw holes.

Table 2
Comparison of screw length in Medio-Lateral (ML) and Antero-Posterior (AP) directions.

Screw length in ML direction				
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)
3	22.5	20	28	2.2
2	25.0	22	30	2.3
1	41.4	32	56	6.8
Screw length in AP direction				
Hole number	Mean distance (mm)	Min (mm)	Max (mm)	S.D. (mm)
3	21.7	18	26	2.3
2	21.1	18	26	2.4
1	20.1	18	26	2.2

Comparison of screw length			
Hole number	ML (mm)	AP (mm)	P-value
3	22.5	21.7	0.27
2	25.0	21.1	*< 0.01*
1	41.4	20.1	*< 0.01*

Surgeons tend to choose an approach which encounters fewer nerves and blood vessels. The brachial vessels, median nerve, and ulnar nerve need to be identified with this approach. A few studies have reported about open reduction and plate fixation on the medial aspect of the humerus [25–27]. Those studies concluded that the medial approach is a viable technique for plating humeral shaft fractures. Laporte et al. [26] demonstrated that the medial approach allows the surgeon to avoid dissection of the radial nerve which also has a cosmetic advantage. Lu et al. [27] reported a retrospective study that compared the medial and anterolateral approach for treating humeral shaft fractures in 34 patients. They concluded that both approaches had equivalent outcomes. The medial approach in the midshaft area does not require a pre-bent plate, and a well-hidden scar can also be designed which improves the cosmetic outcome. Additionally, a biomechanical study by Zheng et al. [28] showed that the mechanical properties of anteromedial plating were comparable to anterolateral and posterior plating. They suggested that the anteromedial plate fixation strength is adequate for the mechanical requirements of humeral shaft fracture treatment. Since MIPO of the humerus was proposed via the anterior approach [4–6], it has gained popularity. Various MIPO approaches for distal third diaphyseal fractures of the humerus have been described, including their advantages and disadvantages (Table 3).

Apivatthakakul et al. [5,29] and Zhiquan et al. [6] demonstrated that the anterior MIPO approach is a safe and effective alternative option for middle and distal third humeral shaft fractures. However, if the fracture line extends distally, this approach is limited by the coronoid fossa. Kobayashi et al. [7] reported a case where the patient had limited elbow flexion after MIPO via the anterior approach because the plate was placed too distally. They recommended that the distal end of the plate should be at or above the upper edge of the coronoid fossa and suggested three-screw

Table 3
Advantages and disadvantages of available MIPO approaches for mid-distal humeral shaft fractures with references.

Surgical approaches	Advantages	Disadvantages	Location of fracture	References
Anterior	- simple & familiar proximal exposure - no need for radial nerve exploration	- uneven bony surface on anterior crest - release of deltoid insertion - pre-contoured plate on proximal part - brachialis splitting - limit distal fixation by the coronoid fossa	Mid-distal shaft	Livani (2004) (4) Apivatthakakul (2005) (5) Zhiquan (2007) (6)
Anterolateral with radial nerve exploration	- more distal fixation on anterolateral surface - can be used in case of pre-op radial nerve palsy	- radial nerve exploration - release of deltoid insertion - pre-contoured plate by bending & twisting	Mid-distal shaft	Livani (2006) (8) Zogbi (2014) (9)
Anterolateral without radial nerve exploration	- more distal fixation on anterolateral surface - reduce risk of iatrogenic radial nerve palsy	- release of deltoid insertion - pre-contoured plate by bending & twisting	Mid-distal shaft	Lee TJ (2016) (10)
Posterior	- flat posterior surface - more distal fixation on posterolateral column	- more extensive radial nerve exploration - iatrogenic radial nerve palsy - delayed union	Distal shaft	Balam (2014) (11) Gallucci (2015) (12)
Anteromedial	- no muscle splitting - easily prepare of loose anteromedial tunnel - longer two distal screws - well-hidden distal scar	- unfamiliar approach - pre-contoured plate on distal part	Distal shaft	

insertion is possible only if the fracture line is more than 6 cm above the coronoid fossa. Livani et al. [4] suggested that in the case of a short distal fragment, fixation on the anterior surface of the humerus is impossible, so the plate needs to be molded to fit the anterior surface of the lateral column to avoid impingement on the coronoid fossa and should be fixed with two bicortical screws. The anterior MIPO approach for the humerus requires midline brachialis muscle splitting at the distal incision. There are some anatomical variations in brachialis muscle innervation. Most of this muscle receives innervation from the MCN, and about 65–80% has a dual innervation by a branch from the RN as well. If the case with has single innervation by the MCN and those branches are injured during muscle splitting, the lateral part of the muscle could be denervated [14,15]. Concha et al. [16] proposed that splitting of the brachialis muscle by anterior MIPO caused muscle scarring. With inadequate postoperative rehabilitation, it may result in limited elbow range of motion.

Few studies have reported on a MIPO technique for distal shaft fracture by placing the plate anterolaterally using dual approaches (anterior approach for the proximal incision and lateral approach for the distal incision) combined with exploration of the radial nerve through an oblique incision [8,9], however, an iatrogenic radial nerve palsy occurred in three of seven patients [9]. Recently, Lee TJ et al. [10] proposed a dual approach for fractures located at least 3 cm proximal to the olecranon fossa which does not require identifying the radial nerve as that nerve is indirectly protected by the submuscular extraperiosteal tunnel. They reported that the occurrence of iatrogenic radial nerve palsy was significantly lower (0%) than with open anterolateral plating (14.2%). Although the plate can be placed more distally on the anterior surface of the lateral column [8] or the lateral surface above the supracondylar ridge [9,10] to avoid the fossa, the difficulty is the necessity to contour the plate by bending and twisting to fit the shape of the distal humerus. Discomfort from the prominence of the plate over the lateral epicondyle can occur if the plate is placed too distally. Proximally, creation of the anterolateral tunnel is somewhat difficult to perform because it is affected by the dense fibrous part of the deltoid insertion.

Balam et al. [11] reported on a study of 37 patients with middle or distal third humeral fractures which were surgically treated using the posterior MIPO approach. Union was achieved in all patients, but two patients developed transient postoperative radial nerve palsy which recovered within eight weeks. Gallucci et al. [12] also described posterior MIPO, reporting that all fractures healed with excellent functional scores. One patient developed an iatrogenic radial nerve palsy that resolved spontaneously over the next six weeks. They concluded that MIPO via the posterior approach is a reliable option for treatment of any middle or distal shaft fractures, particularly those where the fracture line is near the olecranon fossa. However, the morbidity rate with this approach is relatively high as regards the incidence of radial nerve palsy and delayed union. Intraoperative difficulties include that the radial nerve must be meticulously protected and released adequately to avoid any tension on the nerve during plate insertion. Recently, this approach had been evaluated in a cadaveric study. The authors suggested that to reduce the risk of radial nerve injury, careful dissection is required at the proximal incision and that the elbow should be kept in extension during plate insertion [13].

This study demonstrates that the anteromedial MIPO approach can be done through the internervous plane beneath the brachialis muscle without exposing any nerves or any muscle splitting. The plate needs to be slightly contoured at the distal end either preoperatively or intraoperatively. This technique not only reduces the risk of iatrogenic radial nerve injury from surgical exploration during the anterolateral or posterior MIPO approach, it also reduces the risk of brachialis muscle denervation and muscle scarring with the anterior MIPO approach. For technical reasons, we suggest reducing the fracture first and doing temporary fixation with an external fixator on the anterior or lateral side as described by Lee HJ et al. [30]. The length is checked with the intra-operative fluoroscopy and the rotation is determine by using the AP image of the epicondylar plane of the distal humerus distally and use the biceps tendon as an anterior landmark proximally. After which MIPO on the anteromedial will not be difficult. However, contraindications include previous surgery around the humerus with the scarring of the soft tissue and preoperative radial nerve palsy as this method does not provide access to the RN.

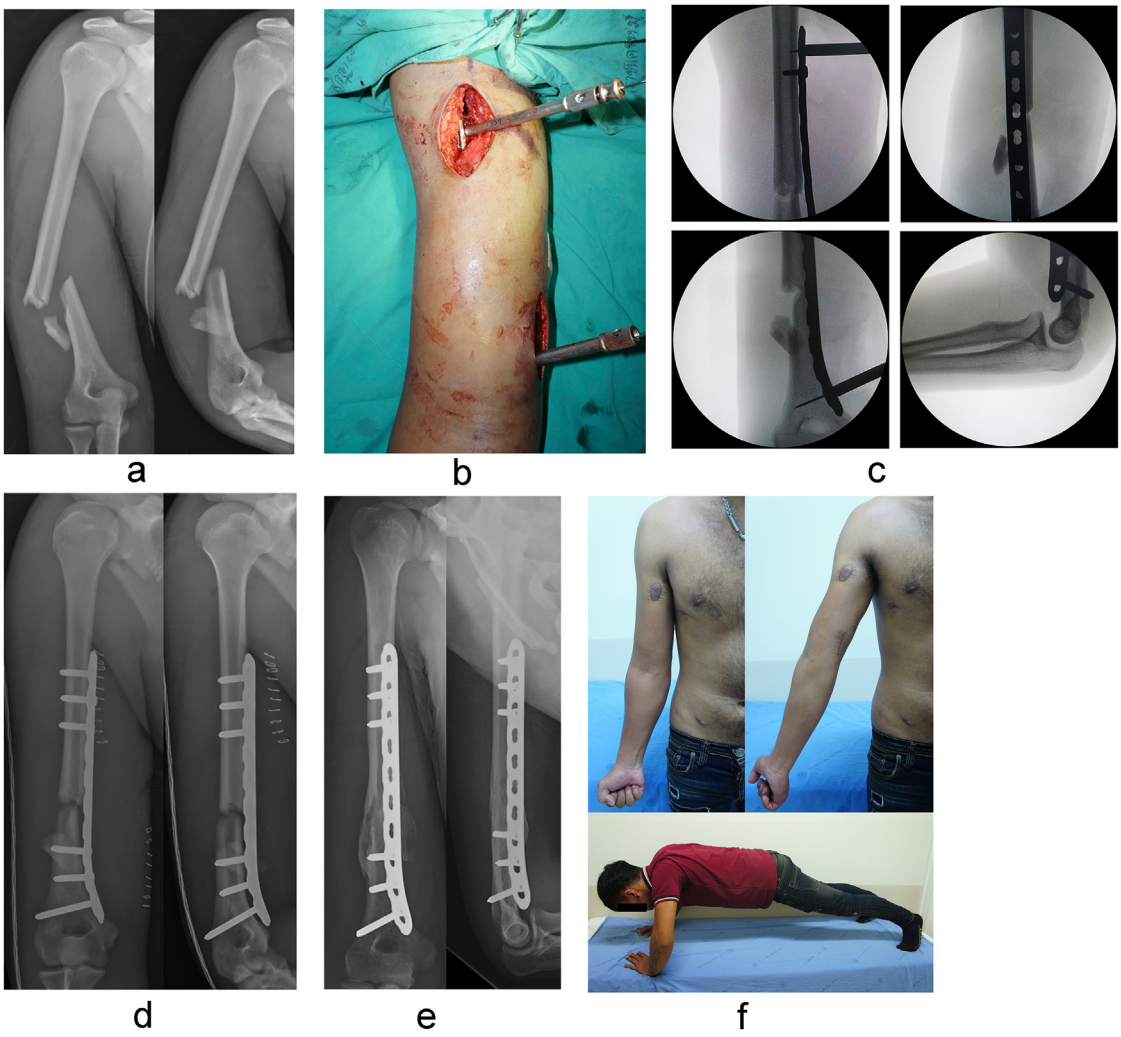

Fig. 7. a. 20 year old male with fractured distal shaft of humerus, AO/OTA 12B-2. b. Distal and proximal incisions with the anteromedial MIPO approach. c. Intraoperative fluoroscopic images (AP and lateral views). d. Immediate postoperative x-rays. e. One year postoperative x-rays showing complete healing with callus bridging the fracture. f. Well-hidden medial scar at the elbow with full recovery of function.

Based on our study, the anteromedial MIPO approach could be an alternative option for distal humeral shaft fractures with the length of the distal fragment at least 4 cm from the proximal edge of coronoid fossa. In cases that the fracture is extended very distal which could not fix with two long locking screws, the fixation will not stable, we would recommend the posterior approach. This approach could also be utilized to enhance the stability of fixation, especially in cases of severe osteoporosis, periprosthetic fractures, and pathologic fractures that need biplanar fixation. Dual plating could be done using this approach in combination with another approach (either posterior or lateral) to reconstruct both columns of the distal humerus while preserving the blood supply of surrounding tissue and accelerating fracture healing as there is less invasive surgical dissection.

A limitation of this study is that the measurements were made using intact humeri, while in patients with humeral fractures the anatomical landmarks are usually distorted. We recommend reduction of the fracture and temporary use of an external fixator in order to maintain the anatomical alignment as accurately as possible. Prospective clinical studies are needed to evaluate the outcomes of this technique.

Clinical case

A 20 year old male fell from a height and suffered an ipsilateral closed fractures of the right distal third humeral shaft and scapular neck with hemopneumothorax. After being clinically stabilized, he underwent the anteromedial MIPO of the right humerus using a 10-hole narrow LCP. There were no neurovascular complications and the alignment was acceptable. Bony union was achieved at 12 weeks postoperatively. One year follow-up showed full range of motion of his right shoulder and elbow with well-hidden surgical scars (Fig. 7).

Conclusions

The anteromedial MIPO approach can be performed through the internervous plane beneath the brachialis muscle without exposing any nerves or causing any muscle splitting with a 12-hole plate. Both proximal and distal screw insertion must be done with direct exposure. Insertion of percutaneous screws in the middle part of the plate between the two incisions is not possible. This approach could be an alternative for extra-articular distal third humeral shaft fractures which provides less invasive surgical

dissection, allows the use of longer distal screws, and achieves better cosmesis.

Conflicts of interest

The authors received funding from the Faculty of Medicine and Musculoskeletal Science and Translational Research Center (MSTR), Chiang Mai University, Thailand. We received no payments or other benefits from any commercial entity.

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