


CLINICAL ARTICLE

Single Modified Posterior Approach through the Space of the Proximal Radioulnar Joint for Terrible Triad Injury: A Comparative Study

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Objective: In order to reduce surgical scars and the risk of neurovascular injury for the treatment of terrible triad injuries of the elbow (TTI), minimally invasive and better therapeutic effect approaches are being explored to replace the conventional combined lateral and medial approach (CLMA). This study was performed to compare the clinical effect and security of the modified posterior approach (MPA) through the space of the proximal radioulnar joint vs the CLMA for treatment of TTI.

Methods: This study retrospectively analyzed 76 patients treated for TTI from January 2009 to December 2020 (MPA: n = 44; CLMA: n = 32). Treatment involved plate and screw fixation or Steinmann pin fixation for the radial head and ulnar coronoid process fractures. Surgeons only sutured the lateral ligament because the medial collateral ligament was usually integrated in the TTI. The continuous variables were compared by the independent Student t-test and the categorical variables by the χ^2 -test or Fisher's exact test.

Results: Both groups of patients attained a satisfactory MEPS after the operation. The MEPS (MPA: 96.82 ± 6.04 vs CLMA: 96.56 ± 5.51) was not significantly different between the two groups ($p > 0.05$). However, the MPA resulted in better elbow flexion and extension (MPA: 123.98 ± 10.09 vs CLMA: 117.66 ± 8.29), better forearm rotation function (MPA: 173.41 ± 6.81 vs CLMA: 120.00 ± 12.18), and less intraoperative hemoglobin (MPA: 9.34 ± 5.64 vs CLMA: 16.5 ± 8.75) and red cell volume loss (MPA: 3.09 ± 2.20 vs CLMA: 6.70 ± 2.97) (All $p < 0.05$). Although the CLMA had a shorter surgery time (MPA: 171.73 ± 80.68 vs CLMA: 130.16 ± 71.50) ($p < 0.05$), it had a higher risk of neurologic damage (MPA: 0 vs CLMA: 4) ($p < 0.05$). Four patients developed forearm or hand numbness after the CLMA, but no patients developed numbness after the MPA. All 76 patients were followed up for 15 months postoperatively.

Conclusion: The MPA through the space of the proximal radioulnar joint has more prominent advantages than the CLMA for TTI, including single scar, clear exposure, good fixation, lower risk of neurovascular injury, and better elbow joint motion. It is a safe and effective surgical approach that is worthy of clinical promotion.

Key words: Elbow joint; Single modified posterior approach; Space of proximal radioulnar joint; Terrible triad injuries

Introduction

Posterior dislocation of the elbow accompanied by fracture of the radial head and ulnar coronoid is called a "terrible triad injury (TTI)" of the elbow. This injury is well-known for its complicated wound pattern, associated

complications, and poor clinical prognosis. Therefore, the treatment of TTI remains controversial¹⁻³.

The therapeutic methods for TTI can be classified into surgical and nonsurgical treatments. The goal of any treatment is to achieve a stable joint with satisfactory

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Received 24 February 2022; accepted 5 July 2022

TABLE 1 Primary clinical data

Items	The modified posterior approach (n = 44)	The lateral combined with medial approach (n = 32)	F/ χ^2	p
Sex (male/female)	35/9	24/8	0.220	0.639
Age (years)	35.14 ± 13.02	33.03 ± 10.64	1.484	0.461
Fracture causes			2.815	0.245
Car accident	11	6		
Sports injury	10	13		
Fall from high places	23	13		
Lateral fracture			0.789	0.374
Left side	21	12		
Right side	23	20		
Mean injury time(d)	14.00 ± 8.78	12.66 ± 6.95	1.582	0.481
Regan–Morrey types			3.321	0.190
I	16	14		
II	13	13		
III	15	5		
Mason types			7.032	0.071
I	5	1		
II	14	6		
III	16	10		
IV	9	15		
Intraoperative Hemoglobin loss	9.34 ± 5.64	16.5 ± 8.75	2.064	<0.0001
Intraoperative red cell volume loss	3.09 ± 2.20	6.70 ± 2.97	1.625	<0.0001
Mean surgery time (min)	171.73 ± 80.68	130.16 ± 71.50	1.262	0.025

function, allow early exercise, and reduce complications⁴. Some patients can reportedly be treated non-surgically. Guitton and Ring⁵ used conservative treatment for four TTI patients, three of whom achieved good results. The authors stated that if patients are treated conservatively, they must satisfy the following requirements to achieve satisfactory results: (i) the elbow joints are concentric; (ii) the fracture fragments of the radial head and coronoid process are relatively small, and the fracture fragments reach the state of no or slight displacement after closed reduction; and (iii) no mechanical obstruction is present during elbow flexion, extension, and rotation⁵. Thus, only a few patients with mild injury are suitable for nonsurgical treatment; most patients need surgery.

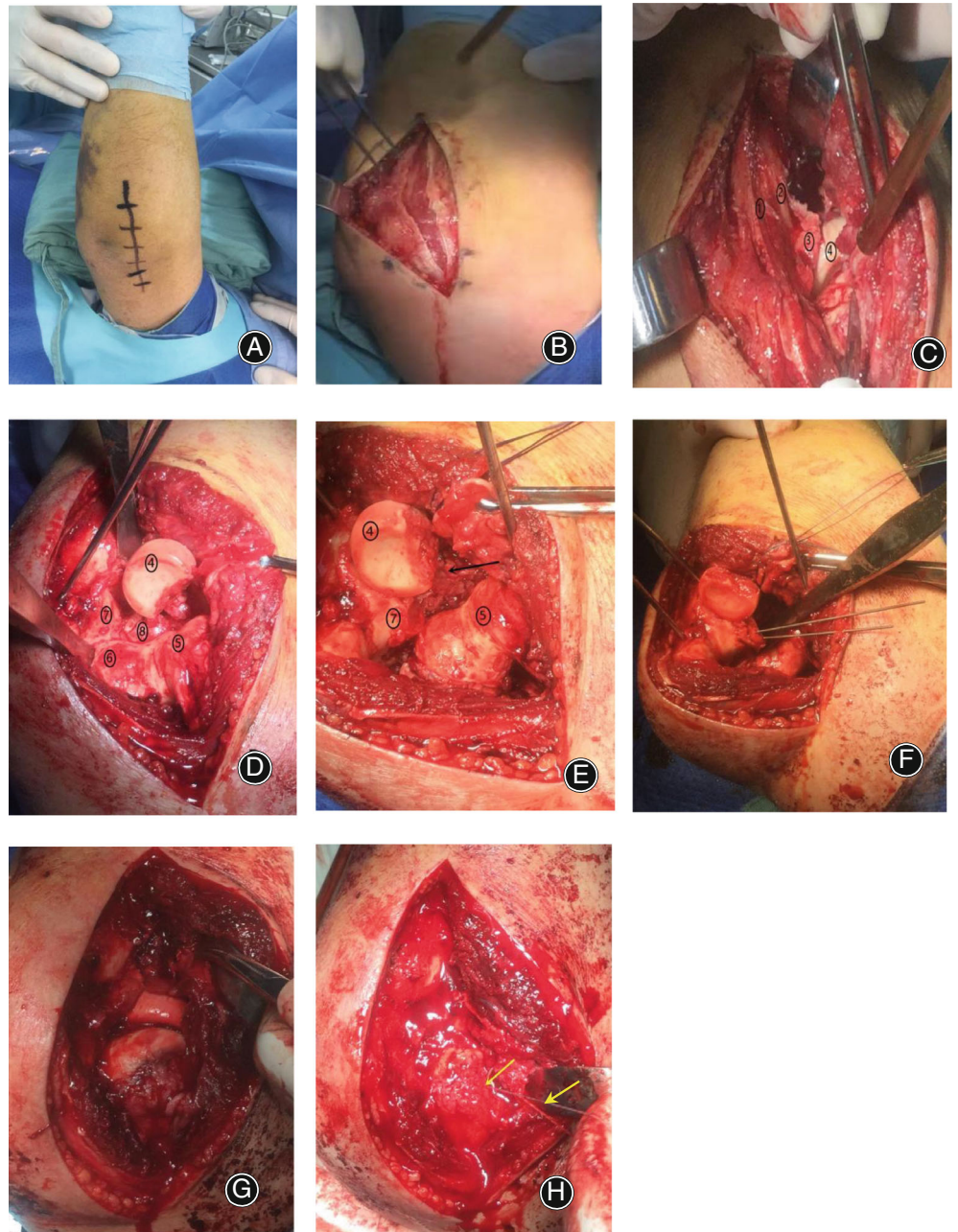
The stability of the elbow joint is related to the injury site of the elbow, and fracture of the ulnar coronoid process affects the stability of the anterior column of the elbow joint. Rupture of the lateral collateral ligament and fracture of the radial head lead to decreased stability of the lateral column. It often associates severe soft tissue injuries and posterolateral rotational instability⁶. The injury of the medial collateral ligament leads to instability of the medial column. However, most TTI do not involve rupture of the medial collateral ligament; therefore, it is unnecessary to repair injuries of the medial collateral ligament in TTI⁷.

The treatment of TTI has presented a great challenge to orthopaedic surgeons, which is often accompanied by devastating complications, such as elbow stiffness (10.3%), failures of osteosynthesis (6.7%), and ulnar neuropathy (19.1%)^{8–10}.

TTI of the elbow joint can be treated through multiple approaches, including lateral, anterior, posterior, and combined

approaches^{11,12}. Exposing the ulnar coronoid fracture through the anterior approach to the elbow joint has many limitations, including extensive soft tissue dissection, neurovascular damage, and a poor surgical view due to the presence of important nerves, blood vessels, and abundant muscle tissue. Many surgeons prefer to manage TTI through the lateral Kocher approach, which facilitates clear exposure and repair of the lateral ligaments, joint capsule, and radial head. However, it is not easy to restore and fix ulnar coronoid fractures using this approach. Although previous scholars have proposed that a single lateral approach can be used to treat TTI of the elbow, this technique still has limitations¹³. First, it is difficult and time-consuming to restore and fix the ulnar coronoid fracture because of poor exposure of the ulnar coronoid. Second, if the ulnar coronoid fracture is close to the medial side or combined with an olecranon fracture, it becomes extremely difficult to fix the ulnar coronoid fracture only through the single lateral approach. The conventional posterior trans-olecranon approach requires an extended posterior incision, extensive free medial and lateral skin flaps, and removal of the olecranon, which may result in serious damage to the soft tissue, a compromised blood supply, new fractures, and elbow stiffness. Researchers have noted that the CLMA achieves a better therapeutic effect than the single lateral approach or single anteromedial approach for TTI¹⁴. The CLMA may be the preferred choices for the treatment of TTI. However, this approach has been reported to cause large intraoperative soft tissue disruption at the lateral and medial elbow, it increased the risk of postoperative elbow stiffness, ulnar nerve symptoms, or heterotopic ossification^{15,16}. Therefore, surgeons are still expecting a novel and better approach.

FIGURE 1 Surgical process of the modified posterior approach through the space of the proximal radioulnar joint for treatment of terrible triad injury. (A) Surgical incision of the skin. (B) Deep fascial incision. (C) The anconeus muscle and supinator were removed from the ulna with the periosteum. The incision was extended along the lateral space of the triceps brachii to a point 4 cm above the elbow, and the posterior articular capsule of the elbow joint was opened to expose the proximal radioulnar joint. ① The incision plane of anconeus muscle with periosteum. ② Annular ligament of radius. ③ Posterior articular capsule. ④ Head of radius. (D) The Kirschner wires were reversed medially and the humeroulnar joint was partially dislocated. Good exposure of the ulnar coronoid fracture was obtained. ④ Head of radius. ⑤ Ectepicondyle of humerus. ⑥ Entepicondyle of humerus. ⑦ Coronal process of ulna. ⑧ Anterior capsule of the elbow joint. (E) Repair of the anterior capsule of the elbow joint. ④ Head of the radius. ⑤ Ectepicondyle of humerus. ⑦ Coronal process of ulna. (F) Restoration and fixation of the coronoid process fracture. (G) Restoration of the elbow joint after fixation of the fracture of the radial head and ulnar coronoid process. (H) Repair of the lateral collateral ligament and annular ligament



The aims of the present study were: (i) to introduce the details of the MPA procedures for the treatment of TTI; (ii) to evaluate the efficacy and safety of the MPA through comparing it with the intraoperative and postoperative results of the CLMA; (iii) to provide clinical guidance of the MPA for the future treatment of TTI.

Methods

The Inclusion and Exclusion Criteria

Before the operation, all patients underwent anterior and lateral X-ray examinations of the elbow joint, CT scans and

three-dimensional reconstruction of the elbow joint to evaluate the degree of fracture comminution and articular surface involvement, and magnetic resonance imaging to examine injuries of the elbow ligaments if necessary (Table 1). The inclusion criteria were (i) the ability to tolerate surgery; (ii) previously normal elbow function with no history of traumatic elbow fracture; (iii) fresh fracture with timely treatment; and (iv) diagnosis of terrible triad injury of the elbow by X-ray and computed tomography (CT) examination. The exclusion criteria were (i) malignant tumors and other primary diseases that influence bone metabolism; and (ii) shaft fractures of the radius and ulna. This study was approved by

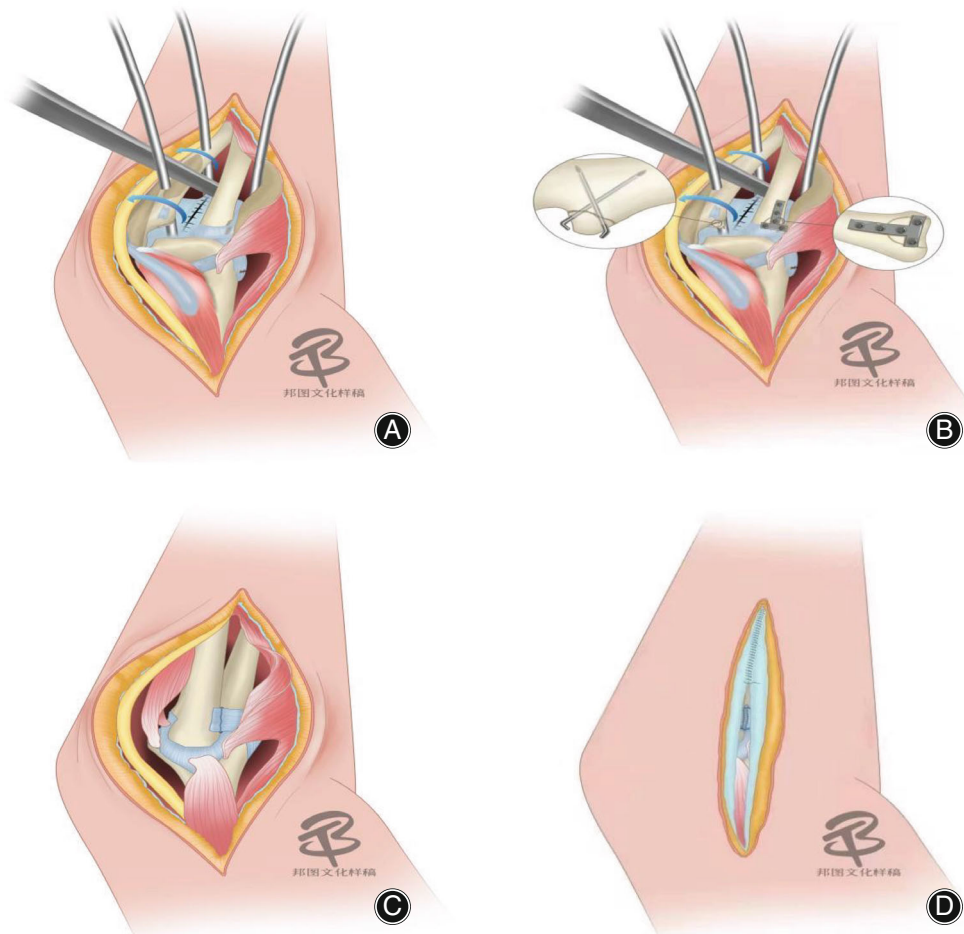


FIGURE 2 Plate and Steinmann pin fixation through the modified posterior approach from the space of the proximal radioulnar joint. (A) The incision was extended along the lateral margin of the crista ulnae through the midpoint of the line between the olecranon and the lateral condyle of the humerus to a point 4 cm above the elbow. The total length of the incision was about 10 cm. The periosteum attached to the anconeus muscle and supinator of the ulna was removed, exposing the posterior elbow joint and proximal radioulnar joint. We inserted two Kirschner wires vertically from the crista ulnae, separated the proximal radioulnar joint by a periosteum detacher, and exposed and sutured the front elbow capsule. (B) We reversed the Kirschner wires medially and partially dislocated the humeroulnar joint, attaining good exposure of the ulnar coronoid fracture. We then fixed the fracture with Steinmann pins (Arthrex). We restored the radial head fracture simultaneously. (C) We removed the Kirschner wires and periosteum detacher, reduced the proximal radioulnar joint and humeroulnar joint, and sutured the radial annular ligament. (D) After we sutured the muscle fascia, the periosteum of the anconeus muscle and supinator was placed back on the ulna. Finally, we closed the wound layer by layer

the Ethics Committee of the Second Xiangya Hospital Affiliated to Central South University (IRB/IEC NO.K034).

Patients Clinical Data

This study involved 76 patients with TTI of the elbow (59 men, 17 women; age range, 18–69 years; average age, 34.25 years). All patients were diagnosed with fresh closed TTI and consented to undergo surgical treatment in the Second Xiangya Hospital Affiliated to Central South University from January 2009 to January 2020. Among the 76 patients, 44 were treated with the single MPA through the space of the proximal radioulnar joint, and 32 were treated with the CLMA. The ulnar coronary fractures were assessed using the Regan–

Morrey classification¹⁷. The radial head fractures were assessed using the Mason–Johnston classification¹⁸. The number of various fracture types were presented in the Table 1. All patients were treated with closed manual reduction and plaster external fixation. We asked the patients to take initiative finger movement and perform wrist extension and flexion activities, raise the affected limbs, take Panlongqi or other drugs orally to reduce swelling, and take etoricoxib to relieve pain. The elbow skin was required to be wrinkled before surgical treatment.

Surgical Approaches

General anesthesia was induced, and the patient was placed in the supine position, lying flat on the operating bed with a

balloon tourniquet on the affected limb. The surgical approach was randomly selected by the researchers. In the early phase of this study period, we selected the CLMA to treat TTI, but we found there existed some postoperative complications such as delayed neuritis, two surgical scars, and so on. Thus, we later attempted to use a single MPA through the space of the proximal radioulnar joint to treat TTI.

The MPA through the space of the proximal radioulnar joint was performed as follows.

Location of the Incision

First, the incision was extended along the lateral margin of the crista ulnae through the midpoint of the line between the olecranon and the lateral condyle of the humerus to a point 4 cm above the elbow. The total length of the incision was about 10 cm (Figure 1A,B).

Clear Exposure of the Proximal Radioulnar Joint

Second, the periosteum attached to the anconeus muscle and supinator of the ulna was removed to expose the posterior elbow joint and proximal radioulnar joint. We inserted two Kirschner wires (Arthrex, Naples, FL, USA) vertically from the crista ulnae, separated the proximal radioulnar joint by a periosteum detacher, and exposed and sutured the front elbow capsule. Notes: (i) Surgeons peeled the periosteum attached to the anconeus muscle and supinator of the ulna and did not impair anconeus muscle and supinator. It creates conditions for sticking the complete periosteum back to ulna later; (ii) If the radial annular ligament was not disrupted in the injury, surgeons should incise it for later rotating the proximal ulna and leave two stumps for final suture (Figures 1C and 2A).

Rotating the Proximal Ulna and Restoring Fracture

Third, we reversed the Kirschner wires medially and partially dislocated the humeroulnar joint, attaining good exposure of the ulnar coronoid fracture. We then fixed the coronoid fracture with Steinmann pins (Arthrex). We restored the radial head fracture simultaneously. Notes: Surgeons rotate the ulnar proximal just enough to expose and repair the

coronoid fracture. It should avoid excessive rotation in case of damaging the forearm interosseous membrane (Figures 1D–G and 2B).

Repairing the Soft Tissues

The final, we removed the Kirschner wires and periosteum detacher, reduced the proximal radioulnar joint and humeroulnar joint, and sutured the radial annular ligament. After we sutured the muscle fascia, the periosteum of the anconeus muscle and supinator was placed back on the ulna (Figures 1H and 2D). Notes: Do not impair or suture the periosteum, surgeons just need to suture the muscle fascia of the anconeus muscle and supinator, the anconeus muscle and supinator with periosteum will naturally reset to their primary sites.

The CLMA was performed as follows. A lateral incision was made between the extensor carpi ulnaris and the anconeus, facilitating exposure and restoration of the collateral ligament, lateral elbow, and radial head. A medial incision was made along the medial epicondyle of the humerus to protect the ulnar nerve and fix the fracture of the ulnar coronoid process.

The treatments of the radial head fracture included plate-screw internal fixation and radial head replacement. We used a plate and screw to fix the fracture of the ulnar coronoid process. During the operation, the elbow valgus stress test and varus stress test were negative. We confirmed that the medial collateral ligament did not rupture in all patients, thus we did not repair the medial collateral ligament. No patients exhibited dislocation of the elbow joint during flexion and extension. A wound drainage tube was placed, and the deep fascia, subcutaneous tissue, and skin were successively sutured (Table 2 and Figures 1 and 2). Except for the surgical approach, there were no differences in any other surgical variables between the two groups.

Restorative Maneuvers

Fixation of the coronal fracture was performed with 1.0-mm Steinmann skeletal pins (Arthrex) for type I fractures and with two or three titanium screws and one titanium plate (Arthrex) for type II and III fractures. Restoration of the

TABLE 2 Postoperative function

Items	The modified posterior approach (n = 44)	The lateral combined with medial approach (n = 32)	F	p
Flexion and extension	123.98 ± 10.09	117.66 ± 8.29	1.468	0.005
Forearm rotation	173.41 ± 6.81	120.00 ± 12.18	3.232	<0.0001
MEPS	96.82 ± 6.04	96.56 ± 5.51	1.190	0.852
Excellent and good rate			0.827	0.363
Excellent	35	28		
Good	9	4		
Acceptable	0	0		

Data are presented as mean ± standard deviation or n.; Abbreviation: MEPS, Mayo Elbow Performance Score.

radial head fracture was performed with one or two counter-sunk head thread-forming screws (Arthrex) for type I and II fractures, with two or three titanium screws and one titanium plate (Arthrex) for type III fractures, and with two or three titanium screws and one titanium plate or replacement of the radial head (Arthrex) for type IV fractures. The lateral collateral ligament was repaired by stitching it with non-absorbable sutures.

Postoperative Care

If the wound drainage volume was <50 mL within 24 h after the operation, the drainage tube was removed. The elbow was fixed at 90° with a plaster brace for 1 week, during which time we allowed the patients to exercise their wrist and shoulder joint randomly. One week after the operation, we replaced the plaster with an adjustable brace and allowed the patients to perform moderate elbow joint flexion and extension exercises and forearm rotation function exercises. The brace was removed 6 to 8 weeks postoperatively, at which time unrestricted function exercises were encouraged. The use of antibiotics was dependent upon the presence of obvious signs of bacterial infection. Indomethacin was routinely used for 1 month to prevent ectopic ossification.

Follow-Up and Postoperative Therapeutic Evaluation

We followed up all patients for 15 months, and no patients were lost to follow-up. The hemoglobin concentration and hematocrit were measured 3 days before and 1 day after surgery. At the end of the 15-month follow-up, we recorded all patients' range of motion of the injured elbow joint, including forearm rotation and flexion and extension. All patients were assigned a Mayo Elbow Performance Score (MEPS) according to the range of motion of their elbow joint¹⁹. A final score of ≥90 was regarded as excellent, 75 to 89 as good, 60 to 74 as acceptable, and <60 as poor. Postoperative complications, including neurologic damage and heterotopic ossification, were also recorded.

The Hemoglobin Concentration and Hematocrit

They were measured by simple routine blood test. Hemoglobin concentration refers to the amount of hemoglobin contained in per unit volume (L) blood. Hematocrit is the volume ratio of red cells in the whole blood. Researchers used these two parameters to evaluate the intraoperative blood loss.

Surgery Time (min)

It begins with applying the aseptic operation and ended with suturing the last incision.

The Injured Elbow Joint Motion Range

Elbow flexion and extension: Patients remained in supine position; the upper limbs were placed on both sides of the trunk with the palm up. The protractor was placed on the lateral side of elbow and positioned in the lateral epicondyle of the humerus. Surgeons could measure the angles between

the forearm midline and the humeral midline at the extreme elbow flexion and extension positions. Forearm rotation: Patients took the sitting position; the elbow was bent 90° with the upper arm aligned with the trunk. The palm should grip a pencil. Surgeons could measure the forearm rotation angles made up by the pencil at extreme pronation and supination position and use Mayo Elbow Performance Score (MEPS) to assess the functional outcome of the injured elbow at 15 months after surgery.

Complications

Within the postoperative 15 months, if the injured limb appeared to show numbness or motor dysfunction and the electromyography exam showed neuronal impairment, those patients would be diagnosed as delayed neuritis. At the same time, patients with elbow joint pain or soft tissue masses and grainy shadows in the soft tissue by X-ray would be diagnosed as myositis ossificans.

Statistical Analysis

All data were analyzed using statistical software Prism 9.0 (GraphPad Software, San Diego, CA, USA). Measurement data are expressed as mean ± standard deviation. Prior to analyzing the data, researchers confirmed the homogeneity of variance in each group. The continuous variables (age, mean injury time, intraoperative hemoglobin loss, intraoperative red cell volume loss, mean surgery time, flexion and extension, forearm rotation, MEPS) were compared by the independent Student t-test. The categorical variable (sex, fracture causes, lateral fracture, Regan-Morrey types, Mason types, excellent and good rate after surgery complication rate) were compared by the χ^2 -test or Fisher's exact test. Two-tailed $p < 0.05$ was considered significantly different.

Results

Basic Clinical Data

As shown in Table 1, there were no significant differences in sex, mean age, causes of fracture, or mean duration of injury between the two groups (all $p > 0.05$). Intraoperative hemoglobin loss (MPA: 9.34 ± 5.64 vs CLMA: 16.5 ± 8.75) and intraoperative red cell volume loss (MPA: 3.09 ± 2.20 vs CLMA: 6.70 ± 2.97) were significantly lower in the MPA than in the CLMA (both $p < 0.05$). The surgery time (MPA: 171.73 ± 80.68 vs CLMA: 130.16 ± 71.50) was significantly longer for the MPA than the CLMA ($p < 0.05$).

Elbow Range of Motion and MEPS

Elbow flexion and extension (MPA: 123.98 ± 10.09 vs CLMA: 117.66 ± 8.29) and forearm rotation (MPA: 173.41 ± 6.81 vs CLMA: 120.00 ± 12.18) were significantly better after the MPA than after the CLMA (both $p < 0.05$). As shown in the preoperative and postoperative CT images, the MPA resulted in satisfactory restoration and remarkable improvement of the elbow range of motion (Figures 3 and 4). The MEPS (MPA: 96.82 ± 6.04 vs CLMA: 96.56 ± 5.51)



FIGURE 3 Computed tomography images. (A, B) Preoperative computed tomography showed the No.1 patient with the terrible triad of the right elbow; (E, F) Preoperative computed tomography showed the No.2 patient with the terrible triad of the left elbow. (C, D) Postoperative computed tomography showed that the fracture of No.1 patient was well restored, and the joint was stable. (G, H) Postoperative computed tomography showed that the fracture of No.2 patient was also well restored, and the joint was also stable

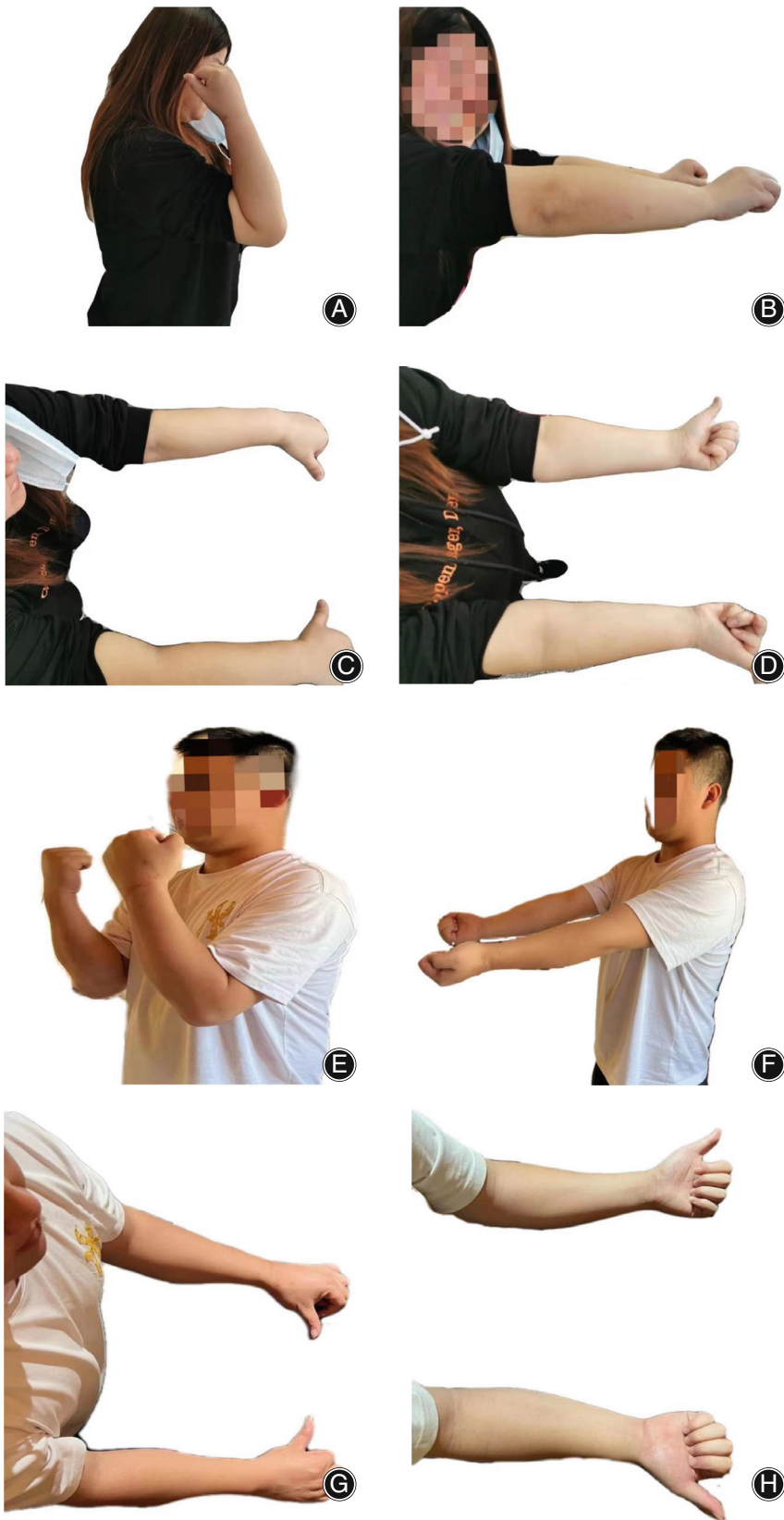


FIGURE 4 The single modified posterior approach resulted in satisfactory restoration and remarkable recovery of the elbow range of motion at 15 months after surgery. (A, B) The flexion and extension function of No.1 patient at 15 months postoperatively. (E, F) The flexion and extension function of No.2 patient at 15 months postoperatively. (C, D) The forearm rotation of No.2 patient at 15 months postoperatively. (G, H) The forearm rotation of No.2 patient at 15 months postoperatively

was not significantly different between the two groups ($p > 0.05$) (Table 2).

Postoperative Complications

We compared postoperative complications such as delayed neuritis and myositis ossificans between the two groups. Four patients undergoing the CLMA developed delayed neuritis half a year after the operation, three of them had numbness, tingling, or paresthesia in the forearm and ring and little finger pulp, and these symptoms became severe during long time elbow flexion. One of them had numbness at the radialis back of hand. The electromyography exam showed ulnar or radial nerve impairments respectively at the elbow joint. These four patients received methylcobalamin for neurotrophic treatment and ulnar or radial neurolysis while removing internal fixations. Only one patient kept experiencing numbness at the radialis back of hand and the remaining three patients recovered without the above symptoms. Meanwhile, two patients undergoing CLMA developed myositis ossificans at 1 month postoperatively. They reported pain and touched soft tissue masses at the injured elbow. The X-ray showed grainy shadows in the soft tissues. Doctors fixed the injured elbow at 90° of elbow flexion by cast immobilization until the grainy shadows no longer extended. Then, patients were encouraged to do functional exercise and the ectopic bone were removed while removing internal fixations. Both patients received function improvements and their pain eased. The results showed a significantly lower incidence of delayed neuritis (MPA: 0 vs CLMA: 4) after the MPA than after the CLMA ($p < 0.05$). The incidence of myositis ossificans (MPA: 0 vs CLMA: 2) was not significantly different between the two groups ($p > 0.05$) (Table 3).

Discussion

This clinical study confirmed our conjecture. We could rotate the proximal ulna to repair the coronacoid fracture and repair the fracture of the radial head and the annular ligament within this space of proximal radioulnar joint.

Repairing the Coronacoid Fracture

It is very intuitionistic and safe to repair the coronacoid fracture through rotating the proximal ulna by the

MPA through the space of the proximal radioulnar joint. No patients experienced dislocation of the humero-ulnar joint during the 15 months follow-up. It requires further study to see if the modified approach preserves the complete triceps brachii muscle and avoids the occurrence of postoperative elbow extension weakness. In addition, it does not cause an interosseous membrane tear. The interosseous membrane is the membranous structure that connects the ulna and radius. Its five components are the central band, the distal oblique bundle, an accessory band, a dorsal oblique accessory cord, and a proximal oblique cord²⁰. Studies have shown that the interosseous membrane contributes to the stability of the forearm. Interosseous membrane rupture may cause humeroradial joint and ulnocarpal joint impaction, elbow and wrist pain, and limited forearm movement²¹⁻²³. Gutowski *et al.*²⁴ reported that the values for supination and pronation increased by 26% and 22%, respectively, after cutting the interosseous membrane of the forearm. In the present study, patients who underwent the MPA did not develop these symptoms. Therefore, we believe that the MPA to the elbow joint does not cause interosseous membrane tears.

Repairing the Fracture of the Radial Head and the Annular Ligament

Similarly, it is very intuitionistic and safe to repair the radial head fracture and suture the lateral radial collateral ligament *via* the MPA. As for the radial annular ligament, if it was ruptured at the time of the injury, it can be directly sutured through this MPA. If the ligament remained intact after the injury, it must be cut off and then sutured after reduction of the ulnar coronoid process and radial head. In the present study, no patients developed radial head dislocation throughout the long-term follow-up.

As for the medial collateral ligament, Forthman *et al.*²⁵ reported that it is unnecessary to repair the medial collateral ligament in the treatment of TTI. Therefore, after checking that we had attained good stability of the elbow joint after reduction of the fracture and repair of the lateral collateral ligament, we chose not to repair the medial collateral ligament.

This study illustrated we could repair the TTI through the MPA without the risk of nerves and vascular injury. Meanwhile, the MPA has lower blood loss, better elbow function recovery, and lower risk of delayed neuritis than the CLMA.

Intraoperative Blood Loss

We compared intraoperative hemoglobin and red cell volume loss of the two different approaches on the TTI. The results showed that the single MPA had less blood loss than the CLMA ($p < 0.05$). The likely reason for this discrepancy is that the single MPA restores the ulnar coronoid process and the radial head fracture through the space of the proximal radioulnar joint, thus it avoids large vascular injury and reduces skin incision.

TABLE 3 Postoperative complications

Items	The modified posterior approach (n = 44)	The lateral combined with medial approach (n = 32)	p
Complication rate (%)	0	12.50	0.004
Delayed neuritis	0	4	0.028
Myositis ossificans	0	2	0.174

Postoperative Function

With respect to the elbow range of motion and the MEPS, this study showed that the single MPA resulted in better elbow flexion and extension and better forearm rotation than the CLMA at the end of the 15-month follow-up ($p < 0.05$). The first reason may be the large soft tissue damage caused by the CLMA, which resulted in large postoperative subcutaneous scars. It may influence postoperative elbow joint function. The second reason lies in less sensory nerve distribution in the posterior elbow than the medial or lateral side and more serious postoperative pain after the CLMA than the single MPA. To some extent, the postoperative pain would influence early functional exercise of the injured elbow, patients with the single MPA might exhibit more positive functional exercise performances than those with the CLMA. However, the MEPS was not significantly different between the two groups ($p > 0.05$). This is because the CLMA already produces high elbow range of motion scores in the relevant part of the MEPS, and the wider elbow range of motion produced by the single MPA did not further increase the MEPS.

Postoperative Complications

Regarding the postoperative complications of delayed neuritis and myositis ossificans, our results showed that the single MPA group had lower risk of delayed neuritis than the CLMA group ($p < 0.05$), but no difference in terms of the myositis ossificans ($p > 0.05$). The single MPA restores the ulnar coronoid process and the radial head fracture through the space of the proximal radioulnar joint, thus it avoids neural injury.

Strengths and Limitations

This study is the first to compare the novel MPA and the CLMA for TTI *via* a large number of clinical cases. Except for the pain (part I) and daily activities (part IV) scores of MEPS that were collected from patients recall, the remaining data were obtained from the clinical record systems. Meanwhile, two researchers completed all statistical analyses and checked all results one by one. All the parameters presented the efficacy and safety of the MPA for TTI.

However, the present study is a retrospective case-control study, all patients were from a simple hospital and most clinical data were collected from patients recall and clinical record systems. Thus, we cannot exclude the possibility of selection bias and recall bias. The insufficient number of cases and lacking prospective multi-center clinical study limits the credibility of our research.

Conclusion

In this study, the modified posterior approach for the treatment of terrible triad injuries of the elbow joint demonstrated several advantages including a single approach, clear exposure, fewer complications, and satisfactory elbow function. Thus, it is worthy of further clinical application and

additional prospective studies with larger and multi-center samples, to clarify the clinical value of the single MPA.

Author Contributions

Dianqing Li, PhD, performed the follow-up tasks and wrote the manuscript; Deye Song, PhD, and Jiangdong Ni, PhD, contributed to the conception of the study; Dr. Sihuai Tang, Dr. Zhi Gao, Dr. Penglin Li, Dr. Xudong Liu, and Dr. Wenbin Xu contributed significantly to analysis and manuscript preparation.

Acknowledgments

We would like to express our gratitude to Prof. Deye Song, Prof. Jiangdong Ni, and our colleagues at Department of Orthopedics, The Second Xiangya Hospital of Central South University for helpful clinical research guidance. Thanks to my beautiful and virtuous wife, Hanrui Song, for modifying the figures in this paper.

Funding Information

This work was supported by The Natural Science Foundation of Hunan Province in China (2020JJ4805).

Conflicts of Interest

The authors declare that they have no conflicts of interest or sources of support concerning this article. This paper has not been published elsewhere in whole or in part. All authors agree to give permission to reproduce the material signed by the author(s) and publishers concerned.

Availability of Data and Materials

The datasets supporting the results of this article are included within the article and its additional files.

Compliance with Ethical Standards

Ethical approval: The study protocol was approved by the Institutional Review Board at the Second Xiangya Hospital of Central South University, Hunan, P.R. China, and written informed consent was obtained from the patient for publication of this study and any accompanying images.

Consent to Publish

Not applicable.

Consent to Participate

Not applicable.

Informed Consent

Written informed consent was obtained from the patient for publication of this case report and any accompanying images. A copy of the written consent is available for review by the Editor in Chief of this journal.

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