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Original article

Results of terrible triads in the elbow: the advantage of primary restoration of medial structure

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Abstract
Background. The purpose of this study was to report the clinical and radiological outcomes and surgical strategy for terrible triad injury of the elbow. We hypothesized that the outcomes of this type of injury would be satisfactory if the medial structure was routinely restored at the same time as the repair of the lateral structure.
Methods. We retrospectively reviewed the results of this treatment performed in 13 elbows with terrible triads. Our surgical protocol included fixation or replacement of the radial head and repair of the ruptured lateral ulnar collateral ligament through the lateral traumatic window. In all cases, simultaneous fixation of the coronoid and repair of the common flexor muscle were performed through the medial traumatic window. In eight patients with medial collateral ligament injury, the ligament was always repaired. The follow-up period ranged from 18 to 41 months (mean, 25 months).
Results. The flexion-extension arc of the elbow averaged 128° and forearm rotation averaged 134.6°. The mean Mayo elbow performance score was 95 points (range, 85 to 100), which corresponded to ten excellent results, and three good results. Concentric stability was restored to all cases. As postoperative complications, one patient had ulnar nerve neuropathy.
Conclusions. The present operative procedures restoring all damaged lateral and medial structures through the lateral and the medial windows provided satisfactory clinical and radiological outcomes and are recommended for patients with terrible triad injury.

Introduction

Elbow dislocation associated with both radial head and coronoid fractures is a complex injury that includes damage to both the bone and soft tissue which are essential for elbow stability. This pattern of injury is known as the terrible triad of the elbow[1] because of the poor reported outcomes, including recurrent instability, stiffness, post-traumatic arthrosis, and chronic pain.[2–5] However, the literature provides only limited information, as the reported results of this injury have been mentioned as extensions of other injuries, such as elbow fracture-dislocations. Only a small number of reports focus on the specific injury pattern of elbow dislocation associated with radial head and coronoid fractures.[6–8] Ring et al.[8] reported unsatisfactory results in more than half of the patients treated for terrible triad injuries. Recently, as the knowledge of biomechanics and osseous and ligamentous structures of the elbow joint has grown, good treatment results for terrible triad injuries have been reported.[6,7,9] The authors of these studies emphasized that sufficient elbow stability and congruency must be achieved to allow for early motion and to prevent arthritis, both of which are important for obtaining good overall results. They also recommended using a systematic algorithm for the determination of the extent of restoration of damaged structures. Based on these treatment algorithms, most authors agreed with restoration of the radial head (fixation or replacement), lateral collateral ligament (LCL), and coronoid process. However, the management of the medial structures, including the medial collateral ligament (MCL) and the flexor-pronator muscle complex, remains controversial. Some orthopedic surgeons believe that repair of the MCL is an important part of the operative treatment of an elbow fracture-dislocation,[10–12] and several biomechanical studies also support the important role of the MCL in valgus stability of the elbow.[13,14] Others insist that MCL repair is the final step in the treatment of terrible triad injury of the elbow and is rarely necessary.[7,15]

We consecutively treated 13 cases of terrible triad injury of the elbow, which were treated by one single surgeon in a consistent manner. All damaged structures were identified through both sides of the traumatic window. The lateral traumatic window was made up of

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the lateral ulnar collateral ligament (LUCL), the extensor muscle complex, and the lateral epicondyle of the humerus. The radial head was located in this window. The medial traumatic window consisted of the medial side of the trochlea and the flexor-pronator muscle complex. The MCL and the coronoid fracture were located in this window. We repaired all damaged structures, including the medial structures (MCL and flexor-pronator muscle complex), during a single surgery instead of using a staged technique. Thus, we report the injury patterns of the medial structures and the clinical results of restoration of the damaged medial structures in elbow dislocations with radial head and coronoid process fractures.

Subjects, materials, and methods

We identified 14 consecutive skeletally mature patients (14 elbows) who had an elbow dislocation associated with fractures of the radial head and coronoid process between December 2002 and May 2006. The patients were informed that data from the case would be submitted for publication, and gave their consent. One patient was lost to follow-up prior to definitive assessment of the outcome, leaving 13 patients for evaluation. There were 7 male patients and 6 female patients, with a mean age of 43.8 years (range, 15 to 76 years). The mechanisms of injury included 12 falls from a lower height and one high-velocity fall from a great height. The 13 elbows were treated at a mean time of 6.3 days (range, 1 to 13 days) after the injury.

The specific indications for operative intervention included a displaced intraarticular fracture, inability to obtain or maintain a concentric reduction in a closed fashion, and residual instability of the elbow in a functional arc of flexion and extension (30° to 130°).[16]

Injury and treatment details are listed in Table 1. All patients were treated with the same technique, identification, and complete restoration of all damaged structures.

We categorized the coronoid fractures according to the method of O'Driscoll et al.[17] There were six type 1 fractures (two of subtype 1 and four of subtype 2) observed and all of them were treated with pull-out sutures. There were six type 2 factures (one subtype 1, one subtype 2 and four subtype 3) observed, two of which were treated with pull-out sutures, three with a buttress plate, and one with both. There was one type 3 fracture (subtype 2), which was treated with screws and pull-out sutures. According to the Mason-Johnston classification, all radial head fractures were type IV because they were associated with a dislocation. However, considering only the fractures, there were two Mason type I fractures, seven Mason type II fractures, and four Mason type III fractures. We performed open reduction and internal fixation of the radial head in ten elbows and prosthetic replacement in three elbows (one was silicon and two were metal).

Operative techniques

The principle of operation in this study was the restoration of all damaged structures (1) to recover the congruency of the elbow joint and (2) to provide sufficient stability to the injured elbow so that the full range of motion was possible immediately after surgery.

Patients were placed in a lateral decubitus position under general anesthesia, and the injuries were approached through a posterior global incision. The

Table 1. Injury and treatment details

Patient no.	Radial head Mason classification	Treatment	Coronoid O'Driscoll type	Treatment	LUCL	Treatment	MCL	Treatment	External support	Additional procedure
1	II	OR	1,2	Pu	PA	A	MS	D + FI	Brace	
2	III	OR	1,2	Pu	PA	A	No	FI	Brace	
3	II	OR	1,1	Pu	PA	A	PA	A + FI	Brace	
4	II	OR	2,3	Pu	MS	D	PA	A + FI	Brace	
5	I	OR	2,3	Pu	PA	A	No	FI	Brace	
6	II	OR	2,2	B	PA	A	PA + DA	A + FI	Brace	
7	II	OR	1,1	Pu	PA	A	No	FI	Brace	
8	II	OR	2,2	B	PA	A	PA	A + FI	Brace	
9	II	OR	1,2	Pu	PA	A	PA	A + FI	Brace	
10	III	PR	2,3	Pu + B	PA	A	PA	A + FI	Brace	
11	I	OR	1,2	Pu	PA	A	PA	A + FI	Brace	
12	III	PR	2,1	B	PA	A	No	FI	Brace	Ulnar nerve release
13	III	PR	3,1	B	MS	D	No	FI	Brace	

OR, open reduction; PR, prosthesis replacement; PA, proximal avulsion; MS, midsubstance tear; Pu, pull-out sutures; DA, distal avulsion; A, suture anchor; B, buttress plate; D, direct repair; FI, flexor imbrications; LUCL, lateral ulnar collateral ligament; MCL, medial collateral ligament approach to the medial and lateral sides using a thick fasciocutaneous flap was intended to reduce wound complications. A lateral side traumatic plane was created during dislocation, and thus a specific incision was not necessary. LUCL damage or rupture injuries were identified, and the fracture status of the radial head was identified (Fig. 1A). With respect to the lateral soft tissue structure, all cases showed damage to the LCL complex. There was avulsion from the lateral epicondyle of the distal humerus in 11 cases and midsubstance

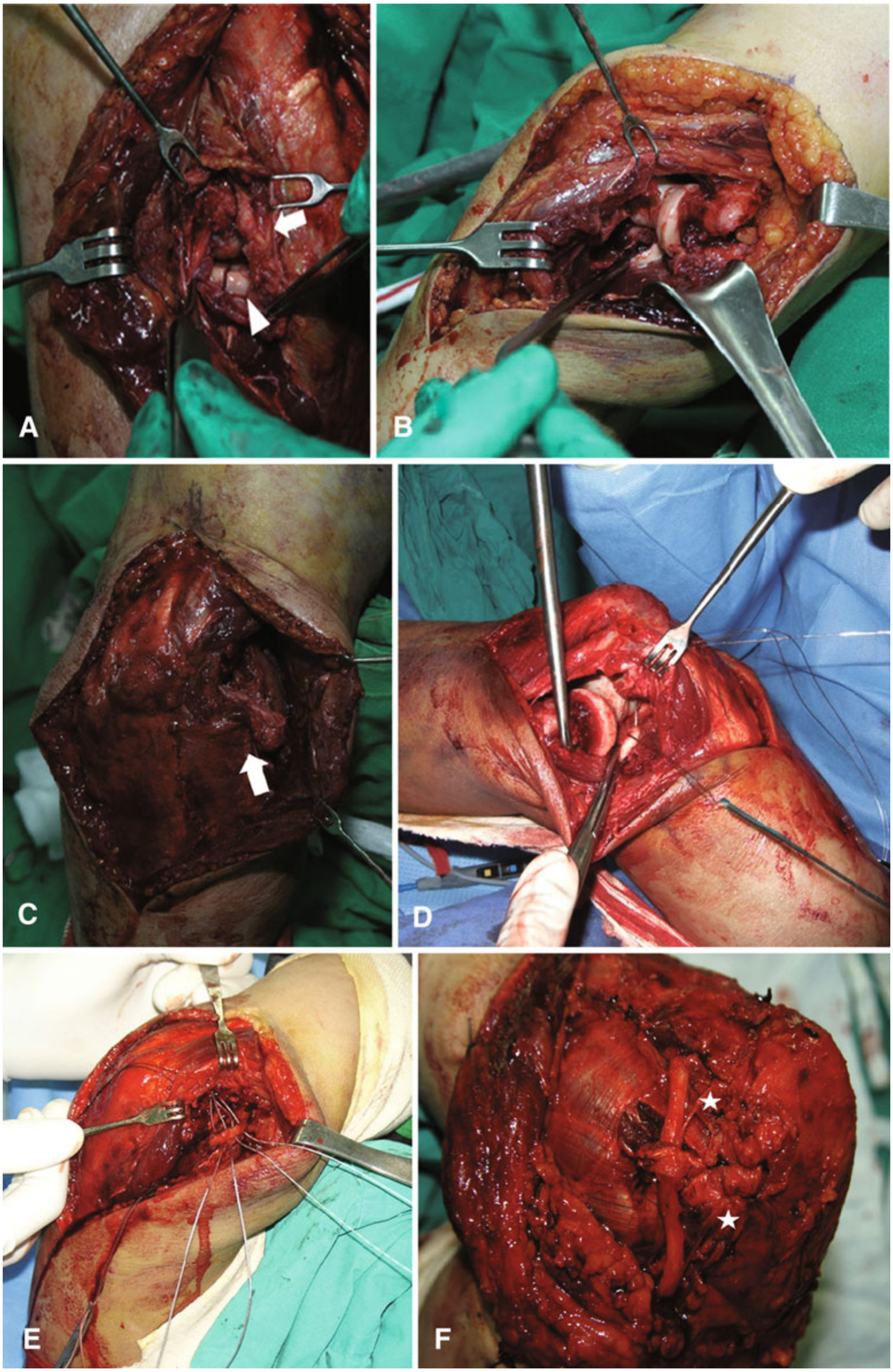

Fig. 1A–F. A Radial head fracture is observed in the lateral traumatic window (*white arrowhead*), along with a lateral ulnar collateral ligament (LUCL) rupture (*white arrow*) (case no. 8). **B** The common flexor muscle origin is stripped from the distal humerus (case no. 6) **C** The anterior bundle of the medial collateral ligament (MCL) was observed in the medial traumatic window (*white arrow*) (case no. 8). **D** Established medial traumatic window and stripped common flexor muscle origin without special incision are seen, and pull-out suturing was easily performed on the coronoid fracture through this window (case no. 1). **E** Another type of medial lesion, avulsion of the medial epicondyle, is repaired by anchor suturing (case no. 4). **F** The common flexor tendon, which is stripped from the periosteum, is repaired by imbrication (*white stars*) (case no. 9) tears in 2 cases. The state of the MCL and the coronoid process fracture were observed on the medial side. In all cases, the common flexor-pronator muscle origin was torn from the medial epicondyle of the distal humerus, as in periosteal stripping (Fig. 1B). The medial window was approached mostly through the traumatic plane, with no further soft tissue dissection required (Fig. 1C). Because the pathology of terrible triad injuries can be directly identified through the medial window, coronoid fixation can be performed with a wider view, even in cases of type I and II fractures in which the radial head should be mended without being replaced. In cases when a fracture fragment was large and thus the use of a screw or a plate was possible, fixation of the coronoid process was performed first. If large bone fragments were present, accompanied by crushed or small bone fragments of O'Driscoll type 1, the anterior capsule was restored using pull-out sutures rather than with bone fixation (Fig. 1D).

If the radial head fracture was not accompanied by fragmentation and had sufficient fixability for range of movement (ROM) immediately after surgery, osteosynthesis was performed. If fragmentation was present and limited ROM was observed, prosthetic replacement was performed.

After restoration of the osseous structures, the damaged LCL complex was repaired. Anchor suturing was performed for the avulsions, and direct suturing was performed for the midsubstance tears. The most important step in achieving a successful isometric repair is the placement of the sutures at the center of rotation of the elbow, which is located at the center of the capitellar curvature on the lateral epicondyle.[7]

Finally, the damaged medial soft tissue structure including the MCL complex and common flexor origin were repaired. Six cases had a detachment of the MCL from the medial epicondyle and one case had a rupture at the midsubstance. One case had a double disruption of the MCL at both the origin and insertion sites, which were detached from the medial epicondyle and were accompanied by an avulsion fracture of the coronoid sublime tubercle. The MCL detached from the medial epicondyle was repaired using suture anchors, and the sublime tubercle fracture was restored (Fig. 1E). The torn muscle was tightly repaired through a 5-mm overlap at the traumatic plane for common flexor-pronator muscle stripping (Fig. 1F). Tensioning with running lock sutures was also performed in the MCL and common flexor origin.

After all of the damaged osseous and ligamentous structures were repaired, the congruency and stability were checked between 20 and 130° under a C-Arm fluoroscopy in one or more positions of forearm rotation.[3] The wound was closed along the layer, and a sterile dressing was applied.

Postoperative management

If the MCL is intact, the elbow is immobilized in a well-padded fiberglass splint at 90° of flexion, with the forearm in full pronation to avoid posterolateral instability and to protect the LCL repair. If both the MCL and LCL have been repaired, the arm should be splinted in a neutral rotation. If the LCL has been securely fixed and the MCL has not, immobilization at 90° of flexion and in full supination should be considered. Supervised motion should generally begin within 2 to 5 days after surgery. Patients should begin active flexion and extension, avoiding terminal extension, depending on the intraoperative evaluation of stability. Full active forearm rotation is permitted with the elbow in 90° of flexion to protect the collateral ligament repair. Indomethacin or irradiation was not applied against heterotropic ossification.

Patient evaluation

The Mayo elbow performance scoring system was used for clinical evaluation. Pain, range of motion of the elbow joint, function, and stability were examined, and synostosis, heterotropic ossification, and congruency were observed via radiographic images of the elbow joint. Posttraumatic arthritis was evaluated according to the Broberg and Morrey classification.[18] The mean duration of follow-up was 25 months (range, 18 to 41 months).

Results

The functional outcomes are listed in Table 2. At the final follow-up, the mean arc of flexion–extension in all patients was 128.8°, the mean flexion contracture was 7.69°, and the mean flexion was 137.3°. The functional arc motion, as determined according to the criteria of Morrey et al.,[16] was recovered in all cases (see examples in Fig. 2A,B). The mean Mayo elbow performance score (MEPS) was 95 points (range, 85 to 100 points), with ten excellent cases and three good cases.

According to our intraoperative examination, no patient demonstrated unacceptable residual instability in extension following restoration of all of the osseous and ligamentous lesions. There were no cases requiring applied hinged external fixator because all patients had congruency and stability intraoperatively with a ROM from 30° to 130°, according to fluoroscopy findings. One patient was experiencing ulnar nerve symptoms. That patient was given ulnar nerve anterior transposition to the subcutaneous level at the initial operation. Three months after the index operation, we performed exploration for the ulnar nerve. The ulnar nerve was adhered

Table 2. Functional outcomes

Patient no.	ROM Extension-Flexion (mean arc)	ROM Pronation/supination	MEPS	Arthritis grade	Complication
1	10–140° (130°)	70/70	90	1	HO
2	10–140° (130°)	70/70	85	1	HO
3	15–130° (110°)	45/20	90	0	
4	5–135° (130°)	70/70	100	0	
5	5–135° (130°)	70/70	100	0	
6	10–140° (130°)	70/70	100	0	
7	5–140° (135°)	70/70	100	0	
8	5–140° (155°)	70/70	100	0	
9	10–130° (120°)	70/70	85	0	
10	5–135° (130°)	75/70	100	0	
11	5–140° (135°)	70/70	100	0	
12	10–140° (125°)	70/70	85	1	Ulnar neuropathy
13	5–140° (135°)	70/70	100	0	

ROM, range of motion; MEPS, Mayo elbow performance score; HO, heterotopic ossification
Arthritis grade: Broberg and Morrey classification[18]

Fig. 2A,B. Findings in case no. 8. **A** Three-dimensional reconstruction picture of a 52-year-old male patient showing the osseous lesions of a radial head fracture and a coronoid fracture. **B** Radiograph at 32 months after surgery showing the anchor suturing on the distal humerus epicondyle and the union after fixation of the radial head and coronoid fractures

to the surrounding soft tissues and we carried out neurolysis. At the time of follow-up, all 13 patients had maintained a concentric reduction of both the ulnotrochlear and radiocapitellar articulations.

Radiographs

All of the radial head fractures which received open reduction and internal fixation obtained union according to the final follow-up radiographs. The coronoid fracture treated with screws and a plate showed a solid osseous union on the final follow-up radiographs. The small coronoid fractures treated with pull-out sutures appeared as nonunions with a gap or osteophytes in the radiographs. The patients, however, did not have pain or a limited ROM.

We used the Broberg and Morrey[18] classification for the radiographic assessment of posttraumatic arthritis. Ten elbows had no evidence of degenerative changes (grade 0) and three elbows had grade 1 changes. There were no grade 2 or 3 changes.

There were radiolucent lines around one of the three silicon-type radial head prostheses, but no evidence of dislocation, subluxation, or progressive bone loss or shortening was observed.

Heterotrophic ossification was observed in two cases, neither of which required additional surgery; their mean ROM was 130°.

Table 3. Summary of referenced articles

	No of patients	LUCL (repaired)	MCL (repaired)	Applying hinged EF	Application time of EF	Flexion contracture (°)	Flexion (°)	Mean arc of ROM (°)	Forearm rotation (°)	MEPS	Instability	Reoperation rate
Pugh et al.[7]	36	All	6/36	3	6.2 weeks	19 ± 9	131 ± 11	112 ± 11	136 ± 16	88	1 PLRI	8/36 (22%)
Zeiders and Patel[9]	32	18	14/32	21	6 weeks	12	131					3 minor HO
Forthman et al.[15]	21	All	None			17	134	117	137			4 ulnar neuropathy
Present authors	13	All	8/13	None	X	7.7	137	128	134	95	0	1 ulnar neuropathy

ROM, range of motion; LUCL, lateral ulnar collateral ligament; MCL, medial collateral ligament; EF, external fixator; MEPS, Mayo elbow performance score; PLRI, posterolateral rotatory instability; HO, heterotopic ossification[19]

Discussion

Currently, some articles related to the treatment of terrible triads have been reporting excellent results.[6,7,9,15] Table 3 shows the summarized data of three of the above mentioned articles. Even though it appears that the authors of these articles followed the same algorithm, there were some differences in the treatment of the MCL and in hinged external fixator (EF) application. However, their clinical results are all very similar. Pugh et al.[7] reported that the LUCL was completely repaired, but that the MCL was repaired in only six patients (16%) and a hinged EF was applied to only three patients. Zeiders and Patel[9] reported that an isolated MCL injury was observed in two patients and repair of both the MCL and LUCL was conducted in 12 cases (33%). They also reported that 21 patients needed hinged EF applications. Forthman et al.[15] said that MCL repair is not routinely necessary in terrible triad injuries of the elbow. These findings suggest that the management of the medial soft tissue structures including the MCL and common flexor-pronator complex is definitely a debatable issue in the treatment of terrible triad injuries.

The MCL functions as an important restraint to valgus and posteromedial rotator instability.[19,20] Secondary constraints to elbow stability are provided by the flexor pronator mass, which arises from the medial epicondyle. These structures dynamically stabilize the elbow against valgus forces.[21] In a biomechanical study of a simulated terrible triad injury, when residual instability was present after LCL repair and radial head repair or arthroplasty, repair of the MCL was more effective than was the fixation of small coronoid fractures in restoring elbow stability.[22] Sectioning of the MCL has been shown to cause gross valgus and internal rotation instabilities of the elbow.[19,21] Transosseous repair of the MCL restored elbow stability in vitro and should allow for early active and passive motion. Muscle activation and forearm supination stabilize the MCL-deficient elbow with the arm in the dependent position. In a biomechanical study, simulated flexor carpi ulnaris (FCU) and flexor digitorum superficialis contractions were used to restore valgus stability to MCL-deficient elbows. Anatomic evidence also supports this finding. In a cadaveric study, Davidson et al.[23] determined that the FCU was the predominant musculotendinous unit overlying the MCL at all flexion angles and was best suited to provide medial elbow support. An et al.[24] studied the medial muscles of the elbow and concluded that they provided a varus moment to the elbow and could resist valgus torque regardless of the position of forearm rotation.

Even though there are numerous biomechanical studies describing the importance of the MCL, Forthman et al.[15] insisted that several biomechanical studies overemphasized the importance of the MCL in the valgus stability of the elbow. They reported good results in 22 terrible triad treatments without MCL repair. Despite the relative complexity of the elbow fracture-dislocation in their series and the lack of MCL repair in all patients, postoperative instability was encountered in only 2 of 34 patients (6%), and those patients were noncompliant with postoperative instructions. Follow-up examinations of simple elbow dislocations, fracture-dislocations, and reconstructive surgeries for elbow instability have demonstrated that the MCL has the potential to heal (or scar) in a way that restores function.[25–28] Therefore, the advantages of leaving the MCL unrepaired include more limited operative dissection and no need to mobilize or formally transpose the ulnar nerve.

In our study, we repaired all damaged structures including medial soft tissue structures and showed excellent results according to the MEPS. There have been several previous studies related to the patterns of medial structure injury in elbow fracture-dislocation. Josefsson et al.[29] performed open reduction on 31 dislocated elbows and found that, whereas all had ruptures of the MCL and LCL, the elbows in patients with concomitant injury to the common extensor origin and the flexor pronator mass were more likely to be re-dislocated when extended. Mckee et al.[30] reported that the MCL was disrupted in 28 of 50 elbows and they also found concomitant rupture or tearing of the flexor-pronator mass on the medial side in nine elbows. We found that the common flexor-pronator complex was ruptured in all our cases, and the MCL was ruptured in eight of 13 cases (61.5%). Six elbows were ruptured on the medial epicondyle, one elbow had tearing at the mid-substance, and the remaining elbow was unusually ruptured on both the medial epicondyle and the sublime tubercle. The prevalence of MCL rupture was similar to that in the report of Mckee et al.[30] We found detachment with the aspect of stripping the common flexor-pronator complex (CFO) on the medial epicondyle in all cases. We performed repair for ruptured MCLs using anchor sutures and imbrication of the CFO as well as the common extensor origin (CEO). We believe that, by repairing this medial soft tissue, the primary and secondary valgus stability of the elbow joint mentioned above was increased and maintained congruency and stability without the use of hinged external fixators in our 13 cases. However, as mentioned by Mathew et al.,[31] further clinical and biomechanical studies of MCL repair in terrible triad injury may be necessary.

Forthman et al.[15] pointed out the disadvantages of this method by stating that the repair of the MCL through the medial side requires further operative dissection and causes injury to the ulnar nerve. However, there is no need for more soft tissue dissection to obtain a medial side approach because all terrible triad cases have injury of the muscle plane similar to that reported by us. Moreover, a medial traumatic window can make the repair of coronoid fractures convenient with a much better view without detachment of the common extensor origin. Also, Forthman et al.[15] reported that subsequent anterior transposition was performed because ulnar neuropathy developed in 4 (18%) of 22 cases after terrible triad operations, and they suggested that in situ release should be performed to prevent this complication. Therefore, it is thought that the restoration of the medial lesion is also important in addition to that of the anterior and lateral lesions in a terrible triad injury, and to accomplish this, we used the approach through both the medial and lateral injured soft tissue window after global posterior incision. Pugh et al.[7] mostly used the lateral window and performed the repair in the order of coronoid process, radial head, and LUCL. However, in cases of repair only through the lateral window, it is possible to perform pull-out procedures with small bone fragments (O'Driscoll type 1) of a coronoid fracture, but it is impossible to perform a buttress plate application to the fracture involving the medial facet (O'Driscoll type 2). The separate use of lateral and medial windows makes the management of coronoid fractures more convenient in a wider space, even without elimination of the radial head, and damaged MCLs and common flexor masses can be easily repaired.

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References

1. Hotchkiss RN, editor. Fracture and dislocations of the elbow. 4th ed. Philadelphia: Lippincott-Raven; 1996.
2. Josefsson PO, Gentz CF, Johnell O, Wendeberg B. Dislocations of the elbow and intraarticular fractures. Clin Orthop Relat Res 1989;246:126–30.
3. Broberg MA, Morrey BF. Results of treatment of fracture-dislocations of the elbow. Clin Orthop Relat Res 1987;216: 109–19.
4. Cobb TK, Morrey BF. Use of distraction arthroplasty in unstable fracture dislocations of the elbow. Clin Orthop Relat Res 1995;312:201–10.
5. Heim U. Combined fractures of the radius and the ulna at the elbow level in the adult. Analysis of 120 cases after more than 1 year. Rev Chir Orthop Reparatrice Appar Mot 1998;84:142–53 (in French).
6. Egol KA, Immerman I, Paksima N, Tejwani N, Koval KJ. Fracture-dislocation of the elbow functional outcome following treatment with a standardized protocol. Bull NYU Hosp Jt Dis 2007;65: 263–70.
7. Pugh DM, Wild LM, Schemitsch EH, King GJ, McKee MD. Standard surgical protocol to treat elbow dislocations with radial

head and coronoid fractures. J Bone Joint Surg Am 2004;86-A: 1122–30.
8. Ring D, Jupiter JB, Zilberfarb J. Posterior dislocation of the elbow with fractures of the radial head and coronoid. J Bone Joint Surg Am 2002;84-A:547–51.
9. Zeiders GJ, Patel MK. Management of unstable elbows following complex fracture-dislocations–the "terrible triad" injury. J Bone Joint Surg Am 2008;90(suppl. 4):75–84.
10. Jensen SL, Olsen BS, Tyrdal S, Sobjerg JO, Sneppen O. Elbow joint laxity after experimental radial head excision and lateral collateral ligament rupture: efficacy of prosthetic replacement and ligament repair. J Shoulder Elbow Surg 2005;14:78–84.
11. Rosell P, Clasper J, Ring D, Jupiter JB, Zilberfarb J. Roles of the medial collateral ligament and the coronoid in elbow stability. J Bone Joint Surg Am 2003;85:568–9.
12. Tullos HS, Bennett J, Shepard D, Noble PC, Gabel G. Adult elbow dislocations: mechanism of instability. Instr Course Lect 1986; 35:69–82.
13. Schwab GH, Bennett JB, Woods GW, Tullos HS. Biomechanics of elbow instability: the role of the medial collateral ligament. Clin Orthop Relat Res 1980;146:42–52.
14. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. Am J Sports Med 1983;11: 315–9.
15. Forthman C, Henket M, Ring DC. Elbow dislocation with intra-articular fracture: the results of operative treatment without repair of the medial collateral ligament. J Hand Surg Am 2007; 32:1200–9.
16. Morrey BF, Askew LJ, Chao EY. A biomechanical study of normal functional elbow motion. J Bone Joint Surg Am 1981;63:872–7.
17. O'Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD. Difficult elbow fractures: pearls and pitfalls. Instr Course Lect 2003;52:113–34.
18. Broberg MA, Morrey BF. Results of delayed excision of the radial head after fracture. J Bone Joint Surg Am 1986;68: 669–74.
19. Pichora JE, Fraser GS, Ferreira LF, Brownhill JR, Johnson JA, King GJW. The effect of medial collateral ligament repair tension on elbow joint kinematics and stability. J Hand Surg Am 2007;32:1210–7.
20. O'Driscoll SW, Morrey BF, Korinek S, An KN. Elbow subluxation and dislocation. A spectrum of instability. Clin Orthop Relat Res 1992:186–97.
21. Armstrong AD, Dunning CE, Faber KJ, Duck TR, Johnson JA, King GJW. Rehabilitation of the medial collateral ligament-deficient elbow: an in vitro biomechanical study. J Hand Surg Am 2000;25:1051–7.
22. Beingessner DM, Stacpoole RA, Dunning CE, Johnson JA, King GJW. The effect of suture fixation of type I coronoid fractures on the kinematics and stability of the elbow with and without medial collateral ligament repair. J Shoulder Elbow Surg 2007; 16:213–7.
23. Davidson PA, Pink M, Perry J, Jobe FW. Functional anatomy of the flexor pronator muscle group in relation to the medial collateral ligament of the elbow. Am J Sports Med 1995;23:245–50.
24. An KN, Hui FC, Morrey BF, Linscheid RL, Chao EY. Muscles across the elbow joint: a biomechanical analysis. J Biomech 1981;14:659–69.
25. Ring D, Hannouche D, Jupiter JB. Surgical treatment of persistent dislocation or subluxation of the ulnohumeral joint after fracture-dislocation of the elbow. J Hand Surg Am 2004;29: 470–80.
26. Jupiter JB, Ring D. Treatment of unreduced elbow dislocations with hinged external fixation. J Bone Joint Surg Am 2002;84: 1630–5.
27. Mehlhoff TL, Noble PC, Bennett JB, Tullos HS. Simple dislocation of the elbow in the adult. Results after closed treatment. J Bone Joint Surg Am 1988;70:244–9.
28. Protzman RR. Dislocation of the elbow joint. J Bone Joint Surg Am 1978;60:539–41.
29. Josefsson PO, Johnell O, Wendeberg B. Ligamentous injuries in dislocations of the elbow joint. Clin Orthop Relat Res 1987; 221:221–5.
30. McKee MD, Bowden SH, King GJ, Patterson SD, Jupiter JB, Bamberger HB, et al. Management of recurrent, complex instability of the elbow with a hinged external fixator. J Bone Joint Surg Br 1998;80-B:1031–6.
31. Mathew PK, Athwal GS, King GJ. Terrible triad injury of the elbow: current concepts. J Am Acad Orthop Surg 2009;17: 137–51.