Original Contribution

Kurume Medical Journal, 63, 7-14, 2016

Primary Hinged External Fixation of Terrible Triad Injuries and Olecranon Fracture-Dislocations of the Elbow

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Received 13 January 2016, accepted 22 June 2016
J-STAGE advance publication 16 January 2017

Edited by NORIO YAMASHITA

Summary: This study aimed to introduce a new treatment that apples primary hinged external fixation for complex fracture-dislocations of the elbow in 12 cases. We retrospectively assessed the functional outcomes of eight patients with terrible triad injuries and three patients with an olecranon fracture-dislocation of the elbow, who were treated at our hospital using a primary hinged external fixator between June 2012 and December 2014. Ten patients underwent repair or replacement of the radial head, while three underwent repair of the olecranon. In principle, they were treated without reconstruction of the coronoid fracture and collateral ligament injury. The patients were evaluated for a mean follow-up period of 16 months after the initial surgery. Early mobilization was encouraged while the hinged external fixator was in place. At the follow-up, the mean Mayo Elbow Performance Score was 93 points; the results were "excellent" in six cases and "good" in five. No patients had recurrent elbow instability. Only one patient needed an additional procedure after the initial operation. These results suggested that primary hinged external fixation without repair of the ligament and soft tissue is an effective minimally invasive surgery for the management of terrible triad injuries and olecranon fracture-dislocations of the elbow.

Key words primary hinged external fixation, terrible triad injury, olecranon fracture-dislocation, complex fracture-dislocation of the elbow, coronoid process fracture

INTRODUCTION

The treatment of complex fracture-dislocations of the elbow is challenging even for expert elbow surgeons owing to difficulties with anatomical reduction of the articular surface and the instability of ligamentous and soft-tissue injuries [1,2]. Complex fracture-dislocations of the elbow, such as terrible triad injuries and olecranon fracture-dislocations, typically remain unstable after reconstruction of the bony and ligamentous structures [3,4]. Consequently, the results of treating these injuries are often disappointing because of post-traumatic instability, stiffness, and early arthrosis [5,6]. As a result, there is often a need for further treatment and additional procedures [7,8].

The current gold standard treatment for complex elbow fracture-dislocations is internal fixation and stability restoration, which includes reconstruction of the capsular and ligamentous structures, to allow early mobilization [7,9]. However, it is technically challenging to perform multiple procedures around the elbow joint. Furthermore, the surgical approach depends on the fracture type and the need for additional surgery such as ligament repair. Consequently, extensive dissection is needed, precluding the use of minimally or less invasive surgery. There is an evolving understanding of the role of external fixators in the management of such injuries [10]; this approach may allow surgeons

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Abbreviations: CBCC, coronoid-brachialis capsular-ligamentous complex; LCL, lateral collateral ligament; MEPS, Mayo Elbow Performance Score; ROM, range of motion.

to circumvent some of the difficulties associated with the internal fixation of complex elbow injuries.

Several authors have reported on the use of a hinged external fixator in the treatment of elbow instability [3,11-14]. This approach has been used in the treatment of residual instability after the reconstruction of fractures and ligamentous injuries or as a secondary method in the management of recurrent or chronic instability after injury. In these studies, the authors' findings suggested that the repair of specific ligaments around the elbow may not be necessary after hinged external fixation and that, as long as the elbow is held concentrically for several weeks after the injury, the capsuloligamentous structures heal and elbow stability is restored. However, primary hinged external fixation in the management of acute complex fracture-dislocation of the elbow, such as terrible triad injury and olecranon fracture dislocation, has not previously been reported.

We assessed the functional outcomes of patients who sustained a complex elbow dislocation and were primarily treated with a hinged external fixator. The aim of the present study was to introduce a new method of primary hinged external fixation and highlight the advantages of the hinged external fixator in the management of unstable complex fracture-dislocations of the elbow.

MATERIALS AND METHODS

We reviewed the cases of 11 patients (six women and five men) treated with primary hinged external fixation at our hospital between June 2010 and November 2013. All of the patients provided informed consent prior to the surgery.

Eight patients with terrible triad injuries and three patients with an olecranon fracture-dislocation of the elbow underwent evaluation at a mean 15.7 months (10-26 months) after primary hinged external fixation. The average age at the time of the injury was 57.6 years (23-82 years). Causes of injury included falling from a height (n = 8), falling from a standing position (n = 2), and motor vehicle accident (n = 1). One patient had a contralateral fracture of the distal radius. Two patients had lower-extremity injuries, including one Pilon fracture and one femoral diaphyseal fracture. The mean time to placement of the hinged external fixator was 13.5 days (3-36 days) after the trauma; only one was placed within 1 week of the injury. The hinged external fixator was removed after an average of 4.0 weeks (3.4-5.0 weeks). No patients were lost to follow-up (Table 1).

SURGICAL TECHNIQUE

All of the surgical procedures were performed under general anesthesia by the same surgeon (KS). The

TABLE 1.
Patient data

Patinet-No.	Age	Sex	Mechanism	Time to hinge (d)	Duration of treatment with hinge (d)	Type of injury	Radial head treatment	Coronoid frcture treatment	Colateral ligament repair	Olecranon treatment	Complicated fx	Type of E-F
1	36	M	fall from height	13	27	TTI[2]	ORIF[5], BG[6]	ORIF	No			OEF[9]
2	36	F	fall from height	10	35	TTI	ORIF	pull-out	No			OEF
3	23	M	MVA[1]	10	26	PFDO[3]	ORIF, BG	ORIF	No	plating		OEF
4	46	M	fall from height	11	26	TTI	ORIF	No	No			OEF
5	78	F	fall from height	22	27	TTI	PAR[7]	No	No			OEF
6	70	F	fall from height	36	24	TTI	RHP[8]	No	LCL anchor suture			OEF
7	58	M	fall from height	9	28	TTI	PAR	No	No		Pilon fx	OEF
8	65	F	fall from height	10	31	TTI	PAR	No	No		contralateral radius end fx	OEF
9	78	F	fall	14	26	TTI	No	No	MCL anchor suture		femoral shaft fx	Galaxy
10	62	M	fall from height	3	29	PFDO	ORIF	No	LCL anchor suture	plating		OEF
11	82	F	fall	11	28	AFDO[4]	RHP	No	No	plating		Galaxy

1) MVA : motor vehicle accident 2) TTI : terrible triad injury 3) PFDO : posterior fracture-dislocations of the olecranon

4) AFDO : anterior fracture-dislocations of the olecranon 5) ORIF : open reduction and internal fixation 6) BG : cancellous bone tip graft

7) PAR : partial autograft replacement 8) RHP : radial head prosthesis 9) OEF : Orthofix external fixator

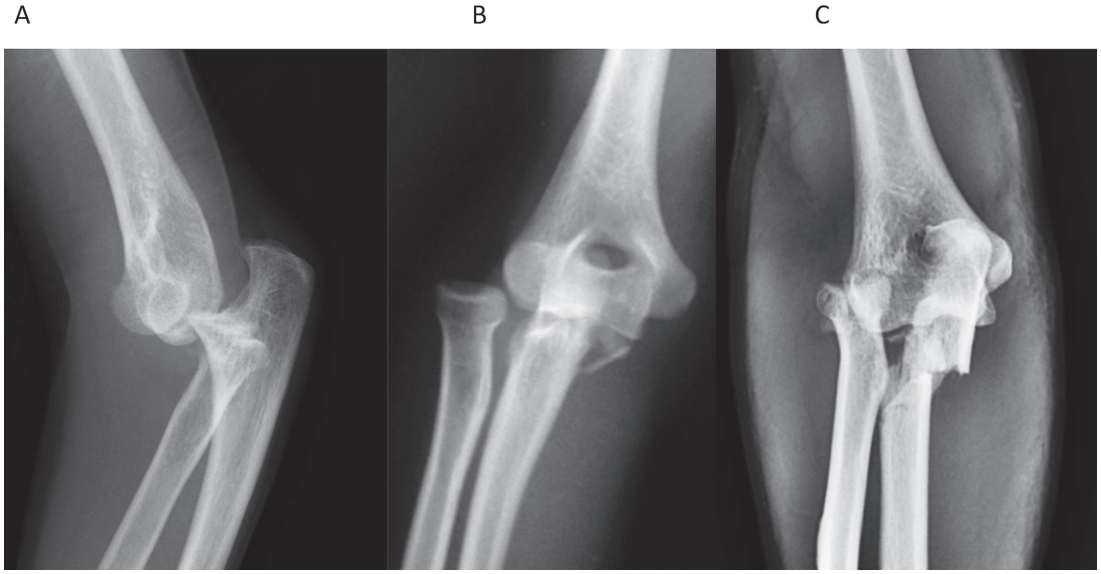

Fig. 1. Patterns of Complex Fracture-Dislocation of the Elbow
A, terrible triad injury : tip type of coronoid fracture
B, varus posteromedial rotational instability pattern : anteromedial facet fracture of coronoid fracture
C, olecranon fracture-dislocation : basal type of coronoid fracture

elbow was exposed via a lateral incision; posterior or medial incisions were made as necessary. With the exception of one radial head fracture with no displacement, all cases were repaired or replaced. Five cases were treated with open reduction and internal fixation, three cases were treated with partial autograft replacement, and two cases were treated with a radial head prosthesis (Judet Prosthesis; Tornier SAS).

Joint instability following reconstruction of the radial head fracture was defined as incongruence of the elbow joint on fluoroscopy. Lateral instability was assessed using Imatani's criteria [15]. According to Imatani's report of 89 cases, gross instability under general anesthesia was defined as a radiocapitellar joint width angle $\geq 10°$ by the varus stress test (an indication of a lateral collateral ligament [LCL] complex injury) and joint opening without an end point by the valgus stress test (an indication of medial collateral ligament injury with ruptured pronation flexor muscles). Gross instability was considered an absolute operative indication. Consequently, reconstruction of the collateral ligament was performed for three cases of gross instability (LCL complex injury, two cases; medial collateral ligament and flexor muscle injury, one case). All three cases were treated with suture anchor fixation. In contrast, three cases of coronoid fracture in the earlier stage of this series underwent internal fixation or Lasso suture fixation. Of these cases, the treatment failed to fix the coronoid process in one. In addition, coronoid fractures in the remaining eight cases were not prospectively repaired. All cases of olecranon fracture that involved a fracture of the proximal ulna were treated with locking plates.

The hinged external fixators were placed under fluoroscopic guidance in all patients; a temporary axis pin was placed in the distal humerus at the center of elbow joint rotation. The true lateral view should show the pin as a dot within the center of the trochlear spool, while the anteroposterior view should show it traversing parallel to the joint along the normal valgus angulation of the distal humerus (Fig. 1). The Orthofix® Elbow Fixator (Orthofix) or Galaxy Fixation System Elbow Hinge (Orthofix) was used. The forearm was placed in a neutral position.

POSTOPERATIVE CARE AND REHABILITATION

When a hinged external fixator is used, early mobilization is encouraged. In all cases, active range of motion (ROM) was instituted as tolerated, while gentle passive ROM was allowed immediately. No limit was placed on flexion or extension. The hinged external fixator was removed 4 weeks after surgery. Physiotherapy was performed by an experienced therapist to achieve a maximum ROM. No prophylaxis against heterotopic ossification was routinely used.

ASSESSMENT OF OUTCOME

The patients were evaluated on the basis of the clinical findings; the Mayo Elbow Performance Score (MEPS) [16] was used for the clinical assessment. Radiographs were reviewed at the last follow-up visit. Complications and additional procedures were ascertained by chart review.

Results

At follow-up (16±8 months), the mean MEPS was 93±8 points; six cases had "excellent" results, while five had "good" results. Assessment of the ROM showed an average flexion of 134±8°, extension of –13±9°, pronation of 80±10°, and supination of 84±5°. Patients had a mean flexion arc of 121±15° and a mean pronosupinatory arc of 164±7°.

No patients had recurrent elbow instability. Radiographic evidence of concentric reduction of the ulnohumeral and radiocapitellar joints was present in all patients. Only one patient needed an additional bone graft procedure after the initial operation since he developed nonunion of the proximal ulna. One patient who underwent internal fixation of the radial head also developed nonunion, but no further surgery was required due as his activities of daily living were not affected. Eight patients (73%) showed evidence of minor asymptomatic heterotopic ossification that did not require treatment.

The use of the external fixator was associated with a single case of a minor complication: a secondary screw hole–related ulnar fracture. This case was treated with a cast and the fracture healed. There were no pin-tract infections. Evidence of arthrosis was apparent in only the oldest patient of this series; however, the patient was asymptomatic and the arthrosis did not disrupt his activities of daily living (Table 2).

DISCUSSION

Coronoid fractures are most commonly encountered in association with other elbow injuries as part of three major instability patterns: terrible triad injury, varus posteromedial rotational instability, and olecranon fracture-dislocation (Fig. 2) [17,18]. Recent biomechanical and clinical studies have brought attention to the role of the coronoid process as an important stabilizer of the elbow [19,20]. Furthermore, it has been suggested that specific types of coronoid fractures are strongly associated with specific patterns of traumatic elbow instability patterns. Large fractures of the coronoid process are typically associated with olecranon fracture-dislocations, while small transverse tip fractures are associated with terrible triad injuries and anteromedial facet fractures are associated with varus posteromedial rotational instability pattern injuries [17]. Knowledge of these patterns is useful in the planning of complex elbow injury management.

The terrible triad injury involves three critical pathoanatomy aspects: posterior elbow dislocation, coronoid fracture, and radial head fracture. While repair or replacement of the radial head and repair of the

TABLE 2.
Results for individual patients

Patinet No.	Follow -up (M)	MEPS	Results	Flex	Ext	Pron	Sup	Complications	Recurrent instablity	Additional procedure
1	10.5	85	G	130	–10	80	80	Pseudoarthrosis of radial head	No	No
2	6.3	85	G	130	−20	90	75	secondary ulna shaft fx	No	No
3	18.5	100	E	130	−10	80	80	No	No	No
4	25.2	100	E	140	−10	95	80	No	No	No
5	26.2	95	E	135	−15	90	80	No	No	No
6	12.4	85	G	125	−15	70	90	No	No	No
7	12.3	95	E	120	−30	80	85	No	No	No
8	9.6	100	E	150	5	70	90	No	No	No
9	12.1	90	G	140	−10	85	90	No	No	No
10	27.2	100	E	130	-5	80	85	pseudoarthrosis of proximal ulna	No	bone graft of proximal ulna
11	12	80	G	140	–20	60	90	arthrosis	No	No

MEPS : Mayo Elbow Performance Score

E : Excellent, G : Good, F : Fair, P : Poor

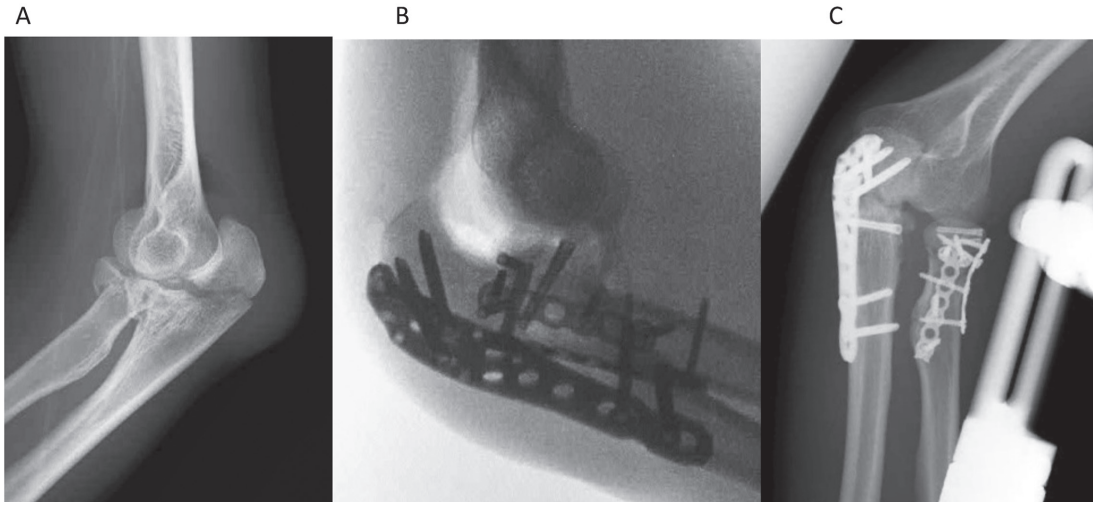

Fig. 2. Complex fracture-dislocation in a 23-year-old man (case 3).
A, radiograph of a posterior fracture-dislocation of the olecranon following reduction.
B, after repair of the radial head and olecranon, posterior instability persisted due to failure to repair the coronoid process.
C, a hinged external fixator was consequently advocated.

LCL complex are technically feasible, the surgical management of coronoid fractures remains challenging. The complexity is due to the fact that coronoid fractures of this pattern are typically shear fractures rather than avulsion fractures and are often too small for reliable screw fixation [21]. Therefore, coronoid-brachialis capsular-ligamentous complex (CBCC) [2] repair is important. Zeiders et al. [2] and Garrigues et al. [22] recently recommended the use of a Lasso suture technique that encircles the small coronoid fragments and the CBCC. This approach would be superior to open reduction and internal fixation, which require the use of lag screw fixation, site-specific plating, and suture anchor fixation.

In contrast, olecranon fracture-dislocations are complex fractures of the olecranon associated with subluxation or dislocation of the radial head and the coronoid process. It is useful to distinguish anterior and posterior displacement patterns in such injuries. Anterior fracture-dislocations of the olecranon are often complicated by fractures of the radial head and coronoid process. Internal fixation of all fractures is essential. However, ligamentous reconstruction is not usually necessary [23]. On the other hand, posterior fracture-dislocations of the olecranon, which are described as a type of posterior Monteggia injury, are often complex fractures that involve the proximal ulna, radial head, coronoid, and lateral collateral ligament

TABLE 3.
Summary of previous relevant reports of the use of hinged external fixation

Auther	Published year	State	No. of cases	MEPS	Mean duration with hinged E-F (w)	Fixator	Reoperation rate (%)
McKee	1998	recurrent	16	E:2, G:10, F:3, P:1	8.5	compass elbow hinge	19
Ruch	2001	recurrent & chronic	8	–	?	OEF	13
Jupitar	2002	chronic	5	E:2, G:3	5	compass elbow hinge	20
Yu	2007	acute	20	E:6, G:5, F:5, P:4	7	compass elbow hinge	20
Sørensen	2011	chronic	17	E:3, G:7, F:3, P:4	6	OEF, DJD II	6
present study	2016	acute	11	E:6, G:5	4	OEF, Galaxy	9

MEPS : Mayo Elbow Performance Score, E : Excellent, G : Good, F : Fair, P : Poor,
OEF : Orthofix elbow fixator, DJDII : Dynamic joint distractor II

[24,25].

In a recent review, Doornberg et al. [26] reported that the key to effective treatment of these fracture-dislocations of the olecranon is precise restoration of the trochlear notch and reconstruction of the coronoid process. The current optimal management of these complex elbow injuries should result in restoration of joint stability and full ROM. However, this is often difficult to achieve surgically because multiple procedures are needed when the aim is restoration of all bony and ligamentous tissues; surgery involving greater dissection is more invasive, resulting in moderate or severe swelling around the elbow joint. The treatment of complex elbow fracture-dislocations should ideally involve minimally invasive surgery that attains both mobility and stability and is technically straightforward.

To date, several authors have reported on the use of the hinged external fixator in the treatment of both acute and chronic elbow instability (Table 3) [3,11-14]. Previous uses included treatment of residual instability after reconstruction of fractures and ligamentous injury or as a secondary device in the management of chronic instability after injury. Yu et al. [16] reported the outcomes of 20 cases of acute complex instability of the elbow treated with hinged external fixation. Interestingly, these authors did not repair the LCL by placing a hinged external fixator. Furthermore, Duckworth et al. [27] reported a review of 17 cases of unstable elbow dislocations and concluded that as long as the elbow is held concentric with a hinged external fixator, the anterior capsuloligamentous structures heal and elbow stability is restored.

In one of the first three cases of this series, we discovered a primary placement of the hinged external fixator (Fig. 3). This was a posterior fracture-dislocation of the olecranon that was first treated by repair of the radial head and the olecranon. Fixation of the coronoid failed because a coronoid fragment had been broken by screwing and the elbow had significant posterior instability. Consequently, a hinged external fixator was applied to the elbow and early functional exercise was prescribed. Fortunately, good elbow function was achieved without the need for additional procedures. This case demonstrated that acute reconstruction of the CBCC-involved coronoid process might not be necessary in cases treated with the placement of a hinged external fixator.

After this experience, we did not prospectively repair the CBCC-involved coronoid process and the collateral ligament; instead, we maintained concentric reduction with hinged external fixation in complex elbow fracture-dislocations. The algorithm that we have developed (Fig. 4) represents a systematic approach to re-establishing stability and functional motion using a less invasive operation and a simplified procedure.

With the exception of first three cases in this series, we primarily used the hinged external fixator in complex elbow injuries following our new algorithm. For-

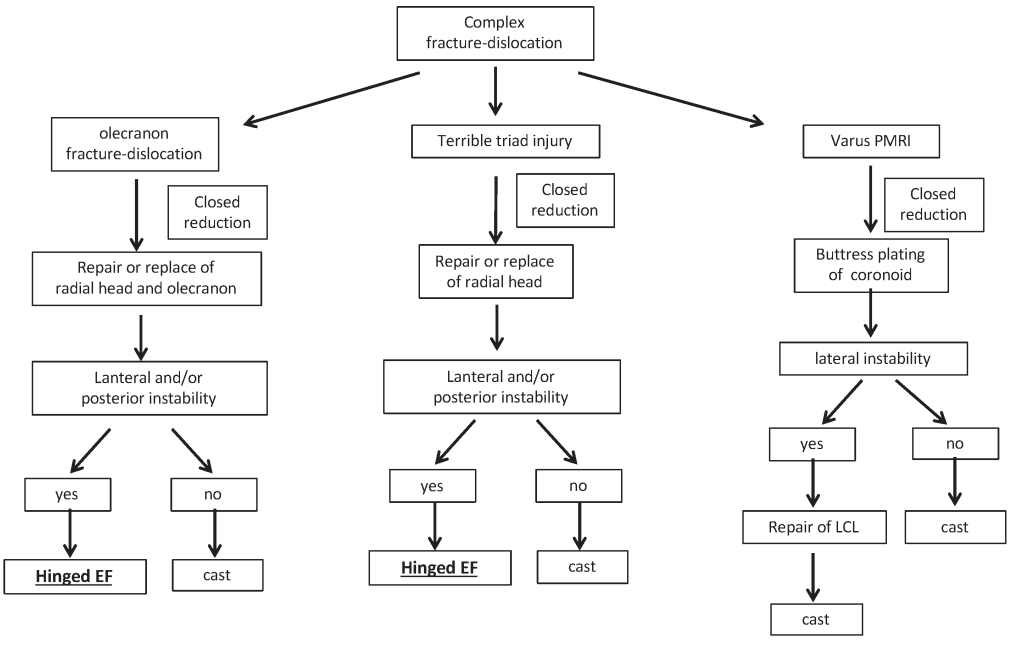

Fig. 3. Treatment algorithm for complex elbow instability

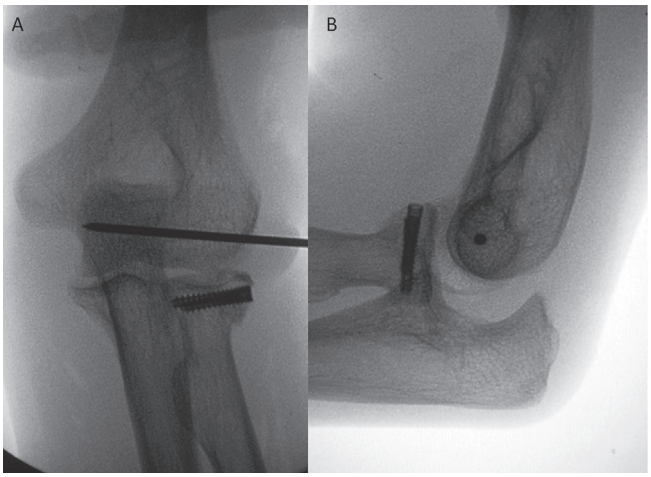

Fig. 4. Intraoperative fluoroscopy
A, anteroposterior view of the axis pin position.
B, lateral view of the axis pin position.
Precise insertion of the axis pin at the center of articulation is the crucial step.

tunately, all patients had excellent or good results. Moreover, only one additional procedure was needed for the treatment of pseudoarthrosis of the proximal ulna. To our knowledge, this is the first report of primary hinged external fixation without repair of the CBCC-involved coronoid process and collateral ligament in the management of complex fracture-dislocations of the elbow. These results were superior to those of any previous reports on the use of a hinged external fixator [3,11-14]. We suggest that the CBCC-involved coronoid process and collateral ligament may also be expected to heal or scar as it does in a simple dislocation without the need for specific attempts at repair or reconstruction; thus, a concentric reduction with hinged external fixation may be maintained.

Based on the results presented here, we recommend the primary use of hinged external fixation in complex elbow fracture-dislocations such as terrible triad injuries and olecranon fracture-dislocations. It should be noted that the application of a hinged external fixator to the elbow is technically demanding because the hinge axis must coincide exactly with the flexion-extension axis of the elbow. The most critical step is correct placement of the axis pin at the center of rotation to reduce frictional resistance and avoid loosening.

This study had several limitations: our sample size was small, the study design was partially retrospective in nature, and the follow-up duration was short. In addition, the procedures were performed by only one surgeon. Therefore, to verify the efficacy of this method, these results will need to be confirmed in a larger series conducted by individuals who did not develop this technique. In addition, many patients with elbow instability can be managed successfully using conventional methods. Further investigations comparing our technique with conventional treatments are needed to validate these experimental findings.

CONCLUSIONS

Here we successfully used a hinged external fixator as the primary treatment for patients with complex fracture-dislocations of the elbow. The concept is based on minimal surgical intervention with early postoperative elbow mobilization, which is intended to avoid posttraumatic stiffness while the anatomy of the joint is restored. Based on the results of this series, we suggest that hinged external fixation is effective and gives excellent or good results in the treatment of terrible triad injuries and olecranon fracture-dislocations of the elbow without requiring repair of the CBCC-involved coronoid process or the collateral ligament. In addition, this strategy may be useful for achieving stability and mobility of the elbow joint with a minimum requirement for additional procedures.

ACKNOWLEDGMENTS: The authors thank H. Hoshiko, M.D., and H. Murakami, M.D., for their valuable assistance with this study.

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