JSES Reviews, Reports, and Techniques 2 (2022) 205–213

Contents lists available at ScienceDirect

JSES Reviews, Reports, and Techniques

journal homepage: www.jsesreviewsreportstech.org

Terrible triad of the elbow and associated variants: a systematic review

Giovanna Medina, MD, PhD*, Rachel E. Keller, DO, Orlando D. Sabbag, MD, Luke S. Oh, MD

Sports Medicine Service, Department of Orthopaedic Surgery, Massachusetts General Hospital, Boston, MA, USA

ARTICLE INFO

Keywords:
Elbow
Terrible triad
Fracture
Dislocation
Radial head
Coronoid

Level of evidence: Level IV; Review

Background: The terrible triad of the elbow (TTE) is a complex injury consisting of simultaneous elbow dislocation or subluxation, radial head fracture, and coronoid fracture. During the initial assessment of a TTE, the typical severity of presenting pain, swelling, and limited range of motion may limit the ability to perform a thorough physical examination and thus divert a clinician's attention away from additional injuries to the ipsilateral upper extremity. Therefore, the purpose of this study was to review the literature for reported cases of concomitant ipsilateral upper extremity injuries associated with a TTE and discuss various strategies to increase clinician awareness to avoid underdiagnosis and missed diagnoses.
Methods: A systematic review of five databases in four languages (English, Spanish, French, and Portuguese), from inception to May 2021, was conducted. Articles describing a TTE with a concomitant osseous, chondral, ligamentous, or musculotendinous injury occurring on the ipsilateral upper extremity were included. The patients were divided into two groups, those presenting with a classic TTE and concomitant ipsilateral upper extremity injury (group 1) and those in whom a TTE variant was described (group 2). A TTE variant was defined as a combination of osseous and/or chondral injuries to the elbow other than the classic description of TTE, in which at least two of the three classical elements of a TTE (elbow dislocation, coronoid fracture, and radial head fracture) were present in addition to other unique elbow osteoarticular injury.
Results: Nineteen articles met inclusion criteria and were further analyzed. A total of 27 patients were analyzed, 23 from group 1 and 4 from group 2. Overall, 33 concomitant injuries were documented in group 1, the most common being an olecranon fracture (27.3%), followed by Essex-Lopresti injury, triceps tendon avulsion, and carpal fracture-dislocation with 4 (12.1%) cases each. Group 2 had four patients, all of whom presented with a unique variant of the classically described TTE.
Conclusion: Despite a characteristic radiographic appearance of the classic TTE, additional injuries of the ipsilateral extremity or variants of the classic TTE may be easily missed, especially in cases resulting from high-energy mechanisms of injury. By analyzing the available data on associated injuries and variants that may occur with a TTE, we hope to increase awareness so that clinicians may recognize these less common but more complex injury patterns.

The terrible triad of the elbow (TTE), first described in 1966,[12] consists of an elbow dislocation or subluxation in combination with coronoid and radial head fractures (RHFs). The most common mechanism of injury (MOI) leading to a TTE is a simple fall on the outstretched hand, resulting in a combined axial and valgus load on the elbow and supination of the forearm relative to the humerus.

The dissipation of energy during this elbow injury, described by O'Driscoll and Morrey, follows a somewhat predictable pattern referred to as the circle of Horii.[20] This injury is characterized by a sequence of events that involve (1) disruption of the lateral collateral ligament (LCL) complex, creating varus posterolateral instability, (2) radial head impact on the capitellum, leading to fracture, (3) posterior/posterolateral elbow dislocation with collision of the coronoid process on the trochlea, resulting in coronoid fracture, and (4) injury to the medial collateral ligament (MCL) and the origin of the flexor-pronator muscles. The MCL often remains intact in a classic TTE, and thus, an MCL injury is not essential for the diagnosis of a TTE.[19,27]

Even though this recognizable injury pattern is commonly observed in cadaveric models of a TTE,[19,27] several factors may alter its clinical presentation. The injury pattern observed depends on

Institutional review board approval was not required for this review article.

*Corresponding author: Giovanna Medina, MD, PhD, 175 Cambridge Street, Suite 400, Boston, MA 02114, USA.
E-mail address: gismedina7@gmail.com (G. Medina).

https://doi.org/10.1016/j.xrrt.2021.10.004

the energy of the trauma, the position of the upper limb at the time of injury, and patient characteristics such as age, sex, underlying osteopenia/osteoporosis, and body mass index. With higher-energy mechanisms, additional injuries to those commonly observed with a typical TTE may occur. Thus, in some situations, these unexpected concomitant injuries may be missed.[19,20]

There is ample literature for the treatment rationale and outcomes after the management of a TTE.[23,27,28,36] However, there is a paucity of data on concomitant upper-extremity injuries that may occur in association with a TTE. Therefore, the purpose of this study was to (1) perform a systematic review of the literature to determine the most common TTE variants and associated injuries and (2) discuss potential strategies to increase clinician awareness and avoid misdiagnosis.

Methods

This systematic review was performed as per the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines and registered in the International Prospective Register of Systematic Reviews. Two independent reviewers (GM and ODS) performed a literature search of five databases from inception to June 2020: PubMed, Web of Science, CINAHL, Cochrane, and EMBASE. A new search was redone in May 7, 2021, before article submission to screen the most recent published data, following the same search strategy. The search terms "terrible triad elbow," "complex elbow fracture-dislocation," and "radial head fracture + coronoid fracture + elbow dislocation" were entered into each of the five databases. Duplicates were excluded, and both reviewers screened the remaining articles by title and abstract. Each of the two independent reviewers is multilingual; therefore, full-text articles written in English, Spanish, French, and Portuguese describing cases of TTE with additional bony, articular, musculotendinous, or ligamentous injuries to the ipsilateral upper extremity were included. Articles that did not describe a TTE or variant and those describing associated injuries not located in the ipsilateral upper extremity were excluded. Any discordant titles, abstracts, or full-text articles were assessed by a third reviewer (RK), who decided to include the study in question. All articles selected for inclusion in this systematic review were assessed using the Joanna Briggs Institute Critical Appraisal Checklist for Case Series and Case Reports (Supplemental Table S1).

Reviewers then independently performed data extraction in duplicate. The following information was extracted from each article: patient age, sex, MOI, fracture types, dislocation type, any osseous, chondral, ligamentous, musculotendinous injuries, or neurovascular injuries, treatment, surgical approach, surgical outcome, postoperative management, follow-up, and complications. The patients were divided into two groups, those presenting with a classic TTE and concomitant ipsilateral upper-extremity injury (group 1) and those in whom a TTE variant was described (group 2). A TTE variant was defined as a combination of osseous and/or chondral injuries to the elbow other than the classic description of TTE, in which at least two of the three classical elements of a TTE (elbow dislocation, coronoid fracture, and RHF) were present in addition to other unique elbow osteoarticular injury. One unpublished case from the senior author (LSO) describing a TTE with two associated injuries was also included in the analysis.

The data from each study were descriptively analyzed and reported in terms of percentages.

Results

The initial literature search produced 2110 results, of which 1227 were duplicates. After removing duplicates, we screened the remaining articles by title alone (866 articles) and by title and abstract (73 articles), excluding those that did not describe a TTE or a variant with concomitant ipsilateral upper-extremity injuries. After exclusion, the full texts of 20 articles were analyzed, and five studies were excluded in this step because they did not meet the inclusion criteria. The final literature search, that is, the updated search performed in May 2021 resulted in 39 new articles, of which four were eligible for inclusion. Therefore, adding the 15 articles from the original search plus the 4 articles from the last updated search, we included in total 19 articles in the study, all of which were case reports or case series describing a total of 27 patients with 28 TTEs. Fifteen of the 19 studies were included in group 1 and described a total of 23 patients with 24 TTEs and 33 concomitant ipsilateral upper-extremity injuries. The other four studies comprised group 2 and described four patients with four unique variants of the typical TTE injury pattern (Fig. 1, Table I). In addition, one unpublished case from the senior author (LSO) describing one patient with a TTE with two concomitant injuries was included in group 1.

Group 1: terrible triad and concomitant ipsilateral upper-extremity injuries

Group 1 had a total of 23 patients (14 men and 9 women) with a mean age of 42.1 years (range, 4.5-72) who presented with 24 TTEs and 33 concomitant injuries. Twelve patients (52.2%) presented a high-energy MOI, four being from motor vehicle accidents (MVAs) and eight from falls from a height. Nine patients (39.1%) had low-energy trauma (eg, fall from standing height), and two patients (8.7%) had an unknown MOI. The most common concomitant injury was an olecranon fracture (9/33, 27.3%), followed by Essex-Lopresti injury, triceps tendon avulsion, and carpal fracture-dislocation with 4 (12.1%) cases each. Figure 2 illustrates the associated injuries.

Caviglia et al[3] published the most extensive series of cases, reporting seven patients with what they called a "tetrad" of the elbow. This injury pattern consisted of a TTE with a concomitant olecranon fracture (Table II). Interestingly, the fracture's complexity and the direction of elbow dislocation were variable, with three posterior and four posterolateral dislocations. Regarding ligamentous injury, all seven patients had an LCL injury, but none had an MCL injury.

Dailiana et al[5] reported the case of a four-year-old girl who fell from a height of 60 cm, resulting in a TTE (impacted RHF, type 2 coronoid fracture, and elbow dislocation) with a concomitant olecranon fracture (transverse type) and avulsion of both the MCL and LCL.

Zha et al[35] described a 26-year-old man who fell off a truck and landed on both hands, resulting in bilateral elbow injuries. The left elbow injury was consistent with a classic TTE with a type 2 RHF, type 1 coronoid fracture, and an elbow dislocation; the authors did not report in which direction. Initial radiographs of the right elbow demonstrated an olecranon fracture with associated elbow subluxation. An open reduction and internal fixation with an olecranon plate via a posterior approach was made. On postoperative day one, the right elbow dislocated (mechanism of dislocation was not reported). Subsequent radiographs showed fractures of the radial head and coronoid. Given the pattern of injury observed, the patient most likely had sustained a concomitant TTE missed at the time of the initial evaluation. The authors did not describe ligamentous injuries.

Three recent studies described a TTE occurring in association with an ipsilateral carpal/wrist fracture and/or dislocation. In the case report by Elloumi et al,[9] a 47-year-old male construction worker fell from the second floor, resulting in a classic TTE with a type 2 RHF and type 1 coronoid fracture (the direction of elbow

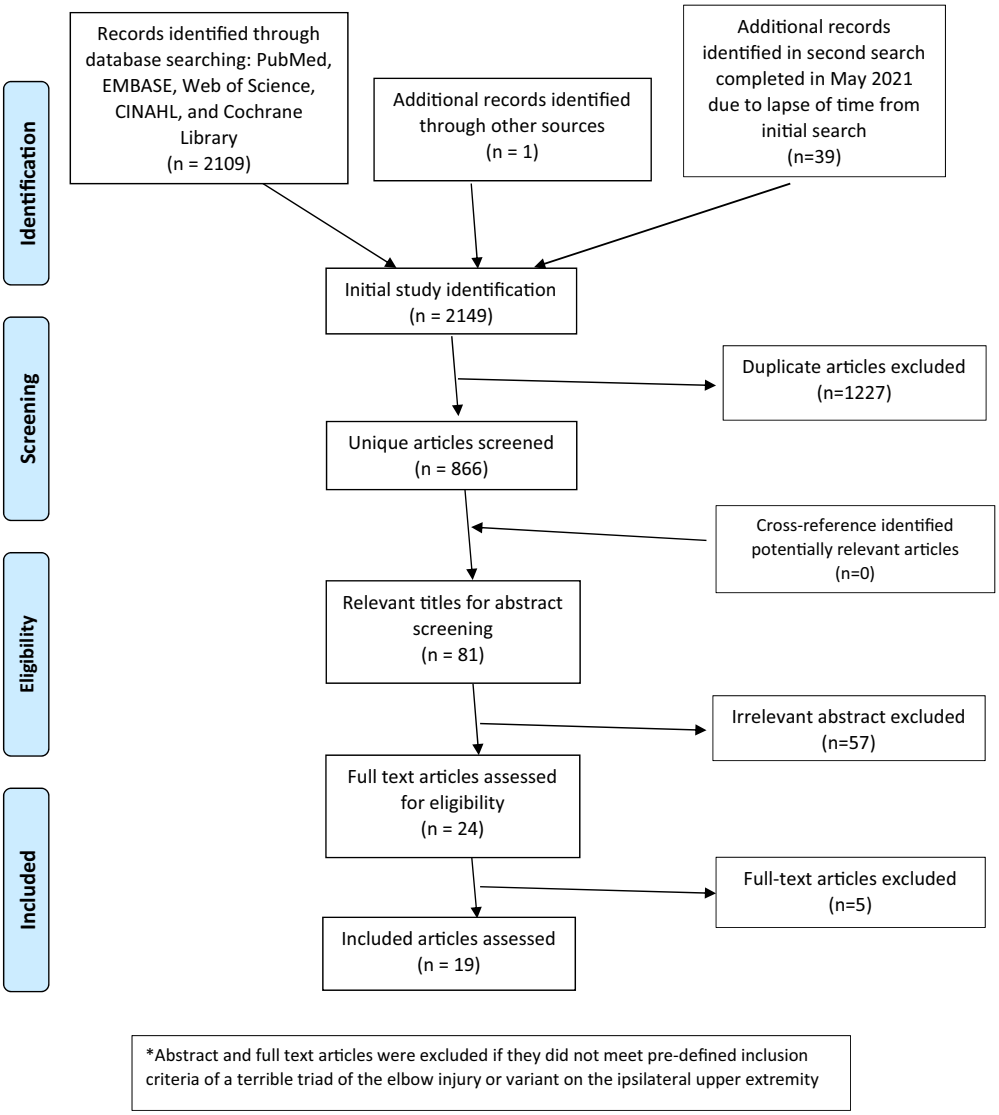

Figure 1 PRISMA flowchart.

dislocation was not reported) in addition to an ipsilateral dorsal perilunate dislocation of the wrist. Only the LCL was injured in this case. The study by Reddy et al[25] addressed the case of a 40-year-old man who was involved in an MVA and was diagnosed with bilateral TTEs with posterior elbow dislocation, type 3 RHF and type 1 coronoid fracture with LCL injury, as well as a trans-scaphoid fracture with perilunate dislocation on the left side, and volar lunate dislocation on the right side. Seijas et al[31] reported a case of a TTE with multiple associated injuries in a 34-year-old man who fell from a height of two meters down the stairs. In addition to a TTE (with posterior elbow dislocation), he presented with ipsilateral scaphoid and patella fractures and contralateral olecranon and RHFs. The authors did not report the type of RHF and coronoid fracture nor the ligamentous injuries. Shinohara et al[33] described the case of a 38-year-old man who sustained a TTE (type 3 RHF, type 1 coronoid fracture, and posterior elbow dislocation) after a fall from a height of 3 m. In addition, initial radiographic studies showed a distal radius fracture and an Essex-Lopresti injury. Eleven days after the injury, when surgical treatment was performed, a dorsal perilunate dislocation which was not apparent at the initial assessment was revealed and treated. Both LCL and MCL were avulsed.

Diaz-Suarez et al[8] described the case of a 41-year-old man who was involved in an MVA and sustained a TTE (type 3 RHF, type 1 coronoid fracture, and posterolateral elbow dislocation) associated with an ipsilateral ulnar diaphyseal fracture and injury to the MCL and annular ligaments.

In 2009, Seijas et al[30] performed a study on the epidemiology, treatment, and outcomes of 18 patients with TTE. In their series, two patients, a 45-year-old woman (type 2 RHF, type 1 coronoid fracture, posterior elbow dislocation) and a 17-year-old man (type 2 RHF, type 2 coronoid fracture, posterior elbow dislocation), had associated Essex-Lopresti injuries. However, in their report, it was unclear whether the associated Essex-Lopresti injuries were diagnosed at initial evaluation or later during follow-up. Moreover, no other individualized information about these two cases was reported, such as the MOI, clinical follow-up, or complications. In 2020, Ramzi et al[24] published the case of a 56-year-old man who fell from his bike onto an outstretched hand sustaining a TTE (type 2 RHF, type 2 coronoid fracture, posterior elbow dislocation). In

Table I
Summary of the articles included.

Author	Title	Journal	Year of publication	Design
Kumar et al[14]	A Rare Combination of Fractures around the Elbow: Bony Variant of Terrible Triad	*Chinese Journal of Traumatology*	2015	Case report
Courtney et al[4]	A Terrible Quartet Injury of the Elbow: A Terrible Triad Variant with a Capitellar Shear Fracture	*Journal of Bone and Joint Surgery Case Connect*	2014	Case report
Lambers, K and Ring, D[15]	Elbow Fracture-Dislocation with Triceps Avulsion: Report of 2 Cases	*Journal of Hand Surgery*	2011	Case report
Elloumi et al[9]	Floating Forearm with Terrible Triad Injury of the Elbow: A Case Report	*Journal of Orthopaedic Case Reports*	2018	Case report
Caviglia et al[3]	Fracture of the distal complex elbow dislocation: is terrible tetrad a new entity?	*Revista latinoamericana de Cirugia Ortopedica*	2016	Case series
Shetty et al[33]	Our Experience of a Case of Terrible Triad of Elbow	*Nitte University Journal of Health Science*	2014	Case report
Dailiana et al[5]	Pediatric Terrible Triad Elbow Fracture Dislocations: Report of 2 Cases	*Journal of Hand Surgery*	2013	Case report
Rooke et al[29]	Pediatric Terrible Triad Injury of the Elbow: A Rare and Easily Missed Injury	*Journal of Bone and Joint Surgery*	2018	Case report
Bhavsar et al[2]	Results of Posterior Dislocation of Elbow Associated with Bony and Soft Tissue Injury	*Malaysian Orthopaedic Journal*	2013	Retrospective case series
Zha et al[35]	Severe injury of bilateral elbow joints with unilateral terrible triad of the elbow and unilateral suspected terrible triad of the elbow complicated with olecranon fracture: one case report	*International Journal of Clinical and Experimental Medicine*	2015	Case report
Seijas et al[30]	Terrible triad of the elbow	*Journal of Orthopaedic Surgery*	2009	Case series
Seijas et al[31]	Terrible triad of the elbow—role of the coronoid process: a case report	*Journal of Orthopaedic Surgery*	2005	Case report
Desai et al[7]	Terrible Triad of the Elbow: A Case Report of a New Variant	*Journal of Postgrad Medicine*	2006	Case report
Reddy et al[25]	Traumatic Bilateral Terrible Triad of Elbow with Left Trans-Scaphoid Peri-Lunate Dislocation and Right Lunate Dislocation	*International Journal of Current Research*	2016	Case report
Diaz Suarez et al[8]	Unusual case of complex fracture dislocation of the elbow	*Strategies in Trauma and Limb Reconstruction*	2018	Case report
Shinohara et al[33]	Floating forearm associated with terrible triad injury and Essex-Lopresti injury: a case report and literature review	*Journal of Shoulder and Elbow Surgery International*	2021	Case report
Dehghani Nazhvani et al[6]	Terrible triad elbow fracture dislocation with ipsilateral triceps avulsion and radial shaft fracture: a case report	*JBJS Case Connect*	2020	Case report
Ramzi et al[24]	Terrible triad of the elbow with an ipsilateral Essex-Lopresti injury: a case report	*Journal of Surgical Case Reports*	2020	Case report
Gajendran et al[10]	Terrible triad elbow fracture-dislocation with triceps and flexor-pronator mass avulsion	*Orthopedics*	2015	Case report

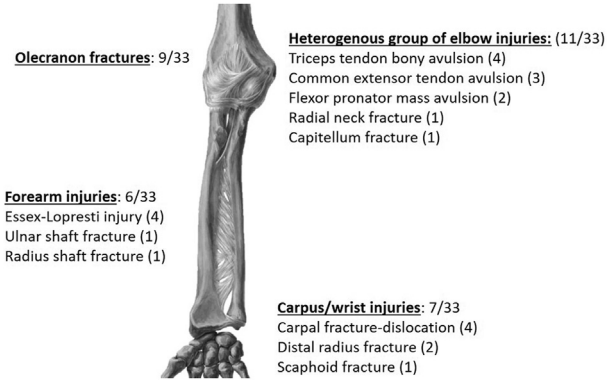

Figure 2 Most common associated injuries to the TTE. *TTE*, terrible triad of the elbow.

addition, initial imaging identified an Essex-Lopresti lesion, and during surgery, an avulsion of the common extensor tendon and LCL were observed.

The study by Courtney et al[4] described a 62-year-old woman who fell down a flight of steps and landed on her outstretched hand, resulting in a TTE (comminuted RHF, comminuted type 1 coronoid fracture, and posterolateral elbow dislocation) with concomitant capitellar shear fracture and complete tear of the LCL. In their report, they described this injury as a "terrible tetrad" or "quartet".

Shetty et al[32] described the case of a 43-year-old female patient who fell on her outstretched hand, resulting in a posterior elbow dislocation with associated coronoid, radial head, and neck fractures. Unfortunately, the authors did not report on the status of the ligaments.

Table II
Group 1: Terrible triad and concomitant ipsilateral upper-extremity injuries—details from the findings reported in each study.

Article	Age and gender	MOI	Fractures	Elbow dislocation	Ligament lesion	Other injuries
Elloumi et al[9]	47 yo M	Fall from the second floor	Coronoid, RH	Yes	LCL	Dorsal perilunate dislocation of the wrist (ipsilateral)
Reddy et al[25]	40 yo M	MVA	Coronoid, RH (bilateral)	Posterior (bilateral)	LCL (bilateral)	Left wrist: trans-scaphoid fracture with perilunate dislocation Right wrist: volar lunate dislocation
Courtney et al[4]	62 yo F	Fall a flight of steps	Capitellum, coronoid, RH	Posterolateral	LCL	None
Dailiana et al[5]	4.5 yo F	Fall from 60 cm	Coronoid, olecranon, RH	Yes	LCL and MCL	None
Zha et al[35]	26 yo M	Fall from a truck	Coronoid, olecranon, RH	Subluxation	NR	None
Lambers and Ring[15]	44 yo M	Fall 35 ft from the roof	Coronoid, RH	Posterior	LCL	Triceps tendon bony avulsion Complex intraarticular distal radius fracture (ipsilateral)
Dias-Suarez et al[8]	41 yo M	MVA	Coronoid, RH	Posterolateral	MCL and annular ligament	Ulnar diaphyseal fracture (ipsilateral) Third and fourth PIP joint dislocation (contralateral)
Seijas et al[31]	34 yo M	Fall from 2-m stairs	Coronoid, RH	Posterior	NR	Scaphoid fracture (ipsilateral) Patella fracture (ipsilateral), olecranon and RH fractures (contralateral)
Seijas et al[30]	45 yo F	NR	Coronoid, RH	Posterior	NR	Essex-Lopresti lesion (ipsilateral)
	17 yo M	NR	Coronoid, RH	Posterior	NR	Essex-Lopresti lesion (ipsilateral)
Shetty et al[33]	43 yo F	FOOSH	Coronoid, RH, radial neck	Posterior	None	None
LSO	63 yo M	Fall from the ladder	Coronoid, RH	Posterolateral	LCL and MCL	Triceps tendon avulsion and common extensor tendon (ipsilateral)
Shinohara et al[33]	38 yo M	Fall from 3 m	Coronoid, RH	Posterior	LCL and MCL	Distal radius fracture, Essex-Lopresti lesion, dorsal perilunate dislocation (ipsilateral)
Dehghani Nazhvani et al[6]	23 yo M	Fall from 82 ft	Coronoid, RH	NR	LCL and MCL	Radius shaft fracture, triceps tendon bony avulsion and common extensor tendon (ipsilateral), flexor-pronator mass avulsion
Ramzi et al[24]	56 yo M	FOOSH	Coronoid, RH	Posterior	LCL	Essex-Lopresti and common extensor tendon (ipsilateral)
Gajendran et al[10]	29 yo F	FOOSH	Coronoid, RH	Posterior	LCL	Triceps tendon bony avulsion and flexor-pronator mass avulsion (ipsilateral)
Caviglia et al[3]	45 yo M	Fall from own height	Coronoid, RH	Posterolateral	LCL	Olecranon fracture
	18 yo F	MVA	Coronoid, RH	Posterolateral	LCL	Olecranon fracture
	62 yo F	Fall from own height	Coronoid, RH	Posterior	LCL	Olecranon fracture
	35 yo M	Fall from height	Coronoid, RH	Posterolateral	LCL	Olecranon fracture
	70 yo F	Fall from own height	Coronoid, RH	Posterior	LCL	Olecranon fracture
	54 yo M	MVA	Coronoid, RH	Posterior	LCL	Olecranon fracture
	72 yo F	Fall from own height	Coronoid, RH	Posterolateral	LCL	Olecranon fracture

F, female; *FOOSH*, fall on outstretched hand; *LCL*, lateral collateral ligament; *M*, male; *MCL*, medial collateral ligament; *MOI*, mechanism of injury; *MVA*, motor vehicle accident; *NR*, not reported on the original article; *OSH*, outstretched hand; *PIP*, proximal interphalangeal; *RH*, radial head; *yo*, year-old.

Three studies described a TTE with concomitant triceps tendon avulsion. Dehghani Nazhvani et al[6] in 2020 published a case report of a 23-year-old man who fell from 82 feet. Initial radiographs showed a left TTE (type 3 RHF, type 1 coronoid fracture, and posterior elbow dislocation) and ipsilateral radius shaft fracture. The "fleck sign" was identified on radiographs, and a bony avulsion of the triceps tendon was confirmed with a computed tomography (CT) scan. During surgery, avulsion of the LCL, MCL, common extensor tendon, and flexor-pronator mass was visualized. Gajendran et al[10] described the case of a 29-year-old woman who fell onto her outstretched hand. Radiographs showed an RHF and posterior subluxation of the elbow and small cortical flecks of bone medially and posteriorly. A CT scan identified a comminuted RHF, a coronoid fracture, and triceps tendon bony avulsion. Intraoperative findings also included avulsion of the flexor-pronator mass and LCL. Lambers and Ring[15] reported on a 44-year-old man who fell 35 feet from a roof, resulting in a TTE with concomitant triceps tendon bony avulsion. In addition, the patient had an ipsilateral complex intra-articular distal radius fracture.

A 63-year-old male firefighter treated by the senior author initially presented to the emergency department (ED) with a posterolateral elbow dislocation after a fall from a ladder onto his

Table III
Group 2: Terrible triad variants—details from the findings reported in each study.

Article	Age and gender	MOI	Fractures	Elbow dislocation	Ligament lesion	Other injuries
Desai et al[7]	25 yo F	Fall from the third floor (suicide attempt)	Capitellum, coronoid	Posterior	None	Head injury, zygomatic fracture, fracture of the ribs with pneumothorax, subtrochanteric fracture, and bilateral distal intra-articular fracture of the radius
Rooke et al[29]	12 yo M	Fall from a bicycle	Salter-Harris II radial neck, coronoid chondral injury	Yes	MCL	None
Bhavsar et al[2]	Age NR M	NR	Medial condyle, RH	Posterior	LCL	None
Kumar et al[14]	30 yo M	MVA	Capitellum, coronoid, RH	No	LCL: lax	Distal third of the radius (ipsilateral)

F, female; *FOOSH*, fall on outstretched hand; *LCL*, lateral collateral ligament; *M*, male; *MCL*, medial collateral ligament; *MOI*, mechanism of injury; *MVA*, motor vehicle accident; *NR*, not reported on the original article; *PIP*, proximal interphalangeal; *RH*, radial head; *yo*, year-old.

nondominant upper extremity. Initial radiographs obtained in the ED demonstrated a TTE. After successful closed reduction, a post-reduction CT scan was performed in the ED, which confirmed a TTE with comminuted RHF and coronoid tip fractures. The patient was discharged from the ED and was recommended outpatient follow-up with an orthopedic surgeon. Seven days after the injury, the patient was evaluated in the senior author's office and found a palpable gap in the triceps tendon that was not initially recognized in the ED because of significant elbow swelling. Magnetic resonance imaging (MRI) confirmed a near-complete rupture of the triceps tendon with proximal retraction in addition to a high-grade partial thickness tear of the LCL, common extensor tendons, and MCL.

The findings from each study in group 1 are summarized in Table II.

Group 2: terrible triad variants

Four of the 19 included articles described variants of the typical TTE. Group 2 had a total of four patients (three men and one woman) with a mean age of 22.35 years (range 12-30). Patient characteristics, MOI, TTE variant, and other injuries for each study are described in Table III.

Desai et al[7] reported the case of a 25-year-old polytrauma patient who sustained a TTE variant consisting of a posterior elbow dislocation, coronoid process, and capitellum fractures. No ligamentous injury was reported.

Rooke et al[29] described a case of a 12-year-old boy who presented to the ED after a fall from his bicycle. He was initially diagnosed with a Salter-Harris type 2 fracture of the proximal radius. However, at his 2-week follow-up appointment, a closer view of his initial radiographs demonstrated subtle ulnohumeral subluxation concerning possible pediatric TTE. Further evaluation with MRI and an intraoperative arthrogram confirmed a chondral fragment in the ulnohumeral joint corresponding to the tip of the coronoid process. In addition, there was MCL laxity observed intraoperatively consistent with partial MCL injury.

Bhavsar et al[2] conducted a retrospective case series describing 15 patients with elbow dislocations and associated injuries. One of the 15 cases reported was a man who presented with a TTE variant consisting of posterior elbow dislocation with associated RHF, medial condyle fracture, and LCL injury. The age and MOI were not specified.

Kumar et al[14] described the case of a 30-year-old male farmer who was involved in an MVA and sustained a combination of fractures without dislocation of the elbow, which the authors called a TTE “bony variant”. The patient’s injury included fractures of the capitellum, coronoid process, radial head, and ipsilateral distal third of the radius. The MCL was intact, the LCL was lax, and no ligament repair was performed.

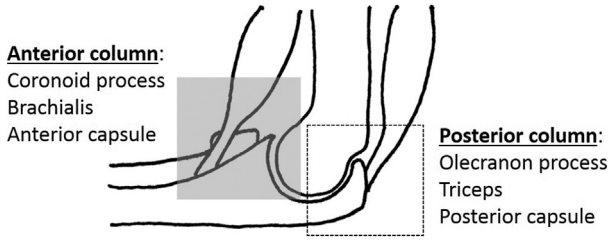

Figure 3 Components of the anterior and posterior columns of the elbow joint.

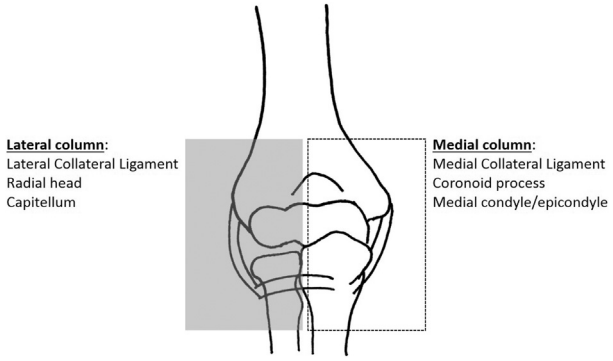

Figure 4 Components of the medial and lateral columns of the elbow joint.

Discussion

The TTE is a complex injury that poses a diagnostic and therapeutic challenge to treating surgeons. During a TTE, energy usually dissipates in a predictable pattern, referred to as the circle of Horii, which sequentially involves the different elbow structures. However, depending on the amount of energy imparted at the time of injury and the direction in which the energy dissipates, other and additional injury patterns may result, affecting different columns, as presented in this review (Figs. 3 and 4).

From the 19 articles included and the senior author's case, there were 27 patients. In group 1, 23 patients presented 24 TTEs with 33 concomitant ipsilateral upper-extremity injuries. If a TTE presents with an ipsilateral associated injury, it will most likely affect the

elbow, which accounted for 20 of the 33 concomitant injuries (60.6%). The most common elbow injuries were an olecranon fracture (27.3%), triceps tendon avulsion (12.1%), common extensor tendon avulsion (9%), flexor-pronator mass avulsion (6%), radial neck (3%), and capitellum fracture (3%).

In this review, our definition of the TTE variant and TTE with concomitant injuries was based on the injury pattern and the MOI classically described for a TTE: a combined axial and valgus load on the elbow and supination of the forearm relative to the humerus. This injury mechanism in which there is a circular pattern of energy dispersion is substantially different, for instance, from a trans-olecranon fracture-dislocation. In a trans-olecranon fracture-dislocation of the elbow, the resulting fractures to the radial head and coronoid process occur because of the impact between the distal humerus and the sigmoid notch.[18,21,26] Thus, because the energy is dissipated longitudinally from the humerus to the ulna, there is typically no injury to the ligamentous complex like in a TTE.[34] In this review, eight of nine cases of concomitant olecranon fractures in group 1 had expected ligamentous disruptions of the LCL and/or MCL following the typical pattern of energy dissipation observed with a classic TTE.[3,5,15] The remaining case describing an olecranon fracture did not explicitly document a ligamentous injury given that a TTE was diagnosed after the initial treatment of the olecranon fracture.[35] However, given the resulting pattern of elbow dislocation and associated radial head and coronoid tip fractures, this case was presumed consistent with a TTE mechanism.

Furthermore, of the 24 TTE cases in group 1, 20 had a ligamentous injury to the elbow, supporting the MOI described previously. The other four patients did not have a report on ligament injury. However, in two of these cases, an Essex-Lopresti injury was present, suggesting that the energy followed a longitudinal direction until it reached the elbow, where it ultimately caused the TTE injuries.

The second most common location for associated injuries in group 1 was the wrist/carpus (21.2%). Interestingly, all these patients had a high-energy MOI initially transmitted from the hand to the carpus after a fall on the outstretched hand. Thus, a plausible explanation for the observed concomitant TTE on the ipsilateral extremity could be that the energy imparted on the wrist was sufficient to continue proximally through the intraosseous membrane toward the elbow.

The forearm was the site of associated injury in 18.2% of cases. Most frequently, an Essex-Lopresti lesion was identified, but shaft fractures of the radius and ulna were also reported. This emphasizes that when a TTE is diagnosed, besides the obvious attention to elbow injuries, the physician should also investigate for the possibility of a concomitant wrist/carpus or forearm injury.

Kumar et al[14] reported an intriguing case in which ligamentous involvement was not observed as is commonly expected with a TTE. The authors described a bony variant of the typical lateral-sided injury resulting from the dissipation of energy in the circle of Horii. They postulated that the MOI was possibly a varus force that first resulted in a capitellum fracture and RHF. The varus force would have also stressed the LCL, which, given its attachment on the supinator crest, would have resulted in avulsion of the coronoid process. Alternatively, the authors hypothesize that a posterior dislocation/subluxation of the elbow with spontaneous reduction could also explain these findings.

Associated injuries to the ipsilateral upper extremity in the setting of a TTE are more likely with a high-energy MOI. Consequently, both the initial and secondary surveys should include a careful and systematic physical examination of the entire upper extremity. The pain and swelling from the TTE may jeopardize the precise identification of some anatomical structures of the elbow joint. Thus, making a complete diagnosis based exclusively on clinical examination is challenging. In addition, the physical examination may be challenging because of patient guarding, and a repeat examination may be necessary once swelling and pain are improved. In the setting of an ulnohumeral dislocation, a few external signs can clue in the physician about the likelihood of concomitant fracture or disruption of additional soft tissue structures. For instance, lateral ecchymosis or pain may represent fracture of the RH, LCL injury, or, less frequently, fracture of the capitellum. Alternatively, the physician can utilize analgesics, utilize local anesthesia, or proceed with an examination under sedation to characterize the extent of the injury more accurately. Moreover, it is essential to emphasize the need for a postreduction examination. Reducing the dislocated elbow may help decrease pain and allow for a better clinical examination after reduction.

Although a thorough physical examination is fundamental, various imaging studies may assist in diagnosis when the clinical examination is challenging. The first imaging modality should be a plain radiograph of the affected joint. If the physical examination indicates possible associated injuries to the wrist or forearm, or if the MOI involves high energy, x-rays of the joints above and below should be considered. Previous studies reported that ipsilateral upper-extremity injuries occur in 10%-20% of patients with complex elbow dislocations.[1,13] Many bony injuries are visible on plain radiographs, and scrutiny of the bony anatomy is recommended. Besides the typical radial head and coronoid fractures, the postreduction lateral radiograph should be scrutinized for a possible “double-arc” sign, indicating a capitellum fracture extending into the trochlea. Capitellar fractures in the setting of a TTE are complicated to manage, as the small size of the capitellum fracture poses a challenge for fixation. This may lead to deviation of the fragment with a subsequent compromise of the range of motion of the elbow joint, impairing the functionality of the upper extremity. Another radiographic sign that may indicate an associated injury is a flake of bone on the posterior aspect of the elbow, meaning an olecranon avulsion fracture. However, a high index of suspicion is required because the “flake sign” may be subtle, especially in the setting of more overt fractures.[15,22] The case report from the senior author and the one by Lambers and Ring[15] did not present the “flake sign”. The authors emphasize that the fact that they favored a posterior approach to the elbow might have helped identify the triceps injury, as this may have been missed if a different approach had been chosen, which is not uncommon for treatment of the TTE.

A CT scan is recommended for detailed assessment of the fractures and to guide preoperative planning and treatment. Three-dimensional reconstruction is beneficial for preoperative planning because it is easier to interpret and provides an image closer to the anatomy that orthopedic surgeons are familiar with. Moreover, digitally subtracting unfractured bones can help identify minor fractures not seen on plain radiographs.[11,16]

Compared with concomitant bony injury, the greater challenge lies in identifying concomitant soft-tissue injuries, which are not readily diagnosed by physical examination, plain radiographs, or CT scan. The treating surgeon should maintain a high suspicion for these soft-tissue injuries, considering that dislocation of the elbow typically causes capsuloligamentous injury and a variable degree of damage to the common flexor and extensor muscles from the epicondyles.[17] The LCL complex may be avulsed from the lateral epicondyle together with the common extensor muscle origin, leaving a bare epicondyle.[23] Performing a global posterior approach during surgical treatment may enable assessment of posterior soft

tissues, such as the triceps tendon, which may not be encountered when performing, for instance, a lateral Kocher approach. If there is a high index of suspicion for concomitant injury, additional studies, such as ultrasound or MRI, should be considered to identify soft-tissue disruption before surgery.

In addition to the inherent drawbacks of a systematic review, this study has some important limitations. As with most, this review is subject to publication bias, as the only cases included were those published in the five databases searched. In addition, the true incidence of concomitant injuries associated with a TTE may be under-represented in this sample. Publication bias is a critical flaw in this review, as there are likely more cases of TTE with associated injuries that have occurred but were either not recognized or have not been published in the literature. However, to reduce our selection bias, we included every available report in five large databases from inception to May 2021, and our search included articles published in four languages. Furthermore, all articles included were assessed using specific quality appraisal tools. Finally, concomitant ipsilateral upper-extremity injuries associated with a TTE and variants of TTE are relatively rare, making it difficult to study in-depth clinically. Moreover, there is a lack of data in the literature addressing this subject. For the abovementioned reasons, this systematic review offers a valuable contribution to our present understanding of this injury pattern and its associated injuries.

Conclusion

Although TTE variants and associated concomitant injuries are uncommon, this review reinforces the importance of keeping a high index of suspicion for these injuries as they can often be missed. A TTE variant was defined as a combination of osseous and/or chondral injuries to the elbow other than the classic description of a TTE, in which at least two of the three classical elements of a TTE (elbow dislocation, coronoid fracture, and RHF) were present in addition to other unique elbow osteoarticular injury. Reported variants were capitellum fractures, radial neck fracture, coronoid chondral injury, and medial condyle fracture. The most common associated concomitant injury was an olecranon fracture (9/33, 27.3%), followed by Essex-Lopresti injury, triceps tendon avulsion, and carpal fracture-dislocation with 4 (12.1%) cases each. Therefore, performing a detailed and careful evaluation of the patient with particular attention to the entire ipsilateral upper extremity is critical, as these additional injuries may delay recovery and/or compromise outcomes if missed. This is particularly important in patients with a reported high-energy MOI, in which a large transfer of energy can propagate from the wrist proximally. In this review, more than half of the patients had a high-energy trauma.

Although the utility of plain radiographs and CTs is widely accepted as part of the clinical algorithm for evaluation of complex elbow fracture-dislocations, it is crucial to perform a thorough secondary survey and repeat physical examination once the initial pain, swelling, and range of motion restriction have improved as well as to consider additional imaging modalities for soft-tissue assessment, such as MRI or ultrasound in select cases. Furthermore, knowledge of the MOI is essential to understand the pattern of fractures and help predict the possible TTE variants and/or concomitant injuries associated with the classical presentation of a TTE. A high-energy axial load onto the hand may be transmitted proximally to the forearm and elbow. This review showed that, most likely, associated injuries will occur in the elbow and, secondly, may affect the wrist/carpus and forearm. By analyzing the available data on associated injuries and variants that may occur with a TTE, we hope to increase awareness so that clinicians may recognize these less common but more complex injury patterns.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.xrrt.2021.10.004.

References

1. Beingessner D, Pollock J, King G. Elbow Fractures and Dislocations. In: Court-Brown CM, Heckman JD, McQueen MM, Ricci WM, Tornetta P, McKee MD, editors. Rockwood and Green's fractures in adults. 8th ed. Philadelphia: Wolters Kluwer Health; 2015. p. 1180-227.
2. Bhavsar N, Patel J, Patel P, Chhapan J. Results of Posterior Dislocation of Elbow Associated with Bony and Soft Tissue Injury. Malaysian Orthopaedic J 2013;7:13-8. https://doi.org/10.5704/MOJ.1303.010.
3. Caviglia HA, Pemoff AB, Blanchetiere HE, Cuestas NG, Alvarez R, Vergara MS. Fractura-luxación del complejo distal del codo, ¿es la tétrada terrible una nueva entidad? Revista Latinoamericana de Cirugía Ortopédica 2016;1:14-20. https://doi.org/10.1016/j.rslaot.2016.05.004.
4. Courtney PM, Shah RP, Mehta S, Donegan DJ. A Terrible Quartet Injury of the Elbow. JBJS Case Connector 2014;4:e88. https://doi.org/10.2106/jbjs.cc.m.00099.
5. Dailiana ZH, Papatheodorou LK, Michalitsis SG, Varitimidis SE. Pediatric terrible triad elbow fracture dislocations: Report of 2 cases. J Hand Surg 2013;38:1774-8. https://doi.org/10.1016/j.jhsa.2013.05.030.
6. Dehghani Nazhvani H, Bemani Lirgeshasi S, Bahari M. Terrible Triad Elbow Fracture Dislocation with Ipsilateral Triceps Avulsion and Radial Shaft Fracture: A Case Report. JBJS Case Connector 2020;10:e20.00308. https://doi.org/10.2106/JBJS.CC.20.00308.
7. Desai MM, Sonone SV, Badve SA. Terrible triad of the elbow: a case report of a new variant. J Postgrad Med 2006;52:43-4.
8. Díaz Suárez R, Luengo Alonso G, Porras Moreno MÁ, Jiménez Díaz V, García Lamas L, Cecilia López N. Unusual case of complex fracture dislocation of the elbow. Strateg Trauma Limb Reconstruction 2018. https://doi.org/10.1007/s11751-018-0322-1. Epub ahead of print.
9. Elloumi A, Mihoubi M, Abdelkafi M, Kedous MA, Mahjoub S. Floating Forearm with Terrible Triad Injury of the Elbow : A Case Report. J Orthop Case Rep 2018;8:38-41. https://doi.org/10.13107/jocr.2250-0685.1248.
10. Gajendran VK, Bishop JA. Terrible Triad Elbow Fracture-Dislocation With Triceps and Flexor-Pronator Mass Avulsion. Orthopedics 2015;38:e143-6. https://doi.org/10.3928/01477447-20150204-91.
11. Guitton TG, Ring D. Nonsurgically Treated Terrible Triad Injuries of the Elbow: Report of Four Cases. J Hand Surg 2010;35:464-7. https://doi.org/10.1016/j.jhsa.2009.12.015.
12. Hotchkiss RN. Fractures and dislocations of the elbow. In: Rockwood CA, Green DP, Bucholz RW, Heckman JD, editors. Rockwood and Green's Fractures in Adults. 4th ed. Philadelphia: Lippincott-Raven; 1996. p. 929-1024.
13. Hwang RW, De Witte PB, Ring D. Compartment syndrome associated with distal radial fracture and ipsilateral elbow injury. J Bone Joint Surg - Ser A 2009;91:642-5. https://doi.org/10.2106/JBJS.H.00377.
14. Kumar V, Kumar A, Aggarwal S. A rare combination of fractures around the elbow: Bony variant of terrible triad. Chin J Traumatol - English Edition 2015;18:363-6. https://doi.org/10.1016/j.cjtee.2015.06.003.
15. Lambers K, Ring D. Elbow fracture-dislocation with triceps avulsion: Report of 2 cases. J Hand Surg 2011;36:625-7. https://doi.org/10.1016/j.jhsa.2010.12.027.
16. Lindenhovius A, Karanicolas PJ, Bhandari M, van Dijk N, Ring D. Interobserver Reliability of Coronoid Fracture Classification: Two-Dimensional Versus Three-Dimensional Computed Tomography. J Hand Surg 2009;34:1640-6. https://doi.org/10.1016/j.jhsa.2009.07.009.
17. Mezera K, Hotchkiss R. Fractures and Dislocations of the Elbow. In: Bucholz R, Heckman J, editors. Rockwood and Green's Fractures In Adults. 5th ed. Philadelphia: Lippincott Williams and Wilkins; 2001. p. 921-53.
18. Mouhsine E, Akiki A, Castagna A, Cikes A, Wettstein M, Borens O, Garofalo R. Transolecranon anterior fracture dislocation. J Shoulder Elbow Surg 2007;16:352-7. https://doi.org/10.1016/j.jse.2006.07.005.
19. O'Driscoll S, Jupiter J, King G, Hotchkiss R, Morrey B. The Unstable Elbow Instr Course Lect 2001;50:89-102.
20. O'Driscoll S, Morrey B, Korinek S, An K. Elbow subluxation and dislocation. A Spectr instability 1992;280:186-97.

21. O'Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD. Difficult elbow fractures: pearls and pitfalls. Instructional Course Lectures 2003;52:113-34.
22. Pina A, Garcia I, Sabater M. Traumatic Avulsion of the Triceps Brachii. J Orthopaedic Trauma 2002;16:273-6. https://doi.org/10.1097/00005131-200204000-00010.
23. Pugh DMW, Wild LM, Schemitsch EH, King GJW, McKee MD. Standard Surgical Protocol to Treat Elbow Dislocations with Radial Head and Coronoid Fractures. J Bone Joint Surg Am 2004;86:1122-30. https://doi.org/10.2106/00004623-200406000-00002.
24. Ramzi Z, Juanos Cabans J, Jennart H. Terrible triad of the elbow with an ipsilateral Essex-Lopresti injury: case report. J Surg Case Rep 2020;2020:rjaa103. https://doi.org/10.1093/jscr/rjaa103.
25. Reddy J, Vishnu S, Naik M, Rao S. Traumatic bilateral terrible triad of elbow with left trans scaphoid peri-lunate dislocation and right lunate dislocation. Int J Curr Res 2016;8:35255-8.
26. Ring D, Jupiter J, Sanders R, Mast J, Simpson N. Transolecranon Fracture-Dislocation of the Elbow. J Orthop Trauma 1997;11(8):545-50.
27. Ring D, Jupiter J, Zilberfarb J. Posterior dislocation of the elbow with fractures of the radial head and coronoid. J Bone Joint Surg Am 2002;84(4):547-51. https://doi.org/10.2106/00004623-200204000-00006.
28. Rodriguez-Martin J, Pretell-Mazzini J, Andres-Esteban EM, Larrainzar-Garijo R. Outcomes after terrible triads of the elbow treated with the current surgical protocols. A review. Int Orthopaedics 2011;35:851-60. https://doi.org/10.1007/s00264-010-1024-6.
29. Rooke GMJ, Maarschalk JA, Navarre P. Pediatric Terrible Triad Injury of the Elbow: A Rare and Easily Missed Injury. JBJS Case Connector 2018;8:e106. https://doi.org/10.2106/JBJS.CC.18.00114.
30. Seijas R, Ares-Rodriguez O, Orellana A, Albareda D, Collado D, Llusa M. Terrible triad of the elbow. J Orthop Surg (Hong Kong) 2009;17:6. https://doi.org/10.1177/230949900901700319.
31. Seijas R, Joshi N, Hernández A, Catalán J, Flores X, Nieto J. Terrible Triad of the Elbow - Role of the Coronoid Process: A Case Report. J Orthop Surg (Hong Kong) 2005;13:296-9. https://doi.org/10.1177/230949900501300314.
32. Shetty SM, Shetty V, Ballal A, Hegde A. Our experience of a case of terrible triad of elbow ring. J Health Allied Sci NU 2014;04:127-30. https://doi.org/10.1055/s-0040-1703820.
33. Shinohara I, Takahara S, Uefuji A, Inui A, Mifune Y, Ichimura K, Nishihara H, Kishimoto K, Aoki K, Takayama H, et al. Floating forearm associated with terrible triad injury and Essex-Lopresti injury: a case report and literature review. JSES Int 2021;5:320-7. https://doi.org/10.1016/j.jseint.2020.09.017.
34. Wyrick JD, Dailey SK, Gunzenhaeuser JM, Casstevens EC. Management of Complex Elbow Dislocations. A Mechanistic Approach 2015;23:297-306. https://doi.org/10.5435/JAAOS-D-14-00023.
35. Zha G, Niu X, Yu W, Xiao L. Severe injury of bilateral elbow joints with unilateral terrible triad of the elbow and unilateral suspected terrible triad of the elbow complicated with olecranon fracture: one case report. Int J Clin Exp Med 2015;8:14214-20.
36. Zhang C, Zhong B, Luo C. Treatment strategy of terrible triad of the elbow: Experience in Shanghai 6th People's Hospital. Injury 2014;45:942-8. https://doi.org/10.1016/j.injury.2013.12.012.