



Prolonged dislocation and delay to surgery are associated with higher rates of heterotopic ossification in operatively treated terrible triad injuries

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ABSTRACT

Background: Heterotopic ossification (HO) formation after complex elbow injuries can significantly impact function. Prior studies have reported a 3%–45% incidence of HO following elbow trauma in a heterogeneous cohort of fracture patterns. The purpose of our study was to evaluate the prevalence of and identify risk factors for HO specifically in patients with terrible triad injuries.

Methods: A total of 61 patients (64 elbows) underwent operative treatment for terrible triad injuries with an average follow-up period of 19.8 months (range, 3–138 months). The medical records were reviewed for demographic data, duration of dislocation, number of reduction attempts, time to surgery, presence of radiographic HO, elbow motion at final follow-up, functional limitations, and need for secondary procedures.

Results: Radiographic HO developed in 77% of patients, and 63% had some level of functional restriction. Thirteen patients (26%) underwent a secondary procedure for HO excision. Patients with HO had a longer time to surgery (4.9 days vs. 2.8 days, $P = .02$), longer duration of dislocation (21 hours vs. 6 hours, $P = .04$), and reduced flexion-extension (94° vs. 112° , $P = .04$) and pronation-supination (109° vs. 163° , $P = .002$) arcs of motion compared with patients without HO. HO was also more likely to develop in patients who required closed reduction than in those with spontaneous reduction prior to presentation.

Conclusion: The prevalence of radiographic and clinically relevant HO after terrible triad injuries was higher than previously reported. Persistent dislocation necessitating a closed reduction, a longer duration of dislocation, and a delay to surgery were associated with the development of HO. Providers should consider earlier surgical stabilization or urgent referral to a specialist for patients with unstable injuries.

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The systematic treatment of terrible triad elbow fracture-dislocations has led to an overall improvement in outcomes; however, the postoperative formation of heterotopic ossification (HO) remains a challenge.^{9,21} HO may result in severe motion restriction and lead to further surgical intervention to restore function. Recent studies reporting on the formation of HO after terrible triad injuries have reported rates of 4%–43% and are limited to small

case series.^{3,21–23} Larger studies evaluating risk factors associated with HO formation after elbow trauma have reported findings in a heterogeneous cohort of patients with different fracture patterns. Aside from general risk factors such as thermal or neurologic injury, prolonged time to surgery, fracture pattern, postoperative immobilization for more than 15 days, and multiple reduction attempts have been reported to increase the risk of HO development after elbow trauma.^{2,5,12,13,23,24} Unfortunately, several of these studies also have come to conflicting conclusions regarding certain risk factors, specifically the timing of surgery,^{6,23,27} likely because of the heterogeneous injury patterns included. The ability to identify at-risk patients would be helpful in providing preoperative patient counseling regarding expected outcomes or potentially modifying a surgeon's practice.

Institutional Review Board approval was received from the University of Washington Human Subjects Division (no. STUDY00004084).

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The purpose of this study was to evaluate the prevalence of radiographic and functionally limiting HO after operative treatment of terrible triad injuries. The second aim was to identify risk factors associated with the development of HO and isolate those that could potentially be modified perioperatively. We hypothesized that prolonged dislocation and delay to definitive surgical stabilization would be associated with more significant radiographic and functionally limiting HO.

Materials and methods

This was a retrospective cohort study of patients with operatively treated terrible triad injuries. A total of 262 proximal forearm fractures (AO–Orthopaedic Trauma Association classification 21C)¹⁸ were identified in our level 1 trauma database from 2003–2017, and 74 patients had a terrible triad injury. The diagnosis was confirmed with standard anteroposterior and lateral radiographic views of the elbow. The inclusion criteria included (1) patients who underwent surgical stabilization of their injury and (2) a clinical and radiographic follow-up period of at least 3 months. The exclusion criteria included patients who did not have injuries or postoperative radiographs available for review. Of those excluded, 3 had less than 3 months of follow-up and 10 did not have radiographs available for review and were therefore excluded. A total of 64 elbows in 61 patients were included in our analysis. No patient received preoperative or postoperative HO prophylaxis treatment or required additional stabilization with a hinged fixator or internal joint stabilizer. All patients were placed in a posterior arm plaster splint after surgery for a period of immobilization that was determined by the treating surgeon. After splint removal, patients were allowed active elbow motion as tolerated with forearm rotation as tolerated with the elbow at 90° of flexion for 6 weeks.

The medical records were reviewed, and demographic data were extracted, including age, sex, smoking status, traumatic brain injury, and polytrauma. Injury-related variables included open vs. closed fracture, mechanism of injury, duration of dislocation, number of reduction attempts, and time to definitive surgical fixation. The duration of dislocation was defined as the time of injury to the time of radiographic evidence of a concentric reduction. The surgical approach, fixation type, lateral and/or medial ligament repair, duration of postoperative immobilization, range of motion at final follow-up, and secondary surgical procedures were also documented. For patients who underwent HO excision surgery, postoperative elbow motion at final follow-up was collected. All dedicated elbow radiographs were reviewed by a surgeon who was dual fellowship trained in trauma and shoulder and elbow and remained blinded to the clinical outcomes. The location of HO was classified as anterior, posterior, or within the collateral ligaments as described by Viola and Hastings.²⁶ The Hastings classification, which characterizes the functional limitation regarding HO, was modified to include the definition of a functional arc of motion as reported by Morrey et al.^{10,19} Patients with functional range of motion, defined as flexion-extension and pronation-supination arcs greater 100°, were categorized as class I. Class IIA patients had a flexion-extension arc of less than 100°; class IIB, a pronation-supination arc of less than 100°; and class IIC, restrictions in both the flexion-extension and pronation-supination arcs of less than 100°. Class III patients had an ankylosed elbow.

Statistical analysis was performed using SPSS software (version 26.0; IBM, Armonk, NY, USA). Categorical data were analyzed using the Fisher exact test or χ^2 test when appropriate. Continuous variables were analyzed using the Student *t* test. Statistical significance was defined as $P < .05$.

Results

The mean age was 44 years (range, 19–65 years), and the mean follow-up period was 19.8 months (range, 3–138 months). Radiographic HO developed in 49 elbows (77%). No statistically significant differences in age, mechanism of injury, sex, smoking status, open vs. closed fracture, polytrauma, type of surgical procedure performed, or surgical approach were found between the 2 groups (Table I). Patients with HO had reduced mean elbow flexion, pronation, and supination at final follow-up compared with patients without HO (Table I). They also had reduced flexion-extension (94° vs. 112°, $P = .04$) and pronation-supination (109° vs. 163°, $P = .002$) arcs of motion. HO was present anteriorly in 39 elbows, posteriorly in 12, only in the lateral ligament in 14, only in the medial ligament in 7, and in both the lateral and medial ligaments in 24.

The mean time to definitive surgery was 4.9 ± 4.3 days in patients in whom HO developed compared with 2.8 ± 2.2 days in those in whom HO did not develop ($P = .02$). The mean duration of dislocation was 21.2 ± 42 hours in patients with HO compared with 6.1 ± 2.6 hours in those without HO ($P = .04$). HO was more likely to develop in patients who presented with a dislocation necessitating a closed reduction than in those with subluxation on initial radiographs ($P = .03$). Sixteen patients required 2 or more reduction attempts; however, there was no difference in the number of reduction attempts between the 2 groups ($P = .09$). A statistically significant linear trend was demonstrated with an increasing number of reduction attempts in the presence of HO ($P = .04$). Six patients required 3 or more reduction attempts and 6 patients had redislocation after successful reduction. HO developed in all of these patients.

Among the 49 elbows in which HO developed, 31 (63%) had clinically relevant HO, defined as greater than class I according to the Hastings classification. The Hastings classification in our cohort is summarized in Table II. A total of 19 patients underwent a secondary surgical procedure. Surgery was performed for reasons unrelated to HO in 6 patients: 3 sustained new fractures to their ipsilateral elbow, 2 had recurrent instability within 6 weeks of the index operation and required further stabilization with a trans-articular screw, and 1 underwent revision to a radial head arthroplasty for radial head nonunion after fixation. In 13 patients (26%), a secondary procedure was performed for HO excision at a mean of 17.5 months (range, 4–105 months). The patient who presented for excision 8 years after injury was a laborer who initially did well but noticed increasing stiffness and functional difficulty with time. Patients who underwent HO excision had a higher rate of posterior HO than those who did not undergo a second surgical procedure ($P = .049$). Those with limited motion in both flexion-extension and pronation-supination (Hastings class IIC) or with an ankylosed elbow (Hastings class III) were also more likely to undergo surgery for HO excision ($P < .001$). The flexion-extension and pronation-supination arcs of motion improved postoperatively to mean values of 33.5° and 72.3°, respectively. One patient had recurrence of HO after excision and required revision HO excision.

Discussion

HO is a well-known complication after operative treatment of elbow fractures. Several studies have reported on the incidence of HO formation and identified risk factors for its development; however, these studies contained a heterogeneous population of elbow injuries including fracture-dislocations; Monteggia fractures; trans-olecranon fractures; and radial head, olecranon, and distal humeral fractures. The mixed cohort of elbow injuries makes it challenging to parse out which risk factors are associated with each fracture pattern. Terrible triad injuries are one of the fracture

Table I

Summary of demographic characteristics, operative procedures, and motion at final follow-up in elbows with and without HO

	HO (n = 49)	No HO (n = 15)	P value
Mean age (range), yr	43.7 (19-65)	45.2 (23-62)	.64
Sex, n			.75
Male	35	10	
Female	14	5	
Open fracture, n	4	0	.57
Polytrauma, n	13	3	.74
Smoker, n	13	3	.74
Traumatic brain injury, n	2	1	.56
Mechanism of injury, n			.58
Motor vehicle or motorcycle accident	8	1	
Fall from height	35	11	
Pedestrian vs. automobile	0	0	
Bike vs. automobile	5	3	
Assault	1	0	
Surgical details, n			
Radial head fracture			.97
Arthroplasty	39	12	
ORIF	10	3	
Coronoid fracture			.27
Suture fixation	39	10	
Screw or plate fixation	5	4	
No fixation	5	1	
Ligament repair			.94
LUCL	46	14	
LUCL + MUCL	3	1	
Mean postoperative immobilization (range), d	5.4 (1-42)*	2.6 (1-14)	.18
Mean elbow motion (SD), °			
Flexion	119 (17)	130 (13)	.02
Extension	24 (21)	18 (15)	.22
Pronation	55 (38)	82 (19)	<.001
Supination	48 (40)	82 (11)	.001

HO, heterotopic ossification; ORIF, open reduction–internal fixation; LUCL, lateral ulnar collateral ligament; MUCL, medial ulnar collateral ligament; SD, standard deviation.

* One patient required stabilization with a transarticular screw and was considered immobilized for 42 days.

patterns associated with higher rates of HO and therefore were the focus of our study. The incidence of radiographic and clinically relevant (greater than Hastings class I) HO in our cohort of operatively treated terrible triad injuries (77% and 48%, respectively) was higher than previously reported in the literature. Closed-reduction manipulation, a longer duration of dislocation, and delay to surgery were associated with increased rates of HO formation.

The development of HO after terrible triad injuries has been well described in the literature; however, these reports were limited to small cohorts. Pugh et al²¹ reported that HO developed in 13.9% of their cohort of 36 elbows. Ring et al²² reported 1 case of HO among 11 patients with a terrible triad injury. Similarly, Broberg and Morrey³ described 1 case of HO in their cohort of 24 patients. A recent study by Shukla et al²³ found a higher rate of HO of 43% in a series of 24 terrible triad injuries. Among the studies that included all fractures about the elbow, the incidence of HO in patients with terrible triad injuries ranged from 18%–71%.^{2,7,12} One reason for our

higher incidence might be the referral nature of our level 1 tertiary center. These patients tend to have higher-energy trauma and undergo delayed surgical intervention because of other, more life-threatening injuries. In addition, none of the patients in this study received HO prophylaxis (often contraindicated in our patients with polytrauma), so our findings likely represent the true incidence of HO in patients with these injuries.

Our study found that a delay to surgery was associated with a higher rate of HO formation. This finding is concordant with the results of prior studies that demonstrated the importance of time to surgery and that treatment within 24–48 hours may decrease the incidence of HO formation.^{2,7,8,12,13,17} Ilahi et al¹³ examined a cohort of 41 fractures about the elbow and found that patients who underwent surgery after 48 hours had a significantly increased incidence of HO. Foruria et al⁷ similarly found that the rate of HO increased by 7.5% each day surgery was delayed, based on their prognostic model. In contrast, Shukla et al²³ found no significance difference in time to surgery; however, the authors highlighted that none of the patients in their cohort underwent surgery within 48 hours of injury.

Patients with prolonged preoperative dislocation or those who presented for care with a dislocation and required closed reduction also had a higher rate of HO. This finding is similar to the results of previous studies that identified fracture–dislocation as a risk factor for HO.^{7,12} Another study found that patients who required multiple reductions (defined as ≥ 2 attempts) were also at increased risk of HO.²³ We were unable to detect a statistically significant difference in the development of HO between patients who required 1 reduction and those who underwent multiple reduction attempts. This is likely because of the relatively low number of patients in the multiple-reduction group; however, it is important to note that HO developed in 8 of 10 patients who underwent 2 reductions and all patients who underwent 3–4 reduction attempts. The presence of recurrent dislocation or prolonged dislocation may suggest that repetitive trauma to the soft tissues around the elbow contributes to the formation of HO. Although this study does not provide irrefutable evidence, we believe that patients with subsequent dislocation after initial reduction should undergo surgical stabilization rather than multiple closed-reduction attempts and we have modified our practice as such.

Of the patients in whom HO developed, 26% elected to undergo excision and contracture release surgery, consistent with previously reported rates.^{7,12} Outcomes after excision were good overall, and the most improvement in motion was seen in pronation and supination. Several previous studies have also reported good outcomes with surgical excision of HO around the elbow.^{15,16,20} In addition, early excision of post-traumatic HO in the elbow has been shown to improve outcomes without an increase in HO recurrence rates compared with patients undergoing late excision.^{4,11,25} Time to excision varied in our population, with the earliest excision occurring at 4 months from the index surgical procedure. Koh et al¹⁴ demonstrated satisfactory results after surgical treatment of elbow stiffness secondary to post-traumatic HO, with an average improvement in motion of 67°. They also found that postponing HO excision for more than 19 months was associated with less favorable results.

There are several limitations to this study, including the lack of patient-reported outcomes and the presence of biases inherent to the retrospective nature of the study. To help mitigate the effect of observer bias, the investigator who evaluated the radiographs for HO remained blinded to the patient history and clinical outcomes. Elbow motion was obtained from the medical charts and not measured in a standardized way with a goniometer. Postoperative follow-up also varied in our population, with 7% of the cohort only undergoing 3 months of total follow-up. The referral nature of our

Table II

Hastings classification in patients in whom heterotopic ossification developed

Class	Elbows, n
I	18
IIA (flexion-extension arc < 100°)	10
IIIB (pronation-supination arc < 100°)	5
IIC (flexion-extension and pronation-supination arcs < 100°)	14
III (ankylosed elbow)	2

tertiary center means patients living remotely are often followed up locally after the initial postoperative visit. This may lead us to underestimate the actual rate of radiographic HO or overestimate the rate of functionally limiting HO. However, 92% of patients in our study in whom HO developed showed evidence of HO on their 6-week postoperative radiographs, reinforcing that the incidence is likely accurate. Of the 4 elbows that did not have more than 3 months' follow-up and were therefore excluded from the final data analysis, 3 showed the development of signs of HO on their 6-week radiographs. Although we agree that the follow-up period is very short, studies have suggested that radiographic evidence of HO develops as early as 2 weeks and that perhaps the absence of HO at 2 weeks may suggest a more favorable outcome.^{1,26}

We present the findings of the largest cohort of patients with terrible triad injuries known to date. The findings of this study will not only improve our ability to better inform patients about their injury but also help identify those at increased risk of HO. This will allow for early counseling and potentially more aggressive treatment. For terrible triad injuries that are persistently unstable, providers should consider earlier surgical stabilization within 48 hours of injury or an urgent referral to a specialist. Future studies are needed to further evaluate the role of prophylaxis in patients who are at higher risk of HO development.

Conclusion

The prevalence of radiographic HO after terrible triad injuries was higher than previously reported, and a majority of patients had some functional motion restrictions. Those with restriction in both flexion-extension and pronation-supination (Hastings class IIC) or an ankylosed elbow (Hastings class III) were more likely to undergo surgery for HO excision. Preoperative radiographic dislocation necessitating a closed reduction, a longer duration of preoperative dislocation, and a delay to definitive surgical stabilization were associated with the development of HO.

Disclaimer

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