Patterns of Complex Carpal Injuries in the Hand from Fireworks

Zhi Yang Ng¹ Alan Shamrock² David L. Chen² Seth D. Dodds² Harvey Chim¹

¹Division of Plastic and Reconstructive Surgery, University of Florida College of Medicine, Gainesville, Florida, United States

²Division of Hand Surgery, Department of Orthopedic Surgery, University of Miami Miller School of Medicine, Miami, Florida, United States

Address for correspondence Harvey Chim, MD, Division of Plastic and Reconstructive Surgery, University of Florida School of Medicine, 1600 SW Archer Road, PO Box 100138, Gainesville, FL 32610, United States (e-mail: harveychim@yahoo.com).

J Hand Microsurg 2018;10:93–100

Abstract

Purpose To describe the various patterns of complex carpal and metacarpal fracture dislocations observed in a consecutive series of firework injuries and the operative management performed.

Materials and Methods We performed a retrospective study of seven consecutive patients (six males; mean age = 22 ± 13 , range, 8–39 years) who presented to a level I trauma center with firework injuries to the hand between July 2014 and January 2016.

Results All injuries were sustained while a lighted firework was held in the hand. The mean length of hospital stay was 13.9 ± 13.8 (range, 4–46) days with an average of 3 ± 2.6 (range, 1–7) surgeries required for both bony and soft tissue reconstruction. Three patterns of injury were seen: type I—no carpal involvement; type II—carpometacarpal joint (CMCJ) dislocations and isolated carpal dislocations; type III—CMCJ dislocations with axial carpal dissociation. One patient had a type I injury, three had a type II injury, and three had a type III injury. Of patients with a type III injury, two of the three had simultaneous axial-radial and axial-ulnar involvement as well as a midcarpal dissociation with divergent dissociation of the carpus and metacarpals.

Conclusion The severity of carpal injuries resulting from fireworks is highly variable but is likely to follow predictable patterns due to the position of the hand and the location of the firework prior to explosion. Surgical reconstruction can be challenging, but adequate outcomes with a functional hand can be achieved through a systematic approach.

Type of Study/Level of Evidence Therapeutic level IV.

Keywords

- fireworks
- blast injuries
- carpal
- hand
- wrist
- axial dislocations

Introduction

More than 625 million emergency room visits occurred between 2006 and 2010 in the United States, and approximately 25,000 were due to firework injuries.¹ The wrist, hand, or finger(s) were involved approximately 40% of the time and resulted in open injuries in 6.5% of cases overall.¹ Such firework-related injuries involve varying combinations of blast, avulsion, crush, laceration, and burn components, resulting in highly complex injuries comprising both bony and soft tissue damage.²

While the extent of injury would certainly differ due to inherent differences between firework devices, Hazani et al recently described a repetitive pattern of injury involving both hyperextension and hyperabduction of the hand and digits with a tendency for involvement of radial-side soft tissue structures due, in part, to the position of the hand when holding onto the firework before it is thrown.³ Interestingly, despite the proximity of the carpal bones, their involvement and pattern of injury in such firework hand injuries has not been properly described in the literature.

received

January 22, 2018

accepted after revision

March 7, 2018

published online

April 25, 2018

©2018 Society of Indian Hand & Microsurgeons

DOI <https://doi.org/10.1055/s-0038-1642069>

ISSN 0974-3227.

It is therefore not inconceivable for high-impact injuries from fireworks to result in extensive soft tissue defects with concomitant open axial carpal dissociations and fracture dislocations.⁴ Herein, we report a consecutive series of patients with firework-related hand injuries and varying severities of carpal involvement. The focus of this report is on the patterns of carpal and metacarpal injuries sustained. We review the management of these cases and suggest possible pathologic mechanism(s) that might be responsible for their presentation.

Materials and Methods

This study was reviewed and approved by the ethics committee of our hospital and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki. Informed consent was obtained from all patients included in the study and reporting adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

A retrospective review of all patients admitted to the hand service between July 2014 and January 2016 with the diagnosis of firework injuries to the hand was performed (►Table 1). Essentially, patients with the severe injuries reported in these series were only seen over July 4 period and over the New Year's holiday season. Relevant data collected include patient age, sex, pre- and postoperative diagnoses, surgical procedures performed, intraoperative findings, relevant imaging studies, and length of hospital stay.

Treatment Protocol

Reconstruction is based on established principles.^{5,6} Initially, radical debridement of all devitalized and nonviable tissues (including revision amputations as necessary) is performed and revascularization of the hand is performed if required. Subsequently, bony stability is achieved through open reduction and internal fixation or pinning of axial carpal dissociations and/or carpometacarpal joint (CMCJ) dislocations to restore anatomical alignment to the carpus as much as possible. Attention then turns to repair of cut structures such

Table 1 Summary of injuries sustained

Patient	Age	Sex	Bony injuries	Soft tissue injuries
1	24	M	Axial-radial, axial-ulnar, and mid carpal dissociations CMCJ dislocations of 1/2/3/4/5 Partial traumatic amputation of distal phalanx of middle finger Near-complete disarticulation at DIPJ of ring finger	Multiple lacerations to all fingers FDS/FDP of index avulsed at musculotendinous junction
2	33	F	Axial-ulnar dissociation, CMCJ dislocations of 4/5 Open CMCJ dislocation with near-complete traumatic amputation of distal phalanx of thumb Traumatic amputation of index finger just distal to MCPJ	Multiple lacerations to thumb, ring finger Total degloving injury to middle finger to MCPJ FDS/FDP of middle, ring, and small fingers avulsed at musculotendinous junction
3	31	M	Axial-radial, axial-ulnar, and mid carpal dissociations CMCJ dislocations of 1/2/3/4/5 Phalangeal fractures of thumb and small fingers Partial traumatic amputations of index, middle, ring fingers	Second common digital nerve, artery long-gap injury Ulnar digital nerve gap of 1.5 cm in thumb
4	39	M	Partial traumatic amputations of thumb (at distal phalanx), index finger (distal to proximal phalanx), and middle finger (base of middle phalanx)	Total degloving injury to middle finger to middle of proximal phalanx Multiple lacerations of ring finger (with exposed but intact extensor tendon) and thenar eminence
5	8	M	CMCJ dislocations of 1/2/3/4/5 Trapezium-trapezoid dislocation Free bone fragments of base of 1/3/5 metacarpals	Hand amputation distal to CMCJ
6	12	M	CMCJ dislocations of 2/3/4/5 Metacarpal fracture of thumb MCPJ subluxation and middle phalanx fracture of index finger MCPJ subluxation of middle finger Metacarpal and distal phalanx fracture of ring finger	Degloved thumb with cut FPL, EPL, digital nerve (radially), and digital artery (ulnar) Volar plate injury over MCPJ of index finger with cut FDP, FDS and digital nerve (radially) Cut digital nerve (radially) and digital artery (ulnar) of middle finger Complete median nerve laceration Ulnar artery at deep palmar arch laceration
7	9	M	Traumatic amputation of hand distal to CMCJ of 1/2/3/4/5 Pisiform dislocation	Loss of viable soft tissue distal to CMCJs

Abbreviations: CMCJ, carpometacarpal joint; DIPJ, distal interphalangeal joint; EPL, extensor pollicis longus; FDP, flexor digitorum profundus; FDS, flexor digitorum superficialis; FPL, flexor pollicis longus; MCPJ, metacarpophalangeal joint.

as tendons and nerves to maximize and preserve functional outcomes. Other procedures such as carpal tunnel release may be performed to relieve associated soft tissue swelling. Finally wound closure is achieved in either primary or delayed fashion using various adjuncts, including skin substitutes, negative pressure therapy, and locoregional or free flaps. Regardless, there should be no hesitation in bringing the patient back to the operating room for repeat debridements if clinically indicated. This is often required due to the delayed effect of the blast injury that often makes second- and third-look debridements important in removing all non-viable tissue.

Results

Seven patients (six male) with a mean age of 22.3 ± 12.6 (range, 8–39) years presented with complex hand injuries sustained secondary to firework explosions during the study period. Six occurred during the July 4 weekend and the remaining patient was injured on New Year's Eve. The exact type of firework was not consistently recorded, but all injuries (►Table 1) resulted from fireworks that detonated while held in the hand. Other associated injuries included superficial burns to the arms, abdomen, chest, face, and ocular

involvement requiring ophthalmology consultation but are not the focus of the current study.

Reconstruction of the hand is detailed in ►Table 2 and required an average of 3 ± 2.6 (range, 1–7) surgeries. The mean length of hospital stay was 13.9 ± 13.8 days (range, 4–46), and two patients (5 and 6) required additional intensive care unit (ICU) support postoperatively. The mean duration of follow-up was 5.3 ± 3.9 months.

Assuming that the typical firework is cylindrical in shape, finger configuration during cylindrical grasp is such that the force produced by the thumb opposes that from the other four fingers with some element of palm contact.⁷ As the fuse burns from a distal to proximal direction toward the hand, the most likely areas to be affected upon detonation are those within immediate proximity. A review of the patients' X-rays suggests that three distinct injury patterns with increasing severity of carpal involvement can be appreciated as the blast injury propagates in both anteroposterior and proximo-distal directions.

Type I—No Carpal Involvement

The carpal bones remain intact and are grossly unaffected. However, due to the pattern of cylindrical grasp, associated soft tissue injuries typically involve the thumb, index,

Table 2 Summary of operative procedures

Patient	Procedures Performed
1	Open reduction and pinning Index X-ray amputation Revision amputation of distal phalanx of ring and middle fingers Local flap for coverage of distal thumb/palmar defect
2	Open reduction and pinning Open reduction and internal fixation of distal phalangeal fracture of thumb Revision amputation of index and middle fingers CMCJ disarticulation of ring and small fingers Fillet of finger flap (ring and small fingers) for soft tissue coverage of ulnar aspect of hand
3	Open reduction and pinning Revision amputations of distal (index, ring fingers) and middle phalanges (middle finger) Interposition nerve conduit repair of ulnar digital nerve of thumb
4	Revision amputations to distal (thumb finger) and proximal phalanges (index finger) Debridement and closure of lacerations
5	Open reduction and pinning Groin flap (15×9 cm) for soft tissue coverage of distal hand Chondrodesis between 3rd metacarpal base and distal radius (due to resting flexion posture of wrist)
6	Open reduction and pinning Open reduction and internal fixation of thumb metacarpal fracture Arterial repairs of (a) ulnar digital artery of thumb to deep palmar arch and (b) ulnar digital artery of middle finger to superficial palmar arch via first dorsal metacarpal artery graft Carpal tunnel release Revision amputations of thumb to proximal metacarpal Ray amputation of 3rd metacarpal Transposition of 2nd metacarpal and index to replace 3rd metacarpal and middle finger Median nerve reconstruction with allografts to radial and ulnar digital nerves of transposed index finger FDP transfer from middle to transposed index finger Contralateral free lateral arm flap for wound coverage
7	Revision amputation of hand distal to CMCJ of 1/2/3/4/5 EDC transfer to capitate (due to resting flexion posture of wrist) Wrist capsulorrhaphy and repair of carpal ligaments (for repair of pisiform dislocation)

Abbreviations: CMCJ, carpometacarpal joint; EDC, extensor digitorum communis; FDP, flexor digitorum profundus.

and middle fingers, reflecting a radial to ulnar trend previously described by Hazani et al.³ The affected digits likely undergo a combination of hyperextension and hyperabduction injuries, resulting in the presentation seen in patient 4 (►Table 1).

Type II—Carpometacarpal Joint Dislocations + Isolated Carpal Dislocations

With higher impact injuries, CMCJ dislocations tend to occur and may extend proximally to involve isolated carpal dislocations with accompanying neurovascular injuries (e.g., median nerve, ulnar artery), and distally to result in CMC

thumb fractures, subluxation of the metacarpophalangeal joint (MCPJ), metacarpal and/or phalangeal fractures, or even traumatic amputations of the digits altogether at or distal to the CMCJ. The extent and degree of associated soft tissue defects of the nerves, vessels, and tendons would certainly be more severe (patients 5, 6, 7) (►Fig. 1).

Type III—Carpometacarpal Joint Dislocations + Axial Carpal Dissociations

These are the most severe cases and result in either axial-radial or axial-ulnar carpal dissociations (patient 2) (►Fig. 2) or a combination of both (patients 1 and 3) (►Figs. 3, 4).

Fig. 1 Type II carpal injury (patient 6)—preoperative radiographs (A, B) showing CMCJ dislocations of 2/3/4/5 and a metacarpal fracture of the thumb with MCPJ subluxations and metacarpal and phalangeal fractures involving index, middle, and ring fingers; postoperative radiographs (C, D) after open reduction and pinning.

Fig. 2 Type III carpal injury (patient 2)—preoperative radiographs (A, B) showing axial-ulnar dissociation with concomitant CMCJ dislocations of 1/4/5 and near-complete traumatic amputation of distal phalanx of thumb. (C) Preoperative dorsal and (D) volar views showing ulnar column of hand dislocated at CMCJ. Due to the severity of the injuries on the ulnar side of the hand with multilevel explosive damage to the vasculature, soft tissue, and bone, the ring and small fingers could not be salvaged. Hence a fillet of finger flap incorporating the viable portions of the ring and small fingers was used to cover the ulnar side of the hand. Postoperative radiographs (E, F) after open reduction and pinning, and soft tissue coverage. Three months postoperative dorsal (G) and volar (H) view.

Fig. 3 Type III carpal injury (patient 1)—preoperative radiographs (A, B) showing combined axial-radial, axial-ulnar, and midcarpal dissociations with concomitant CMCJ dislocations of 1/2/3/4/5 and partial amputations of middle and ring fingers. (C) Preoperative dorsal view showing a cleft in the skin and soft tissue between the index and middle metacarpals extending down to the CMCJ and continuing onto the axial-radial dissociation between the scaphoid and capitate. Postoperative radiographs (D, E) after open reduction and pinning. Six months postoperative dorsal (F) view.

Fig. 4 Type III carpal injury (patient 3)—preoperative radiographs (**A, B**) showing combined axial-radial and axial-ulnar dissociations with concomitant CMCJ dislocations of 1/2/3/4/5 and partial amputations of index, middle, and ring fingers. Postoperative radiographs (**C, D**) after open reduction and pinning. Nine months postoperative lateral views (**E, F**) showing functional grip and key pinch.

In patients 1 and 3, there was also an associated midcarpal dissociation. Typically, there are concomitant dislocations of the CMCJ and near-complete or complete traumatic amputations of the digits at or distal to the CMCJ. As a result, tendons are usually avulsed from their musculotendinous insertions rather than simple lacerations. These high-impact injuries also result in near multiple-level long-segment injuries to the accompanying digital nerves and arteries.

Discussion

Firework injuries to the hand are gaining increasing attention in the literature. Moore et al reported 22 patients with an average age of 9.3 years who suffered a total of 31 fractures (of the metacarpals and/or phalanges only), 19 amputations (2 at CMCJ, 12 at or distal to distal interphalangeal joint [DIPJ], 2 involving thumb interphalangeal joint [IPJ], and 3 distal phalanx of thumb) and 1 dislocation (DIPJ) during the period from December 1987 to December 1997.⁸ In another series of 58 patients, Matheron et al reported 30 (48%) patients with joint involvement or amputations but did not provide further details of the exact injuries.⁹ Recently, Gopalakrishnan et al reported 120 such patients (average 26 years; range, 6–58) treated between 2012 and 2015 and described thumb and digital amputations at the MCPJ and IPJ, and metacarpal and CMC fractures but without further details of carpal involvement, if any at all.¹⁰

In reviewing the literature, we have observed a trend toward increased reporting of severe firework hand injuries and believe that this may be due to a combination of improved awareness and diagnosis,¹¹ as well as greater access by members of the public to fireworks of increasing power.¹² Previously, MacKenzie et al described a predisposition to radial-side soft tissue injuries of the thenar eminence and first web space loss¹³ while Hahn et al suggested further bony involvement of either the thenar or hypothenar rays while sparing those located centrally.¹⁴ Philipson and Southern then described propagation of the blast proximally, which resulted in acute carpal tunnel syndrome, median nerve contusion, and devitalization of forearm muscles.¹⁵ More recently, Adhikari et al proposed a possible mechanism of injury incorporating the aforementioned descriptions with additional thumb CMCJ involvement as it is bi-saddle in configuration, and thus, the most mobile joint of the hand, with a tendency to dislocate dorsally due to the vector of blast injury.¹⁶ Additionally, it has been suggested that further involvement of the digits results from hyperextension at the MCPJ and IPJs where the volar plates are proximally unattached and fixed, respectively, leading to various degrees of partial or complete amputations.¹⁶

We believe that the complex carpal injuries observed in our series involve these pathologic mechanisms described, as well as that typically observed in axial carpal dissociations.⁴ This results in flattening of the carpal arch and radial or ulnar

(or both) sided disruption of the distal carpal row together with the corresponding CMCJs in a peri-capitate fashion. In type II cases, this can result in additional isolated carpal dislocations such as that of the trapezium-trapezoid (patient 5) and pisiform (patient 7); in type III cases, the accompanying metacarpals are affected as well such that the hand and wrist are essentially split into two separate columns (or three in combined axial-radial and axial-ulnar dissociations).

The combined axial-radial and axial-ulnar carpal dissociation is a particularly interesting and devastating form of injury that may have resulted from the firework being held exactly in the center of the base of the palm in the region of the CMCJs prior to exploding, resulting in the explosive force being directed distally as well as in a radial and ulnar trajectory, causing this pattern of injury. The dorsal component of the explosive force is reflected in an associated midcarpal dissociation. The incidence of combined axial carpal dissociations over a 16-year period was previously reported at 6.25% (1 in 16) for traumatic axial disruptions of the wrist,¹⁷ yet in our series, two (67%) of three patients with axial carpal dissociations had this pattern of injury.

Indeed, we would postulate that the pattern and severity of carpal injuries may also depend on how the firework sits in the hand prior to exploding. If the firework is held more ulnar in the hand, this may result in predominantly ulnar-sided injuries as was seen in patient 2. If the firework is held more distally, this may result in a type II injury instead.

The long-term sequela of such devastating injuries is dependent on the extent of concomitant soft tissue injury, especially that of the nerves.¹⁷ Often, these injuries may not be repaired due to other associated soft tissue and bony injuries that make amputation a more reasonable option. Two out of seven patients in the current series required peripheral nerve surgery in the form of interposition conduit repair of ulnar digital nerve of the thumb (patient 3) and median nerve allograft reconstruction of a transposed index finger (patient 5). Soft tissue coverage involved various modalities including a local flap (patient 1), fillet of finger flap (patient 2), groin flap (patient 5), and free flap (patient 6). As suggested by Philipson and Southern, the zone of injury is highly unpredictable,¹⁵ and hence, early free tissue transfers are not advisable. In a series of 27 patients, only 2 underwent acute microsurgical reconstruction and the authors advocated for a delayed-stage reconstructive phase during which procedures such as toe-to-hand transfers and free flaps be performed.¹⁸

Of concern, three patients in this series were young children who sustained devastating hand injuries. The tendency for children to sustain hand injuries related to fireworks has also been previously reported.^{8–10} This is a recurring issue that occurs particularly every of July 4. A concerted effort at patient education targeted at parents and children would probably do much to reduce the incidence and severity of these injuries.

Limitations of this study include a small sample size. However, fortunately, severe injuries to the hand such as these are mainly encountered once a year during July 4 and are not common. In addition, we did not measure functional

outcomes in these series as these are invariably bad. Following severe fireworks injuries to the hand, a bad outcome with multiple digit amputations and a stiff hand is the norm due to the extensive blast injury that often results in multiple level injuries to bone and soft tissue. More often, patients end up with a nonfunctional hand (patient 7) rather than a functional hand with retained grip and key pinch (patient 3). Rather, the aim of this study is to highlight the patterns of bony injuries to the carpus and hand that are highly unusual and may only be caused by a concentrated localized blast injury, in our series, resulting invariably from a firework exploding in the hand. Nevertheless, this series is, to the best of our knowledge, the first in the literature to describe and analyze, in detail, the pattern of bony injuries involving the carpus and hand in severe firework-related hand injuries. Understanding and predicting the pattern of injury to the carpus and hand after severe fireworks injuries may help in patient education to prevent and reduce the severity of these injuries.

Note

This study was reviewed and approved by the ethics committee of our hospital, and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Funding

None.

Conflict of Interest

None.

References

- 1 Canner JK, Haider AH, Selvarajah S, et al. US emergency department visits for fireworks injuries, 2006–2010. *J Surg Res* 2014;190(1):305–311
- 2 Saucedo JM, Vedder NB. Firework-related injuries of the hand. *J Hand Surg Am* 2015;40(2):383–387
- 3 Hazani R, Buntic RF, Brooks D. Patterns in blast injuries to the hand. *Hand (NY)* 2009;4(1):44–49
- 4 Herzberg G. Perilunate and axial carpal dislocations and fracture-dislocations. *J Hand Surg Am* 2008;33(9):1659–1668
- 5 Ng ZY, Askari M, Chim H. Approach to complex upper extremity injury: an algorithm. *Semin Plast Surg* 2015;29(1):5–9
- 6 Ng ZY, Salgado CJ, Moran SL, Chim H. Soft tissue coverage of the mangled upper extremity. *Semin Plast Surg* 2015;29(1):48–54
- 7 Kuo LC, Chen SW, Lin CJ, Lin WJ, Lin SC, Su FC. The force synergy of human digits in static and dynamic cylindrical grasps. *PLoS One* 2013;8(3):e60509
- 8 Moore RS Jr, Tan V, Dormans JP, Bozentka DJ. Major pediatric hand trauma associated with fireworks. *J Orthop Trauma* 2000;14(6):426–428
- 9 Matheron AS, Hendriks S, Facca S, Liverneaux PA. Hand injuries due to firework devices: a series of 58 cases. *Chir Main* 2014;33(2):124–129
- 10 Gopalakrishnan R, Shivakami T, Sugapradha GR. Prevalence and patterns of cracker blast injuries of the hand. *Int Surg J* 2016;3:831–836
- 11 Reinsmith LE, Garcia-Elias M, Gilula LA. Traumatic axial dislocation injuries of the wrist. *Radiology* 2013;267(3):680–689
- 12 Sprick M. This fourth of July, let's leave the fireworks to the professionals. Available at: <https://www.safekids.org/blog/fourth-july-lets-leave-fireworks-professionals>. Accessed July 15, 2016

- 13 MacKenzie DN, Green JA, Viglione W. Firecracker injuries to the hand. *Med J Aust* 2001;174(5):231–232
- 14 Hahn P, Brederlau J, Krimmer H, Lanz U. Explosion injuries of the hand Spatial relationship and injury pattern. *J Hand Surg [Br]* 1996;21(6):785–787
- 15 Philipson MR, Southern SJ. The blast component of firework injuries—not to be underestimated. *Injury* 2004;35(10):1042–1043
- 16 Adhikari S, Bandyopadhyay T, Sarkar T, Saha JK. Blast injuries to the hand: pathomechanics, patterns and treatment. *J Emerg Trauma Shock* 2013;6(1):29–36
- 17 Garcia-Elias M, Dobyns JH, Cooney WP III, Linscheid RL. Traumatic axial dislocations of the carpus. *J Hand Surg Am* 1989;14(3):446–457
- 18 Logan SE, Bunkis J, Walton RL. Optimum management of hand blast injuries. *Int Surg* 1990;75(2):109–114