Firework Injuries of the Hand: An Analysis of Treatment and Health Care Utilization

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Abstract

Background: Firework injuries to the hand can be devastating due to the explosive and ballistic nature of these devices. The aim of this study was to describe the injury and treatment characteristics of patients requiring surgery for firework-related hand injuries and to investigate which factors are associated with an increased utilization of health care resources. **Methods:** A retrospective chart review of patients undergoing surgery for firework-related hand injuries at two American College of Surgeons level I trauma centers between 2005 and 2016 was performed. Twenty cases were identified. These patients were evaluated for demographics, injury characteristics, number and types of surgical interventions, length of stay, and utilization of health care resources. Bivariate analyses were performed to investigate which factors were associated with increased consumption of health care resources. **Results:** Injuries ranged from digital nerve injuries to traumatic amputation. Patients underwent a median of 3 surgical operations. More than half the patients underwent flap or skin graft coverage of a soft tissue defect. The median length of hospital stay was 7 days. Factors found to be associated with an increased utilization of surgical and hospital resources included a first web space injury, thumb fracture, and traumatic amputation of any digit. **Conclusions:** The morbidity inflicted by firework injuries to individual patients is substantial. Patients with severe injuries undergo a median of three surgical operations and have a long duration of initial hospital stay. Knowing which factors are associated with an increased utilization of resources can help prognosticate these preventable injuries.

Keywords: hand injuries, firework, amputation, traumatic, trauma centers, length of stay, thumb, anatomy, surgery, specialty

Introduction

The US Product Safety Commission estimates that fireworks were involved in 12,900 injuries treated in US emergency departments in 2017.¹ The most commonly affected anatomic areas were the hand, wrist, and digits, which accounted for nearly one-third of all injuries. While only a small fraction of these cases undergo operative intervention, those that do require surgery can result in life-altering disability.²

Firework injuries to the hand can be devastating due to the explosive and ballistic nature of these devices. Patients often have a combination of fractures, traumatic amputations, and soft tissue injuries.^{3–5} While the global impact of firework injuries has not been specifically investigated, similar devastating hand injuries often have detrimental effects on quality of life, psychological health, and productivity.^{6,7}

Previous studies have investigated firework injuries to all anatomic areas in large populations.^{8–13} Most of these reports have discussed superficial burns and other injuries that do not specifically involve the surgical management of

hand injuries. The few studies that have focused on severe hand injuries have described the complex patterns of injury and the operations required to treat the injuries.^{3,5,14–17} While these studies have informed us about the injuries associated with fireworks, they have not fully described the extent of surgical and hospital resources consumed following these injuries or which factors are associated with greater resource utilization.

The aim of this study was to describe the injury and treatment characteristics of patients requiring surgery for

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Figure 1. Distribution of injuries based on month, with most injuries clustered around the summer months and July 4 holiday and a minority of injuries occurring around the New Year and other months.

firework-related hand injuries and to investigate which factors are associated with an increased utilization of health care resources.

Methods

After institutional review board approval, we used *Current Procedural Terminology* codes to identify all patients with vascular, skeletal, tendon, nerve, or amputation injury to the digits or hand between January 1, 2005, and December 31, 2016 (Supplemental Material 1). This database queried two level I trauma centers in Massachusetts, a state where fireworks have been banned for consumer purchase since 1943.¹⁸ We reviewed the medical records to identify patients with firework-related hand injuries who underwent operative management.

We evaluated patient-related demographic factors (age, sex, occupation [manual laborer vs nonmanual laborer], tobacco use). Patients were defined as “manual laborer” based on the job description provided in their medical record. We also collected specific details of the injury (month of incident, transfer from outside hospital, dominant hand affected, unilateral vs bilateral injury, fractures, traumatic amputations), treatment parameters (number and types of interventions), and the utilization of other health care resources (length of stay, number of consultations to other services, imaging, number of clinic visits).

Data were analyzed with STATA Version 13.0 (Stata-Corp, College Station, Texas). We described categorical variables with frequencies and percentages and continuous variables with means and standard deviations (SDs) or medians and interquartile ranges (IQRs), depending on

Table 1. Injury Characteristics.

Bilateral hand injury, Number (%)	8 (40)
Dominant hand injury, Number (%)	15 (75)
Patients with thumb fracture, Number (%)	14 (70)
Patients with other digital fracture, Number (%)	18 (90)
Number of digits with fractures, mean (SD)	2.8 (1.7)
Patients with thumb amputation, Number (%)	9 (45)
Patients with other digital amputation, Number (%)	9 (45)
First web space injury, Number (%)	13 (65)
Suspicion for compartment syndrome, Number (%)	3 (15)
Patients with additional (nonhand) injury, Number (%)	9 (45)

normality. Associations between injury characteristics, such as the presence of thumb fracture, and length of stay or number of surgeries were analyzed using the Wilcoxon rank sum test. A value of $P < 0.05$ was considered statistically significant.

Results

Demographics

Between 2005 and 2016, we identified 20 patients who underwent operative treatment for firework-related injuries of the hand. All but one patient were men ($n = 19$; 95%). The mean age was 32 ± 12 years, and most patients worked as manual laborers ($n = 11$; 65%). Despite laws banning the sale of fireworks within our state, most injuries occurred in our state ($n = 15$; 75%) compared with neighboring states where the purchase of fireworks is legal. The most common type of firework was a mortar ($n = 6$; 30%), followed by firecrackers ($n = 4$; 20%), M-80s ($n = 3$; 15%), and bottle rockets ($n = 3$; 15%). One injury (5%) was caused by a Roman candle, and another (5%) was caused by sparklers placed within a glass container, resulting in shrapnel-like injury. In 2 cases (10%), the firework type was not specified. Outside hospital transfers accounted for 65% of patients. Most injuries occurred within the month of July ($n = 12$; 60%), and 25% occurred outside the summer months ($n = 5$; Figure 1). The median follow-up time was 14 months (IQR: 4.9-32 months).

Injury Characteristics

Most patients ($n = 15$; 75%) suffered an injury to their dominant hand, with 40% ($n = 8$) suffering a bilateral hand injury (Table 1). Ninety percent of patients ($n = 18$) sustained at least one metacarpal or phalangeal fracture, with the thumb being the most commonly fractured digit ($n = 14$; 70%). The mean number of digits sustaining at least one fracture was 2.8 ± 1.7 . Half the patients experienced traumatic amputation of at least one digit, with 45% of patients ($n = 9$) suffering amputation of the thumb

Figure 2. Locations of traumatic amputations among 31 total amputations in 20 patients.

(Figure 2). Of the 9 patients with a thumb amputation, most ($n = 4$) had an amputation at the level of the distal phalanx, followed by the metacarpal ($n = 3$) and the proximal phalanx ($n = 2$). Soft tissue injury of the first web space occurred in 65% of patients ($n = 13$).

Almost half ($n = 9$; 45%) the patients suffered additional (nonhand) injuries. These included burns to the chest ($n = 6$), face ($n = 4$), abdomen ($n = 3$), thigh ($n = 1$), back ($n = 1$), axilla ($n = 1$), scrotum ($n = 1$), corneal abrasion ($n = 1$), and tympanic membrane damage ($n = 4$).

Treatment and Health Care Utilization

Most patients ($n = 13$; 65%) underwent surgical debridement and bony fixation. Sixty-five percent of patients ($n = 13$) also underwent soft tissue coverage with either a flap or a skin graft (Figure 3). In addition, one patient underwent replantation of the right index finger, whereas another patient ultimately underwent a toe-to-thumb transfer.

Patients underwent a median of 3 (IQR: 2-4; range: 1-10) surgical operations for their injuries (Table 2). Patients with a first web space soft tissue injury had a median of 4 (IQR: 2-6) operations, whereas patients without web space injury had a median of 1 (IQR: 1-2) surgery ($P < .01$). Other factors associated with a higher number of operations included fracture of the thumb (4 vs 1 surgery, $P < .05$), thumb amputation (4 vs 2 surgeries, $P < .05$), amputation of another digit (4 vs 2 surgeries, $P < 0.05$), or suspicion of compartment syndrome (6 vs 2 surgeries; $P < .05$; Table 4).

The median length of initial hospitalization for each patient was 7 days (IQR: 3-14 days; range: 2-20 days; Table 3). Patients with a first web space injury had a median stay of 8 days (IQR: 5-14 days), whereas patients without had a median stay of 3 days (IQR: 2-3 days) ($P < .05$). Traumatic amputation of any digit was also predictive of a longer length of stay (10 vs 3.0 days, $P < .05$; Table 4). While hospitalized, a median of 4 other services outside the primary surgical team was consulted (IQR: 2-6 services). These were most often occupational therapy, pain service, and burn service. Throughout their hospitalizations and follow-up, patients underwent a median of 5 radiographic procedures (IQR: 3-9 radiographic procedures). Thirty-five percent of patients ($n = 7$) underwent a computed tomographic scan, and 20% ($n = 4$) underwent an arteriogram. Most patients ($n = 12$; 60%) required home care services upon discharge from their initial hospitalization. The median number of postoperative clinic visits was 6.5 (IQR: 5-13 visits).

Discussion

This study describes the injury and treatment characteristics of patients requiring surgery for firework-related hand injuries and the factors associated with increased utilization of health care resources. The morbidity inflicted by firework injuries to individual patients is substantial, even in states where commercial fireworks are illegal. This study demonstrates that: (1) patients with severe firework injuries undergo a median of three operations; (2) more than half of patients can be expected to undergo flap or skin graft coverage of a soft tissue defect; (3) firework injuries are associated with a long mean length of stay (7 days); and (4) factors associated with an increased utilization of surgical and hospital resources include a first web space injury, thumb fracture, and traumatic amputation of any digit.

This study must be interpreted in light of its limitations. First, our institution is within the only state in the United States that has a legal ban on all consumer fireworks, and so our data may not be generalizable to all institutions. It is important to note, however, that many of the fireworks within this study are illegal in all or most other states (ie, M-80s, reloadable mortar shells, larger firecrackers), and previous data have suggested that it is these types of fireworks that are most likely to lead to a severe injury requiring hospitalization and extensive hand surgery intervention.^{1,19,20} Second, it is possible that patients with less severe firework injuries tend to present to local facilities, and our data are overrepresenting the more severe of cases. However, it is unlikely that the injuries severe enough to require the procedures described in this study were treated at non-level I trauma centers.

The close proximity of our institution to other states with more permissive firework regulations (eg, Maine, New Hampshire) likely allowed some patients within our study to

Figure 3. (a) Intraoperative photo of hand following traumatic amputation of thumb at mid-distal phalanx, index finger at middle phalanx, middle finger at proximal interphalangeal joint, and extensive soft tissue injury, including first web space injury, all secondary to a bottle rocket. (b) Hand after 17 months and 9 total surgeries, including 2 abdominal flaps, which allowed for (c) full composite fist.

Table 2. Treatment Characteristics.

Surgeries per patient, median (interquartile range)	3 (2-4)
Patients requiring pinning, Number (%)	13 (65)
Patients requiring flaps, Number (%)	9 (45)
Patients requiring skin grafts, Number (%)	9 (45)
Patients requiring replant, Number (%)	1 (5)

Table 3. Healthcare Utilization.

Length of initial stay in days, median (interquartile range)	7 (3-14)
Number of consults to other services, median (interquartile range)	4 (2-6)
Number of radiographs, median (interquartile range)	5 (3-9)
Patients with CT scans, Number (%)	7 (35%)
Patients with arteriograms, Number (%)	4 (20%)
Patients requiring home care services, Number (%)	12 (67%)
Number of post-op clinic visits, median (interquartile range)	6.5 (5-13)

purchase fireworks that are legal in those states, such as small firecrackers, mortars, and Roman candles. However, at least 30% of the fireworks within our study are illegal in all neighboring states (ie, bottle rockets) or illegal in all states within the country (ie, M-80s, large firecrackers). As all fireworks are illegal in our state, it is difficult to conclude whether a blanket ban on all fireworks has affected which fireworks cause severe injury from our data alone. In the description by Sandvall et al³ of 105 firework injuries, the proportion of injuries due to legal fireworks was much higher than the proportion of injuries due to illegal fireworks. It is interesting to

note that the ratio of their injuries due to mortars (legal in their state) to bottle rockets (illegal) was roughly 50:1, whereas in our study the ratio was 2:1. This suggests that the fireworks one has legal access to influences the proportion of severe injuries due to one type versus another.

The injuries within our population required a median of 3 surgeries, which is higher than that reported with other traumatic hand injuries. Our data corroborate previous studies of severe firework injuries and can be compared with some others.⁵ Sandvall et al² reported a mean of 1.6 surgeries for firework injuries, but 40% of the patients within their cohort did not undergo surgery and thus represent a different patient population. Similarly, Moore reported an average of 1.2 operations, but this cohort only represented hospitalized injuries and was not limited to those that required surgery.⁴ One can compare our data with general traumatic injuries that require revascularization, replantation, or completion amputation, which only require secondary surgery in about 25% of cases, or hand saw injuries requiring surgery, which undergo a mean of 1.2 to 1.7 surgical operations.^{21,22} In contrast to many other traumatic hand injuries, the ballistic nature of fireworks can commonly result in mutilating injuries that require staged or secondary procedures. The index operation is often focused on debridement, while secondary surgeries may incorporate microsurgical soft tissue coverage or other complex reconstruction. The contamination from explosive debris may lead to infection, and other complications such as scar contracture or nonunion/malunion can occur.

One of the most important aspects of injury that resulted in numerous operations was the high rate of first web space injury. Indeed, we found that patients with first web space

Table 4. Injury Characteristics Associated With Increased Utilization of Surgical and Hospital Resources.

Injury Characteristic	Median number of surgeries			Median length of stay, d		
	With	Without	P value	With	Without	P value
Bilateral hand injury	3.5	2.5	.13	6.5	6	.84
Outside hospital transfer	3	4	.35	8	3	.25
Transfer from out of state	3	2	.56	14	5	.11
First web space soft tissue injury	4	1	<.01	8	3	<.05
Thumb fracture	4	1	<.05	8	4	.09
Amputation of thumb	4	2	<.05	8	4	.21
Amputation of another digit	4	2	<.05	12	4	<.05

injuries had a 4-fold median increase in the number of surgeries required compared with patients without first web space injuries. The reason for this is likely explained by the importance of the first web space in facilitating proper thumb and prehensile function. Injuries to the region can result in an adduction contracture that impairs these crucial actions.²³ Contracture of the first web space is the most frequent indication for reconstructive surgery after burns to the hand.²⁴ Skin grafts may be sufficient but often have a tendency to contract; therefore, the use of local, regional, or free flaps is often warranted.²⁵⁻²⁸

Although firework injuries to the hand requiring operative intervention are still relatively rare, the individual costs per patient can be substantial. In a study of 22 pediatric firework injuries, Moore estimated the average hospital charge to be US \$11,582. However, this series included nonsurgical patients with an average of 1.2 surgical operations and an average length of stay of 4.3 days. In contrasting these figures with our median of 3 surgical operations and length of stay of 7 days, this US \$11,582 cost is likely an underestimation of the costs in our patients. In addition, this cost only represents direct hospital fees and does not incorporate cost from loss of productivity, which cannot be overlooked.⁶

Using the number of surgical operations and length of hospital stay as proxies, we were able to determine that certain injury characteristics may be associated with the degree of surgical care and health care resources a patient may require. Clinically, knowledge about the specific injury characteristics that may prolong the length of stay may help surgeons to prognosticate and predict which patients may require a greater extent of care. Future research within this arena is necessary to better prognosticate outcomes following these devastating injuries.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation

(institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was not obtained from patients in this study due to its retrospective noninterventive nature, per our institutional guidelines.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: NCC discloses that he is a consultant for Flexion Medical and Miami Device Solutions and is a lecturer for DePuy Synthes. KRE is a consultant for AxoGen and Integra. Mr RO and Dr SO have nothing to disclose.

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