

Blast Injury to the Hand: Assessing the Injury Pattern and Functional Outcome of the Thumb

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Background: In the United States, approximately 30% of about 10,000 annual blast injuries involve the hand, causing a broad spectrum of injury severity. The first web space is typically most severely affected. As the carpometacarpal (CMC) joint is critical to the unique function of the thumb, we evaluated typical patterns of injury to this joint, subsequent salvageability and functional outcomes of the thumb.

Methods: We conducted a retrospective chart review on patients with blast injuries to the hand from January 1995 through July 2019 and excluded penetrating trauma. We assessed hand function as reported in occupational therapy records. Injury severity was classified independently by structures.

Results: Twenty-one patients were included, two with bilateral injuries, for a total of 23 hands. Eighteen patients had injuries to one or both thumbs, for a total of 20 thumbs evaluated. Average follow-up was 1.58 years. Most injuries qualified as severe in at least one category: soft tissue, neurovascular, or bone/joint. All 10 CMC joint dislocations required surgical fixation and pinning. Eight patients had applicable occupational therapy notes available. Severely injured thumbs had statistically significant decreased range of motion (ROM) at the interphalangeal joint, metacarpophalangeal joint and with radial abduction compared to mildly injured thumbs (*P* value 0.02, 0.03, 0.04, respectively).

Conclusions: Blast injury to the hand often results in severe deficits, frequently affecting thumb functionality and irreversibly altering occupational capabilities. Half the patients studied had severe damage to the thumb CMC joint. Objectively, severely injured thumbs had significantly worse ROM than mildly injured thumbs. (*Plast Reconstr Surg Glob Open* 2021;9:e3767; doi: [10.1097/GOX.0000000000003767](https://doi.org/10.1097/GOX.0000000000003767); Published online 22 September 2021.)

INTRODUCTION

Every year in the United States between 9000 and 12,000 people present to an emergency department with injuries caused by firework explosion. This rate of injury has been stable throughout the 2000s with young males making up the majority of these injuries (64%).¹ According to the Consumer Product Safety Commission, the extremities were involved in 56% of all injuries in

2018, and of these injuries, half involved the hands and fingers.¹ Hand injuries range in severity from mild soft-tissue damage or superficial burns to destruction of bone, neurovascular structures, and skin/muscle loss requiring flap reconstruction or amputation.²⁻⁴

Multiple studies have described injury patterns after blasts, which have shown that severity of injury typically is most severe in the thumb ray and first web space, radiating outward and ulnar.⁵⁻⁷ Typically, these studies have focused on the hand/finger overall injury pattern, with a recent study characterizing carpal injuries.⁸ Our study focuses specifically on the thumb ray and its carpometacarpal (CMC) joint. As the CMC joint is critical to the unique function of the thumb and the thumb is responsible for 40%–50% of total hand function,^{9,10} we set out to evaluate the patterns of injury to this joint, subsequent salvageability of the thumb, and objective range of motion (ROM) measurements of thumb after blast injuries.

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METHODS

Our institutional review board approved our retrospective chart review. Utilizing our institution's clinical research data warehouse database, we queried for all patients who presented to our institution with blast injury to the hand from January 1995 through July 2019 and were treated by our providers. Study parameters excluded patients under the age of 18 and those injured from gunshots or other penetrating trauma. Patient demographics, hand dominance, injured hand, and subsequent surgeries were recorded. We evaluated all initial and post-reduction x-rays when available and compared them to radiology reports. Operative reports and initial consultation notes, together with the x-ray findings, provided a record of all injured structures. We evaluated hand function using occupational therapy records to assess active thumb ROM (AROM). For the purposes of this article, we defined AROM as the maximum achieved purposeful movement along the two-dimensional flexion/extension arc at each joint, measured in degrees, along with opposition. If the record included multiple measurements taken at different time points after injury, we used the most recent measurements in our calculations. If a patient had a revision amputation, the affiliated joint was not included in the analysis as this would skew the average ROM. Statistical analysis utilized two-sample, unpaired T-testing with one-tailed *P* values. We considered *P* values of less than 0.05 to be significant.

For each patient, we recorded three aspects of thumb injury: soft-tissue, neurovascular, and bone/joint injuries (Table 1). Soft-tissue injury was characterized as mild if there were lacerations/superficial burns, moderate if there was loss of tissue or avulsion, or severe if there was damage to underlying intrinsic muscles or tendons. Neurovascular severity was characterized as mild if no obvious neurovascular injury occurred, moderate if nerve or artery was damaged but finger remained perfused and vascular/nerve repair was not needed, or severe if repair was required or attempted. Bony/joint severity was characterized as mild if there were distal and/or proximal phalanx fractures only, moderate if fractures involved the metacarpal, or severe if there was fracture/dislocation of the CMC joint or scaphotrapezotrapezoid (STT) disruption. On occasion, we encountered severe ulnar hand injuries with sparing of the thumb. In each of these instances, the thumb was not considered injured, even though the patient had a severely damaged ulnar hand. These thumbs were not included in our analysis. Each injured thumb was given a score from one to three for each injury category based on Table 1. The scores from each category were

added together to give a total score, which ranged from three to nine per injured thumb. We considered overall thumb injury to be severe if any of the three aspects of thumb injury had a score of three.

RESULTS

A total of 21 patients had blast injuries to the hand. Twenty of the patients were male with an average age of 39 years (range 21–63) (Table 2). The dominant mechanism of injury was firework explosion, representing 20 patients. The remaining patient sustained a blast injury from an explosive intended for target shooting. Thirteen patients (61.9%) experienced the injury between the dates of July 2 and July 4, with an additional three patients injured on other dates in July. The average follow-up time was 1.58 years. Nineteen of the injuries were unilateral, affecting the dominant hand 57.9% of the time (*n* = 11). Two patients had bilateral injuries, accounting for a total of 23 injured hands. All but one patient required operative intervention, with patients requiring an average number of three procedures (range 0–11) (Table 2). Eight free flaps provided coverage of five hands. (See table, Supplemental Digital Content 1, which displays free flap coverage for blast injury to the hand—"Acute" indicates that the procedure was done during initial admission. "Delayed" indicates that it was done during a separate admission, <http://links.lww.com/PRSGO/B754>.)

Isolating the analysis to thumb injuries, 18 patients had injuries to one or both thumbs (85.7% of patients), affecting 20 of 23 total hands (87% of hands). Three patients with blast injuries did not have injury to the thumb and therefore were excluded from analysis. Severe injuries occurred in 12 thumbs based on soft tissue (60%), 10 thumbs based on neurovascular injury (50%), and 11 thumbs based on bony/joint injury (55%). Injury severity in the thumb was dichotomous—either mild (*n* = 7) or severe (*n* = 13). Figure 1 stratifies total injury scoring for the thumb, which again showed a dichotomous distribution with all but two thumbs having either a score of three or at least seven. Severely injured thumbs required more surgeries on average compared to mildly injured thumbs (3.5 versus 1.3). Additionally, in the severely injured thumbs, the majority had a severe rating in all three categories (69.2%) (Fig. 2). Looking specifically at thumb CMC joint injuries, there were 10 CMC dislocations (50% of injured thumbs). All 10 CMC dislocations required surgical fixation and pinning. Table 3 characterizes the number of fractures throughout the hand in patients with injured thumbs. Five thumbs required some form of revision amputation. Three avascular thumbs were salvaged

Table 1. Blast Injuries to the Thumb Classified by Structure and Severity

	Mild	Moderate	Severe
Soft tissue	Superficial lacerations/burns	Loss of tissue or avulsion	Damage to underlying intrinsic muscles or tendons
Neurovascular	No obvious neurovascular injury	Neurovascular damage but perfusion was maintained, and no repair needed	Repair required or attempted
Bony/joint	Proximal and/or distal phalanx fractures only	Fractures involved the metacarpal	CMC joint dislocation or STT disruption

Table 2. Demographics of Study Patients with Blast Injuries to the Hand

	N (%)
Total patients	21 (100)
M	20 (95.2)
F	1 (4.8)
Avg. age	38.9
HTN	1 (4.8)
DM	2 (9.5)
Tobacco	
Y	4 (19.0)
N	11 (52.4)
Unknown	6 (28.6)
Dominant hand	
R	19 (90.5)
L	1 (4.8)
Unknown	1 (4.8)
Injured hand	
R	10 (47.6)
L	9 (42.9)
Bil	2 (9.5)
Injured dominant	13 (61.9)
Avg. surgeries	3 (0-11)

by revascularization. None of the revascularized thumbs required emergent take backs to the operating room for anastomotic failures.

Occupational therapy notes were available for only nine patients with thumb injuries (50%). One of these patients did not undergo therapy until after a toe-to-thumb transfer and was excluded. The following AROM data represents averages of the eight remaining patients (Table 4). There were four patients with a mild injury severity score and four with a severe injury score. At the interphalangeal (IP) joint, average AROM was 18 degrees (range: 15–20 degrees) in the severely injured thumbs and 54 degrees (range: 30–80 degrees) in the mildly injured thumbs, which was statistically significant (*P* value 0.02). For the metacarpophalangeal (MCP) joint, the severe category achieved an average AROM of 18 degrees (range: 0–45 degrees), whereas the mild

category averaged 46 degrees (range: 30–60 degrees) (*P* 0.03). Severely injured thumbs achieved an average of 23 degrees of radial abduction (range: 12–45 degrees) compared to 43 degrees (range: 35–50 degrees) in mildly injured thumbs (*P* 0.04). Similarly, severely injured thumbs fared worse in palmar abduction, with an average of 24 degrees (range: 0–45 degrees) versus the 43 degrees (range: 35–50 degrees) exhibited by the mildly injured thumbs (*P* 0.07). The patient who underwent complete amputation of the thumb had a toe-to-thumb transfer performed 23 months after injury. After toe transfer, he achieved 40 degrees of flexion at the reconstructed MCP joint. We also attempted to look at sensory data in the patients with ROM data; however, Semmes–Weinstein testing was limited to three of the severe thumbs and only two of the mild thumbs. The severe thumbs had a wider range of Semmes–Weinstein values (2.83–4.56), compared to the mild thumbs (2.44–3.61).

DISCUSSION

Our study focuses on characterization of blast injuries to the thumb ray at a single level-I trauma center. Prior studies have previously described overall firework injury demographics,^{11,12} blast demographics and injury patterns to the hand,^{2,3,5–7,12–14} and wrist.⁸ We investigated firework injury to the thumb and its joints, especially the effect on the CMC joint, and showed that more severe injury leads to objectively decreased ROM. As blast injuries typically cause complex injury involving all structures of the hand, we feel that classifying thumb injury categorically into soft tissue, neurovascular, and bony/joint allows a more comprehensive breakdown of thumb injury pattern.

Based on our severity index, injuries were bimodal, typically either mild or severe in all three categories. Although we considered any thumb injury with at least one category having a score of three to qualify as a severely injured thumb, by extrapolating our scores the

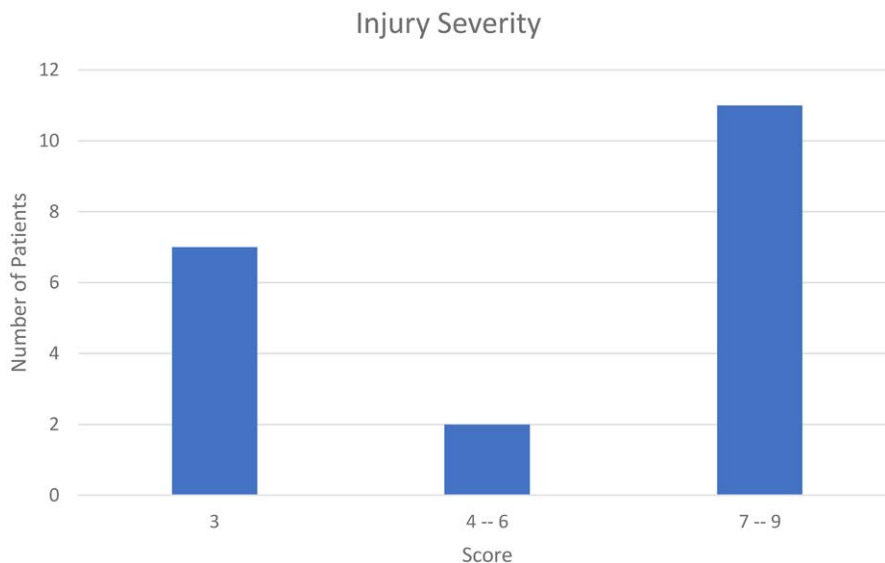


Fig. 1. Injury severity scoring: 1 point for mild, 2 points for moderate, 3 points for severe injuries per category. Minimum score of 3 and maximum of 9.

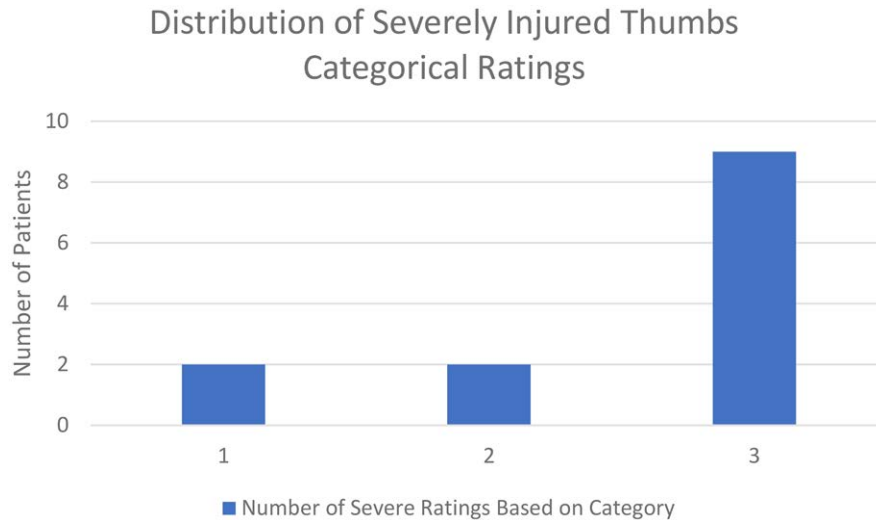


Fig. 2. Distribution of severely injured thumbs (n = 13) based on the number of severe categorical ratings. Most patients with a severe thumb injury had all three categories rated as severe.

distribution remained essentially bimodal when we looked at total injury scores (Fig. 1). We feel that this justifies our consideration of a severely injured thumb with a score of three in any injury category. We did not have comprehensive information on the types of fireworks causing these injuries; however, commercially available fireworks tend to be either low-powered or high-powered.¹³ It makes intuitive sense that mild injuries tended to be caused by the lower-powered fireworks and vice versa. That being said, a high-powered missile thrown from the hand and exploding some distance away could cause less severe injury; however, the typical radial to ulnar pattern would likely not be seen as described below.

Multiple studies have shown that the typical hand injury pattern caused by blast injury begins with the most severe damage to the thumb and first web space, with decreasing severity for the ulnar digits.^{2,5,13} Most patients are injured when the device explodes before they can release the projectile, which is held between the thumb and index finger. The blast forces the thumb into hyperextension and palmar abduction, effectively splitting the first web space. The thumb CMC joint tends to dislocate dorsally, as this is a very mobile and relatively unstable saddle joint. The CMC joints of the fingers are anatomically more stable, and the blast force tends to produce more metacarpal fractures rather than joint dislocations. The proximal attachments of the MCP volar plate are weak and because of this if dislocation occurs it is typically dorsal. The IP joints have a tightly adherent volar

plate, both proximal and distal, leading to a higher proportion of amputations at these levels. At this distal level, the intrinsic muscles are often disinserted or transected as well. As expected, the soft-tissue and neurovascular damages are typically more severe on the palmar aspect of the hand/digits as well.^{2,5,13}

The thumb CMC joint is critically important for opposition. Opposition is a complex movement that relies on a combination of both abduction/adduction and flexion/extension arcs. The CMC saddle joint has a relatively loose capsule that allows for the critical freedom of movement.^{15,16} The important anterior oblique and ulnar collateral ligaments support the ulnopalmar portion of the joint, whereas the abductor pollicis longus tendon, which is in close contact with the radial collateral ligament, has multiple slips that support/cover the radial surface of the joint. The posterior oblique and intermetacarpal ligaments further support the dorsal, ulnar portion of the joint.^{15,16} The thenar muscles cover and protect the palmar aspect of the joint. There is a relative paucity of support over the dorsal portion of the joint, which explains the propensity for dorsal CMC dislocation with blast injuries.⁵

Dislocation of the thumb CMC is seen in fewer than 2% of injured hands^{17,18}; however, based on the nature of blast injuries, it is not unexpected that 50% of all injured thumbs and 76.9% of the severely injury thumbs had thumb CMC dislocation. One other severely injured thumb had complete destruction of the scaphoid, but

Table 3. Associated Fractures in Patients with Injured Thumbs

	Metacarpal	Proximal Phalanx	Middle Phalanx	Distal Phalanx
Thumb	2	3	X	6
Index	4	4	0	2
Middle	5	0	1	6
Ring	3	1	0	2
Small	0	1	1	0

Table 4. Average Active Range of Motion Measured in Degrees Compared Severe to Mild Injured Thumbs

	Severe, n = 4 (range)	Mild, n = 4 (range)	P value
IP	18 (15-20)	54 (30-80)	0.02
MCP	18 (0-45)	46 (30-60)	0.03
Radial abduction	23 (12-45)	43 (35-50)	0.04
Palmar abduction	24 (0-45)	43 (35-50)	0.07

somehow that CMC joint was not disrupted. Our data support that thumb CMC dislocations rather than metacarpal fractures predominate in blast injuries. This is highlighted in Table 3 as there was only one thumb metacarpal fracture. The index and middle finger metacarpals were more commonly fractured, both having four fractures. CMC dislocations were treated by reduction and percutaneous pinning. Even though anatomic reduction was achieved, there was significantly decreased ROM compared to the mildly injured thumbs (Table 4). Given the complex ligamentous anatomy surrounding the thumb CMC, dislocation is not without consequence: even after anatomic reduction and extensive hand therapy there is continued ankylosis that we believe is due to periarticular arthritis.

Dislocation of either the trapezium or trapezoid requires a major force and is a marker of severe blast injury. The trapezoid articulates with four bones and has multiple short, stout ligamentous attachment to the adjacent base of index metacarpal, capitate, trapezium and scaphoid. It is wedge-shaped with the wide portion situated dorsally, which helps explain that the trapezoid will tend to dislocate dorsally. The multifaceted articulations result in geometry that resists dislocation. The trapezium has strong attachments through both dorsal and volar scaphoid, trapezial and trapezio-trapezoid ligaments. These are much stronger than the attachments to the base of the metacarpal at the CMC joint, which explains why there are frequent dislocations at this joint as opposed to the STT joint¹⁹ (Fig. 3).

The nature of severe blast injury leads not only to bony/ligamentous injury, but typically to severe soft-tissue injury of the skin and intrinsic musculature. Muscle avulsion, which correlates with CMC dislocation or trapezium fractures/dislocation makes anatomic sense. The flexor pollicis brevis, opponens pollicis, and abductor pollicis brevis have their origins at either the trapezium or scaphoid.¹⁹ The adductor pollicis originates from the index and middle metacarpal as well as the intermetacarpal ligaments. With blast injuries, the sudden, forceful radial supination of the thumb and subsequent CMC dislocations avulse these muscles. The first dorsal interosseous is also subjected to sudden force and may fail as the thumb ray is abducted. Muscle avulsion/injury leads to extensive scarring surrounding the CMC joint resulting in greater stiffness, even with anatomic reduction. In addition to intrinsic musculature damage, it is not uncommon to have flexor pollicis longus (FPL) tendon avulsion from the muscle belly as well (Figs. 4 and 5). These soft-tissue injuries can require complex coverage with free flaps (Fig. 5) (SDC 2–5, Video 1). (See figure, Supplemental Digital Content 2, which displays AP (A), oblique (B), and lateral (C) of severe blast injury of the hand with nearly amputated thumb. The thumb CMC joint has dorsal dislocation and distal phalanx amputation. The index metacarpal is also dislocated dorsally. The STT appears to be intact even with massive disruption of the thumb and index finger, <http://links.lww.com/PRSGO/B755>.) (See figure, Supplemental Digital Content 3, which displays patient from Supplemental Figure 1 with severe blast

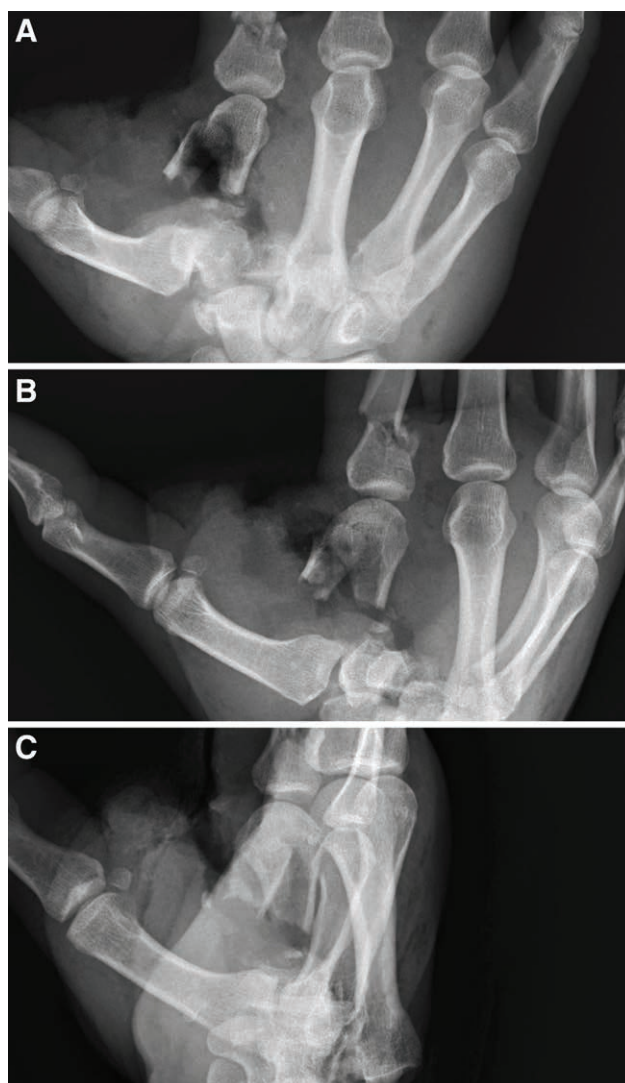


Fig. 3. Initial plain films of an injured hand after blast. A, AP, oblique (B), and lateral (C) x-ray of blast injury showing thumb CMC dislocation with fractured trapezium and dislocated trapezoid. The thumb CMC is dorsally dislocated. In addition, the index finger metacarpal has a comminuted fracture. The middle finger metacarpal CMC is dislocated dorsally as can be seen in (C).

injury to the hand. The trapezium is visible in the base of the wound and there is extensive intrinsic damage. Notice the dorsal dislocation of the thumb CMC joint. The thumb is devascularized and required revision amputation. <http://links.lww.com/PRSGO/B756>.) (See figure, Supplemental Digital Content 4, which displays A, patient from Supplemental Figures 1 and 2 who required a large anterolateral thigh flap to cover his thenar eminence, ring and middle fingers. B and C, After healing his ALT, the second toe-to-thumb transfer was performed to help improve the function of his hand as his native thumb required revision amputation through the MCP at the initial blast injury, <http://links.lww.com/PRSGO/B757>.) (See figure, Supplemental Digital Content 5, which displays A, patient with severe blast injury to the hand involving the first web-space with obvious intrinsic disruption and devascularized

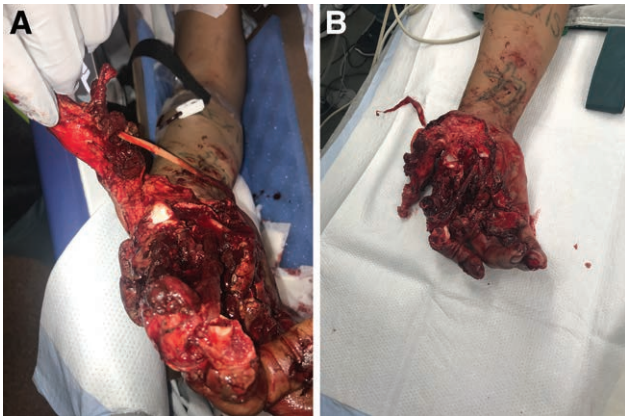


Fig. 4. Soft tissue damage after blast injury. A, Severe blast injury to the right hand with exposed trapezium and avulsed FPL tendon. B, Same hand with a better view of the severe damage that radiates from the first webspace. Notice the less severe damage to the more ulnar digits. The thumb was devascularized and required amputation.

thumb requiring revascularization. B, Same patient showing well-healed free ALT for soft-tissue coverage, <http://links.lww.com/PRSGO/B762>.) (See Video 1 [online], which displays the patient from Supplemental Figure 4 showing active ROM. His opposition is poorer compared to the mild injured thumbs.)

Blast force leads to direct injury to the vessels regardless of dislocation or fracture. Rapid displacement of the thumb proximal phalanx and supination of the metacarpal cause elongational stress on the digital arteries and the princeps pollicis, which can result in avulsion or intimal damage leading to thrombosis. The associated muscle injury further reduces collateral circulation, which further exacerbates scarring. Some reports suggest that acute ligament reconstruction may improve stability of the joint and lead to decreased propensity for

chronic CMC pain and instability.^{17,20,21} In these reports, however, the injuries were not from blasts. In a blast injury scenario, we feel that closed reduction and pinning at the time of exploration is adequate, and ligamentous reconstruction, given the soft-tissue damage, is often not feasible. Chronic instability was not found in any of our severely injured patients due to periarticular scarring. Adhikari et al⁹ commented in their study that mildly injured hands had near normal ROM and severely injured hands had extensive postinjury stiffness, but they did not provide any objective data. Our data show significantly greater ROM in mildly injured thumbs compared to the severely injured thumb.

For avascular thumbs from blast injury, revascularization is indicated. As the zone of injury is extensive, vein grafting is required from either the wrist or snuff box level. All three thumbs which required vein grafting survived and there were no anastomotic complications/take backs. Though stiff, the thumb can be utilized as a post which we feel is a better alternative to an amputation. This is difficult to quantify functionally; however, in our experience, these patients anecdotally perform better.

Our study is not without limitations. As these injuries are typically very complex, it is difficult to distill down similarities among the multitude of injuries. Patients were typically referred from outside hospitals, and there was incomplete information on the exact type of fireworks. In addition, the therapy documentation was not complete in all patients as they often returned to their home cities to receive postoperative care. The type and quality of therapy provided varied widely and documentation available was often limited. ROM data were often available in therapy notes, but there was limited data on pinch, grip, and sensation. Associated fractures of the thumb and adjacent digits likely affect functional outcomes; however, quantifying the long-term effect on ROM and other functional outcomes is difficult. Simple



Fig. 5. Pre-operative injury and post-operative flap coverage of severe blast injury. A, Volar view of severe blast injury to the right hand with avulsion of FPL tendon from muscle belly with severe damage to the intrinsic muscles. The thumb was also devascularized and required revascularization. B, Dorsal view of the same hand showing complete degloving of soft tissue from the entire right thumb with essentially sparing of the remaining hand. C, Lateral view of the same hand following coverage with lateral arm free flap. D, AP view of the same hand after coverage.

versus comminuted, extra versus intra-articular fractures likely have differing effects on ultimate hand function; however, more patients with ROM/functional data would be needed to elucidate these effects.

CONCLUSIONS

Blast injury to the hand often results in severe deficits, frequently affecting thumb functionality and irreversibly altering occupational capabilities. Half of the studied thumbs had severe damage to the CMC joint of the thumb. Objectively, severely injured thumbs had significantly worse ROM compared to mildly injured thumbs. Evaluation of the thumb CMC joint is important in these injuries, and further analysis of postinjury function may guide future treatment.

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