CURRENT CONCEPTS

Crush Injuries of the Hand

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Crush injuries of the hand are a rare but devastating phenomenon, with historically poor outcomes. A compressive force, usually caused by a high-energy mechanism such as a motor vehicle or industrial accident, crushes and transiently increases the pressures within the hand. This force acts on the incompressible blood in the vasculature and leads to a dramatic rise in tissue pressures and damage to multiple tissue types, including bones, blood vessels, nerves, and soft tissues. A wide zone of injury results from a delayed inflammatory reaction involving the zone bordering the crushed cells, which may initially belie the severity of the injury. As such, these injuries go on to produce tremendous inflammation and swelling, potentially followed by compartment syndrome or other vascular damage, infection, neurological injury, and tissue necrosis. Crush injuries with minimal skin disruptions can be particularly challenging to accurately diagnose and manage. This paper provides a review of the initial evaluation of hand crush injuries as well as short- and long-term management strategies. *(J Hand Surg Am. 2017;■(■):■−■. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

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CRUSH INJURIES TO THE HAND ARE a rare but devastating phenomenon, with historically poor outcomes.[1,2] A compressive force, usually caused by a high-energy mechanism such as a motor vehicle or industrial accident, crushes and transiently increases the pressures within the hand. This force acts on the incompressible blood in the vasculature and leads to a dramatic rise in tissue pressures causing damage to bones, blood vessels, nerves, and soft tissues.[3] A wide zone of injury results from a delayed inflammatory reaction involving the bordering zone, which may initially belie the severity of the damage. These injuries go on to produce tremendous inflammation and swelling, potentially followed by compartment syndrome, vascular damage, infection, neurological injury, and tissue necrosis.[4] Crush injuries with minimal skin disruption can be particularly challenging to accurately diagnose and manage. This paper provides a review of the initial evaluation of hand crush injuries as well as short- and long-term management strategies.

DIAGNOSIS AND INITIAL MANAGEMENT

Many such injuries are associated with high-energy trauma, and Advanced Trauma Life Support principles must be applied as necessary to preserve life over limb. The patient must be evaluated in a systematic fashion to avoid missed injuries.

History

Once the patient is stable, a pertinent medical history should be obtained with particular attention to injury timing and mechanism; the former is crucial in determining salvage versus amputation because

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devascularized muscle can only survive 4 to 6 hours of warm ischemia.[5] An understanding of the injury mechanism can help infer energy level of the crushing force and raise suspicion for occult injuries. Learning the patient's occupation, handedness, and comorbidities helps determine functional needs and goals. Although several scoring systems attempt to estimate outcomes, these do not accurately predict the need for amputation over salvage in upper extremity crush injuries.[4,6]

Clinical examination

The examination begins with an inspection, looking for wounds that may indicate open fractures, tendon or nerve injuries, or even an "exploded hand" as described by Graham.[3] In this constellation, the compressive force generates a predictable injury pattern, beginning with interosseous muscle extrusion through a tension failure of the skin, commonly in the first web space where the skin is weakest; this portends a grave prognosis.[3] Gross swelling and palmar convexity may be clues to impending compartment syndrome or fracture-dislocations.[1,3] A thorough neurological examination should assess the new baseline status of each nerve, including signs of acute carpal tunnel syndrome. In patients unable to cooperate, look for dry, red skin as a sign of sympathetic paralysis; if present, this usually indicates more serious nerve damage (as opposed to neurapraxia). Tendon function in all fingers and the thumb should be assessed, through both tenodesis and active motion of each joint, if possible. Most importantly, assess the hand for perfusion through pulses, capillary refill (especially dorsal paronychial tissue), warmth/color, and Doppler signals because vascular compromise will often determine operative urgency. Acute bleeding should be controlled, most frequently with direct pressure only because clamping can easily injure nearby nerves.

Knowledge of injury patterns assists in prompt and appropriate methodical evaluation. Graham[3] proposed that the "exploded hand" suffers a sequential pattern, beginning with extrusion of the thenar musculature (noted previously) as the thumb becomes coplanar with the hand, in addition to thumb ray dislocation and/or fracture. As the arches of the hand flatten, the force proceeds through metacarpal head−level dissociation and carpometacarpal (CMC) fracture-dislocation of rays II to V. The third stage involves the pericapitate transmission of forces, manifested by intercarpal ligament disruption. The fourth stage sees characteristic longitudinal fractures of the tubular bones. Finally, the fifth stage is neurovascular compromise, resulting in compartment syndrome.

The surgeon must be vigilant for signs and symptoms of compartment syndrome; with 10 separate muscular compartments, the hand poses a particular challenge (Fig. 1). Profuse edema and inflammation increase the volume within the fascial compartments, decreasing perfusion to soft tissues and nerves. Of the classic "5 Ps" of compartment syndrome (pain, pallor, paresthesias, pulselessness, and paralysis), only pain (both out of proportion to clinical examination findings and with passive stretch) is thought to present early enough to recognize and treat the pathology before deep tissue necrosis occurs.[1,7] However, even this conventional wisdom may be unreliable, as a study by del Piñal et al[1] investigating compartment syndrome in crushed hands showed a significant proportion of patients had no pain with passive stretch, perhaps due to concomitant neurological injury or masked by fractures. A rising analgesia requirement is a useful alternative in children and the unconscious. The classic intrinsic-minus position of hand compartment syndrome is also obscured by the significant swelling associated with crush injuries. In all cases of hand compartment syndrome following a closed crush injury, del Pinal et al[1] found that the thenar and first web space muscles were involved. In addition, Ouellette et al[8] showed that 15 of 17 patients (88%) were obtunded at the time of developing compartment syndrome. Because of the lack of reliability of clinical symptoms and serious implications of a missed diagnosis, the surgeon must have a low threshold for directly measuring compartment pressures.

Compartment pressures can be considered either in absolute terms or relative to the diastolic blood pressure. Whereas the value of absolute intracompartmental pressure needed for compartment syndrome has been debated (often 30 mm Hg or more) the relative pressure difference (ΔP) is accepted as more accurate. A study did not find any evidence delineating a particular ΔP causing reduced circulation in the upper extremities, but using lower extremity data, it is accepted that a ΔP less than 30 mm Hg for longer than 2 hours compromises perfusion and is more sensitive and specific than clinical signs.[9] The complication rates with delayed diagnosis are high and include long-term pain, dysfunction, and intrinsic contractures of the hand; thumb contractures are especially poorly tolerated.[2,10] Edema and bleeding can evolve over time, and as such, it is important to perform serial examinations. To minimize ischemia, early recognition and judicious action to relieve the elevated pressures are critical, including removing extrinsic compression,