High-Pressure Injection Injuries

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HIGH-PRESSURE INJECTION INJURIES to the upper extremity are rare, but often devastating. There are no randomized or comparative studies to guide treatment, so sound clinical judgment and surgeon experience are important.

DEFINITION

High-pressure injection injuries occur when equipment capable of achieving pressures sufficient to breach the human skin injects its contents into the human body, most commonly into the hand. The pressure required to penetrate intact human skin is commonly cited at 7 bar (7 × 10^5 N/m^2) or 100 psi. A careful review of that reference provides no source or justification for the number. Nevertheless, oddly, it is cited by multiple authors.

PRESSURE GUNS

High-pressure injuries are commonly incurred by high-pressure guns, which are capable of producing pressures exceeding 2,500 bar (35,500 psi). Most of these guns produce pressures around 2,000 to 12,000 psi. Grease guns produce pressures of 350 to 700 bar. Spray guns, used in the application of paint, lacquer, semifluid cement, hydraulic fluids, and solvents (paint thinner, turpentine, or gasoline), operate in the range of 200 to 500 bar, and diesel fuel injectors range from 140 to 400 bar. Water guns operate between 400 and 550 bar.

CLINICAL EVALUATION

An accurate history is elicited, including pressure of the injection gun, exact material injected, estimate of volume injected, and distance from gun to extremity. The patient is often inexperienced and has received poor education in proper use and the associated hazards. A thorough physical examination is conducted, including the entire upper extremity, documenting entry and, if present, exit wounds, assessing carefully the neurovascular examination of the digit or hand, tendon involvement, and crepitus. The entry wound is often just a small puncture; injected material can sometimes exude or is expressible. Often, pain is not present initially. In addition, the small size of the entry site might lead inexperienced patients to underestimate the true extent of the injury, resulting in devastating delay or inappropriate treatment (Fig. 1). Radiographs are helpful; in cases of air or radiodense materials, they can assess the extent of spread and deep tissue injury. Most of these injuries are work related, and accurate documentation is imperative, including whether safety training was provided for the employee.

Treatment should consist of broad-spectrum antibiotics, tetanus prophylaxis, and in most cases, surgical wide debridement for a true hand emergency. Literature on exact antibiotic regimens and efficacy or evidence is nonexistent. A commonly cited regimen is a first-generation cephalosporin and gentamicin.

Recently, Wong et al proposed a clinical classification system (mild, moderate, and severe), which they used to guide treatment (Table 1). They showed that
vigilant conservative treatment is possible for mild injuries, with acceptable clinical outcomes. They advocated prompt surgical debridement for moderate to severe injuries and for mild injuries that clinically deteriorated. Other authors have used this classification system as well and found it useful to guide treatment, although all patients in that series ultimately required surgical treatment.

A principle generally applicable to debridement is wide extensile exposure stopping at healthy tissue planes in the controlled operating room environment. In most cases, a repeat debridement is indicated to fully assess the extent of injury and viability of tissues. Further treatment depends on the intraoperative findings and needs to be individualized. Various authors have proposed open wound treatment, wound vacuum, delayed primary closure, heterodigital island flaps, cross finger flaps, and free toe pulp transfer. Early or late amputation is common and reasonable in the appropriate scenario. In 1968, Kaufman was disheartened with digit salvage attempts. In 1998, Lewis et al recommended early amputation for nonviable, ischemic digits upon presentation. Because these injuries are highly variable, there is no reference standard; thus, we propose that treatment be tailored to the situation with one of the aforementioned methods. The surgeon must use the method which in his hands will lead to the best outcome and most rapid recovery. The patient must be educated about the risk of disability and early amputation resulting from these devastating injuries.

The injury consists of a mechanical and a chemical component. Kaufman elegantly studied the mechanics of the injury in cadaveric hands by injecting wax at 750 psi. The part of the body subjected to injury has to absorb tremendous kinetic energy carried by the injected material. The typical puncture wound was exuding wax, localized distention was noted, superficial spread beneath the skin was always seen, whereas spread along deeper planes occurred, but it was variable and depended on the injection site as well as the exact course of the stream. The stream enters the skin along the line of fire until it hits a structure of sufficient resistance to deflect it (the flexor tendon annular pulleys, tendons, and bones). Therefore, spread preferably occurred in the subcutaneous plane and surrounded the neurovascular bundles. The weaker areas of the flexor sheath could be penetrated by the wax with injections over joints, but there were no intra-articular penetrations. Eccentric injection created a track lateral to the phalanx with heavy involvement of the extensor and large, ragged exit wounds, similar to gunshot wounds.

The injected material also distends the affected area, thus mechanically compressing vessels and nerves, and frequently also has a chemical noxious effect on the tissues, leading to vasospasm, occlusion of small vessels, and a secondary inflammatory effect.

The most informative article to date is the review by Hogan et al. The authors performed a retrospective analysis of all articles in English from 1966 to Decem-

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<tr>
<th>Severity</th>
<th>Nature</th>
<th>Treatment</th>
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<tr>
<td>Mild</td>
<td>Injected material is usually oil</td>
<td>Conservative during initial treatment period</td>
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<td></td>
<td>Relatively low-pressure injection</td>
<td>Close observation with antibiotics coverage</td>
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<tr>
<td></td>
<td>No treatment delay</td>
<td>± Steroid</td>
</tr>
<tr>
<td></td>
<td>Small area of involvement without proximal extension (confirmed with radiograph)</td>
<td>Prepared for surgery</td>
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<tr>
<td>Moderate</td>
<td>Moderate soft tissue involvement</td>
<td>Prompt decompression, wide debridement, open packing</td>
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<tr>
<td></td>
<td>No treatment delay</td>
<td>± Repeated debridement</td>
</tr>
<tr>
<td></td>
<td>Neurovascular bundles not compromised</td>
<td>Delayed closure</td>
</tr>
<tr>
<td>Severe</td>
<td>Injured by paint and solvents</td>
<td>Prompt decompression and meticulous removal of foreign materials and dead tissue</td>
</tr>
<tr>
<td></td>
<td>From high-pressure spray guns</td>
<td>± Repeated debridement</td>
</tr>
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<td></td>
<td>Delay in treatment</td>
<td>Late reconstruction or staged amputation</td>
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<tr>
<td></td>
<td>Extensive soft tissue involvement with proximal extension</td>
<td>Early amputation if indicated</td>
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ber 2003. They analyzed 435 injection injuries distal to the elbow. The typical patient was male (99%) with a mean age of 34.7 years, with injury to the nondominant (78%) index or middle finger. The overall amputation rate was 30%.

Ten materials accounted for 85% of the injection injuries (Fig. 2). The most toxic agents were organic solvents (paint, paint thinner, gasoline, automotive undercoating, jet fuel, or oil). Patients injected with latex-based paints fared better than those injected with oil paints; water and air injuries fared the best. Notably, hydraulic fluid and grease elicited less inflammatory response.

From the available data, delay to surgery correlated with amputation rate only for the organic solvents. Debridement within 6 hours had a 38% amputation rate, greater than 6 hours was 58%, and no debridement was 88%. Location of the injury also correlated with amputation; the thumb and palm fared better (15% and 25% amputation rates, respectively). The palm can accommodate larger amounts of injected material,\textsuperscript{16} which might explain the higher survival rate, whereas the survival rates after thumb injury are unclear, likely owing to surgical bias and the fact that a stiff but sensate post is highly functional, whereas a stiff finger may impair function of the entire hand.

Intraoperative cultures were positive in only 53 of 126 (42%) patients, which did not correlate with the amputation rate, possibly because many of the injectable organic solvents are sterile and have antibacterial properties.

Higher pressures (> 1,000 psi or > 70 bar) correlated with higher amputation rates (43% vs 19%). Some authors\textsuperscript{17,18} recommended corticosteroids to reduce the secondary inflammatory effect; however, the data are insufficient, and over all, in that review,\textsuperscript{8} the amputation rate was 8 of 15 for patients who received steroids.

Functional outcomes are difficult to study after this injury because of a lack of standardized outcome tools, incomplete reports by authors, and variation in injury patterns. At a mean of 8.5 years postinjury, Wieder et al\textsuperscript{19} documented cold intolerance, hypersensitivity, paresthesias, constant pain, and impairment in activities of daily living. The authors noted the following objective
decreases in function: metacarpophalangeal motion, 8.1%; proximal interphalangeal joint, 24%; distal interphalangeal joint, 30%; grip strength, 12%; and pinch, 35%. Two-point discrimination increased by 49%.

High-pressure injection injuries are devastating injuries that often lead to poor outcomes. It is thought that prompt diagnosis and emergent surgical intervention may decrease the amputation rate. Late intervention and injection with more toxic organic solvents (paint, paint thinner, gasoline, automotive undercoating, jet fuel, or oil) are associated with higher amputation rates, especially in cases of an initially ischemic digit. Debridement needs to be thorough using a wide, extensile exposure. Wound management varies and may consist of loose closure, dressing changes, or negative-pressure wound dressing. More often than not, a second look is necessary to assess viability and reconstructive options, which include amputation, delayed primary closure, local flaps, and heterodigital or free island flaps. A new classification system may allow surgeons to monitor clinically mild injection injuries before surgical intervention; that classification needs to be confirmed in more studies. In cases of salvageable digits, follow-up studies document decreased motion and sensation.

REFERENCES