High-Pressure Injection Injuries of the Hand

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While often innocuous at presentation, high-pressure injection injuries can lead to devastating consequences. Stiffness, chronic pain, infection, and even amputation can occur, with amputation rates ranging between 16% and 48%. Early surgical decompression and debridement are the cornerstones of treatment.

The advent of new technology in the industrial community has introduced high-pressure equipment such as diesel fuel jets, hydraulic lines, plastic injectors, concrete injectors, and paint guns to the workplace.1-4 These tools, paraphernalia, and riggings created a new mechanism of injury beginning in the early 20th century. They may generate pressure from 3000 to 12,000 psi. Only 100 psi is required to penetrate skin.5,6

Hesse7 first reported a high-pressure injection injury in 1925. Rees1 further described the serious nature of these injuries in 1937, when a 47-year-old mechanic underwent a Ray amputation from persistent infection and necrosis after starting the jet of a diesel engine and forcing oil into his right middle finger at 4000 psi.

High-pressure injection injuries initially may appear innocuous but can have devastating consequences if not emergently decompressed surgically throughout the zone of injury. Presentation as a rather innocent puncture wound is misleading. It is imperative that all initial treating physicians recognize this initially subtle and deceptive injury, and act expeditiously as significant residual impairment may occur even with the best of treatment.

This article reviews the pathophysiology, clinical details, and treatment of high-pressure injection injuries of the hand, and also presents four cases.

PATHOPHYSIOLOGY

In 1941, Mason and Queen5 divided the clinical symptoms and findings of high-pressure injection injury into three stages:

- Acute,
- Intermediate, and
- Late.

Acute Stage

The acute stage occurs immediately and is a mechanical phenomenon dependent on the velocity, location, and amount of material injected. It is a result of the introduction of a foreign substance under pressure into a small space. This causes spasm, compression, and damage to digital vessels, and compromises blood flow, leading to white,
mottled tissue and numbness. The velocity of the injected material is comparable to that of high-velocity gunshot wounds. The energy creating the wound is dissipated throughout the tissue involved in the zone of injury. The more energy emitted, the more damage to the tissue. Schoo et al reported a 100% amputation rate for injuries occurring at 7000 psi.

Along with velocity, the site of injection determines where the material will spread. The injected material disperses along fascial planes and within flexor tendon sheaths, typically taking the path of least resistance. Ramos et al reported higher pressure was instrumental in distributing the material more widely along tissue planes.

Digit injections produce a worse permanent partial impairment of the hand than palmar injections owing to the fact that the hand is more distensible than the digit. Furthermore, the amount of material determines the degree of mechanical distention that will impair blood flow. Gelberman et al observed that higher volumes of injected material were associated with poorer results. The longer the material is allowed to remain undecompressed in the tissue at high pressures, the worse the morbidity.3,9

Intermediate Stage

Severe fibrosis and the formation of oleogranulomas resulting from a foreign-body tissue reaction comprise the intermediate stage of high-pressure injection injuries. Progressive digital stiffness and loss of function occurs.

The inflammatory response may be variable depending on the type of material injected. Paint is a combination of pigment, which adheres to tissue, and solvent, which evaporates.

Gillespie et al reported emulsified latex-based paints were less likely than oil-based paints to cause an inflammatory and fibrotic response. Schoo et al reported an 80% amputation rate with the injection of paint thinner and a 58% amputation rate for injuries secondary to paint.3 Automobile grease (23% amputation rate) and hydraulic fluid (14% amputation rate) appear to be less damaging to the tissue than materials used in commercial paint, especially solvents.3,9

Late Stage

The late stage consists of the breakdown of granulomas and the appearance of widespread cutaneous lesions and sinuses. During this remodeling phase, sinuses have been noted to develop into malignancies.8 Grease injections are especially notorious for causing oleogranulomas, sinuses, cutaneous lesions, and functional loss without amputation.6

Infection

Infection usually is not a primary concern because some injected materials, especially paint and solvents, appear to be bactericidal or bacteriostatic.9 However, injured and necrotic tissue is vulnerable to secondary infection.

Infection easily spreads along the tissue cleavages created by the injury. Toxins and enzymes cause liquefaction necrosis of the superficial fascia, lead to thrombosis of local vasculature, and may propagate proximally as a dissecting fasciitis. Systemic toxicity may occur.12

Clinical Presentation

The puncture wound initially may appear to be insignificant and cause only minor discomfort (Figure 1A). Mild swelling, pain, tenderness, numbness, and venous stasis with dusky discoloration may be present in the flexor pad of the finger. Radiographs may reveal radiopaque material, subcutaneous air, or both (Figure 1B).

The injected material usually penetrates the distal flexor tendon sheath, follows the sheath proximally, and causes a mechanical and chemical flexor tenosynovitis as the finger is not distensible and does not accommodate large amounts of material. Signs and symptoms quickly intensify.
fy. A vicious cycle of ischemia, necrosis, and increasing pain will inevitably occur and spread proximally, jeopardizing the finger and even the extremity.

Infection may compound the injury. Depending on the type and amount of material injected, excruciating pain can develop within hours. Red streaks extending proximally in the extremity and palpable, tender epitrochlear and axillary lymph nodes are later signs of dissemination and may herald necrotizing fasciitis. Acute carpal tunnel and forearm compartment syndromes may occur.

**TREATMENT**

Tetanus prophylaxis should be assured. Early surgical decompression and debridement are the cornerstones of treatment. Cultures should be obtained. Broad-spectrum antibiotics may then be administered as a precaution as 47% to 60% of high-pressure injection injury wounds have positive (often polymicrobial) cultures at initial debridement. Antibiotics may be adjusted later to specific microbial sensitivities and continued until the infection resolves. The wound is left open.

Postoperatively, the extremity is elevated and the wound serially inspected. While surgical debridement and antibiotics serve to halt acute-phase characteristics, steroids may serve as an adjunct for the intermediate inflammatory phase and may improve outcome in the uninfected patient. Additional debridement, decompression, and wound closure or coverage are performed as the situation dictates. Exercises are phased into treatment as symptomatic recovery progresses. Skeletal or soft-tissue reconstruction and even amputation may be necessary in some patients.

**CASE REPORTS**

**Case 1**

A 23-year-old, right-hand dominant painter was cleaning his paint gun with paint thinner. With the tip of his right index finger directly on the nozzle of the paint gun, he sustained a 3000-psi injection injury. He went immediately to the emergency department at a local medical facility where he received a tetanus shot, wound care, and a dressing. He was given instructions for follow-up and was sent home with analgesics.

Approximately 34 hours after the injury, he presented to emergency department at the University of Mississippi Medical Center with marked swelling of the index finger and entire hand, and forearm redness with proximal streaking beyond the elbow. The index finger was numb, stiff, and blue. The patient was taken promptly to the operating room. A Brunner incision was made over the palmar surface of the index finger, and the tendon sheath was opened. Devitalized skin and fat along the course of the flexor tendon was debrided, and the wound was irrigated. The digital nerves were decompressed and appeared contused.

The incision was extended into the palm, and the carpal tunnel was decompressed. Dorsal intrinsic and thenar fasciotomies were performed. Intraoperative cultures were taken, and antibiotics were initiated. The index finger became necrotic (Figure 2A), and forearm compartment syndromes developed. The patient subsequently required forearm decompression, further debridement, index ray amputation, and skin grafting. He was discharged on the 13th hospital day.

Three months postoperatively, the patient’s wounds were completely healed. He had regained nearly full motion of his remaining digits, wrist, and forearm, and 60% of his grip strength (Figures 2B-2C). He then returned to unrestricted work.

**Case 2**

A 28-year-old, right-hand dominant painter injected paint into the tip of his left middle finger while falling from a ladder. He was using a 2500 psi paint gun and stated his finger was approximately 2 to 3 inches from the tip of the nozzle during discharge. He went home and cleaned his finger, and 28 hours after the injury, he presented to the University of Mississippi Medical Center emergency department with progressive pain and swelling.

On physical examination, he had a benign-appearing puncture wound to the left distal phalanx. Radiographs revealed radiopaque material adjacent to the palmar surface of the distal phalanx.

The patient was taken to the operating room, and the finger was decompressed and debrided through a palmar Brunner incision. Paint was confined to the flexor pad. The tendon sheath was not violated. Intraoperative cultures were taken, antibiotics initiated, the wound dressed, and the extremity elevated.

The intraoperative cultures grew coagulase-negative *Staphylococcus aureus*, which was treated according to the sensitivities. A redebridement was performed on the third hospital day. The patient was discharged with oral antibiotics, resolving infection, and a healing wound on the fifth hospital day. The patient recovered sensation and returned to work, but was left with a permanent 20° proximal interphalangeal joint flexion contracture.

**Case 3**

A 27-year-old, right-hand dominant man was painting apartments using a 3000-psi high-pressure paint gun. With paint in the chamber, the gun was inadvertently discharged directly into the tip of his left index finger. He presented to a hospital within 90 minutes of the injury and was referred to the University of Mississippi Medical Center emergency department, where he arrived 4 months after injury and treatment.
hours after injury.

On physical examination, his left index finger was swollen to the level of the metacarpophalangeal joint. The fingertip was numb and tender, and his pain was increasing.

The patient was taken to the operating room where a volar Brunner incision was extended from the site of the injection to the distal palmar crease. The subcutaneous tissue was matted with white paint and the tendon sheath infiltrated. The digital nerves were contused.

The finger was debrided and irrigated, and intraoperative cultures were taken. Ultimately, the index finger became necrotic and required amputation at the metacarpophalangeal level.

The patient was discharged on the 9th hospital day. One month following his injury, the wounds were healed. Two months after injury, his amputation was healed sufficiently to allow him to return to work.

Case 4

A 35-year-old, right-hand dominant man was cleaning a 3000-psi paint gun when he inadvertently discharged paint thinner directly into the tip of his right middle finger. He presented to the University of Mississippi Medical Center emergency department 10 hours after injury.

On physical examination, his right middle finger had a benign entrance wound, but was diffusely swollen and painful to touch. He was taken to the operating room for debridement, irrigation, and decompression of the finger.

A Brunner incision was made on the palmar surface of the middle finger from the point of injury to the distal palmar crease. The tissue throughout the zone of injury and flexor tendon compartment was stained with a mixture of paint thinner and paint.

After one redebridement, the patient was discharged on the fifth hospital day. He ultimately recovered full digital motion (Figure 3). His sensation returned to normal at the tip of the finger, and he returned to work.

**DISCUSSION**

High-pressure injection injuries typically involve the nondominant index finger of a male laborer with an average age of 35 years. They are the prototypical “tip of the iceberg” of surgical emergencies.

While often innocuous at presentation, high-pressure injection injury can lead to serious morbidities such as stiffness, chronic pain, infection, and amputation. The initial presentation may be so benign that the injury may be underestimated and undertreated. This delay in treatment, along with the type, amount, and velocity of the material injected each weigh on the end result.

All four patients described in this article received tetanus immunization, prompt surgical care on arrival at the university’s emergency department, broad-spectrum antibiotics, and intensive hand therapy. No steroids were administered. Despite these efforts, 2 patients required amputations and 1 patient developed necrotizing fasciitis.

In at least one of these patients, a delay in treatment was a major factor. Hayes and Pan reported digital salvage provided debridement was done within 6 hours of injury. Stark et al reported patients treated within 10 hours of injury had a better outcome than those treated later.

Delay in definitive treatment is not the only factor impacting outcome in high-pressure injection injuries. The type and amount of foreign material, and the injury velocity are also factors. For example, despite a 28-hour delay to decompression for the second patient described in this article, the fact that he avoided amputation and had only slight residual stiffness may be attributed, at least in part, to the fact that the finger was not in direct contact with the paint gun and the gun was less powerful.

High-pressure injection injuries behave like an acute flexor tendon sheath compartment syndrome, and are compounded by the toxic effects of a caustic foreign material and often, infection. The injured finger is always at risk. Reported amputation rates vary between 16% and 48%,1,5,14 Early presentation may be so benign that the injury may be underestimated and undertreated. This delay in treatment, along with the type, amount, and velocity of the material injected each weigh on the end result.

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**REFERENCES**