Functional Outcome of High-Pressure Injection Injuries of the Hand

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Background: High-pressure injection (HPI) injury of the hand is a serious injury that can be potentially devastating. There have been a number of publications on the results of its treatment, but we are not aware of a report on the functional outcome of these hands.

Methods: We assessed the functional outcome of 15 patients with HPI injuries. All patients were treated operatively, with a mean delay of 11.7 hours. The patients were examined by a doctor and an occupational therapist using a work simulator.

Results: Our study revealed a significant reduction of static and dynamic muscle testing parameters compared with the uninjured hand. Six patients lost a digit and four patients had to change their occupation after the injury.

Conclusion: Deterioration of hand function is a predictable outcome of HPI injury. This information should be shared with the patient at the outset so as to avoid subsequent disappointment.

Key Words: High-pressure injection, Work simulator, Dynamic muscle testing, Functional outcome.

J Trauma. 2001;50:717–720.

High-pressure injection (HPI) injury is a true hand surgical emergency. The mechanism and pathogenesis of the injury is well described by many authors.[1–3] Although the nondominant index finger has been reported to be a frequent site of injury, this is not a uniform finding throughout the literature.[10] The injected material may course volar to the tendon sheath or enter it. It may track into the forearm proximally in case of an injury to the thumb or little finger via the radial and ulnar bursae, respectively.[4] Breaching the sheath is infrequent because the flexor sheath offers a greater resistance than other soft tissue planes, such as the neurovascular bundle.[5] The degree of damage can vary depending on the injection pressure and the type of injected material. The outcome of HPI injuries may often be unsatisfactory, with considerable loss of hand and finger function. With high-irritant materials, high pressures, and large amounts of injected material, the damage can be so extensive that salvage may not be possible. The reported amputation rates after HPI in the literature range up to 48%.[6]

Unfortunately, there is still considerable lack of awareness regarding this condition. There have been cases where victims have been sent home by emergency department staff with reassurance and simple pain medication. This may stem partly from the fact that the visible injury may appear quite trivial, taking the form of a pin-prick or graze. However, decompression with debridement of all involved tissues is essential for all but a small number of HPI injuries. Patients who have been inadequately treated at the outset usually return to the hospital hours later with excruciating pain and inability to move the involved digit or hand, attracting assessment by a more senior member of the staff, or a hand surgeon. The aim of our study is to outline the prognosis of HPI injuries in an attempt to provide objective information about the functional outcome of these injuries. This information would be useful when counseling patients at the outset and help to avoid disappointment as a result of unrealistic expectations.

PATIENTS AND METHODS

All 46 patients treated at the Pulvertaft Hand Center as a result of HPI injury between 1986 and 1998 were contacted by mail or telephone. As this particular group of patients are of active working age, they have a tendency to move across the country, and it is often not easy to contact them a long time after treatment. Hence, only 15 patients made themselves available for review.

The initial assessment always included radiographs of the involved part, because some types of material may show up on the radiograph, which may be helpful to determine the extent of injury. Antitetanus toxoid and broad-spectrum antibiotics were administered to every patient at arrival. All patients were treated by surgical exploration, debridement, and wound lavage. The operation was performed under brachial plexus block or general anesthesia. A tourniquet was used, but exsanguination of the arm was achieved only by elevation. The surgical procedure consisted of exposing the involved digit through a volar zig-zag incision usually extending into the palm and, on occasion, more proximally. A meticulous debridement of all contaminated or devitalized tissues was performed with saline irrigation. The wound was loosely sutured or left open for later closure. All patients

Submitted for publication June 17, 2000.

Accepted for publication December 18, 2000.

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started immediate physiotherapy. Splints were used initially to hold the fingers in a functional position and later dynamically to regain better digital flexion and extension.

The average follow-up period was 73.5 months, ranging between 6 and 144 months. The clinical examination was performed by a hand surgeon (E.Y.M. or L.C.) and the functional assessment by a senior occupational therapist. Data concerning hand dominance, site of injury, injected material, and time from injury to operation were recorded. The number of doctors seen before a treatment plan was constructed was identified, as was the number of operations each patient underwent. Amputated digits were also recorded. The patient satisfaction about the outcome (not the treatment) was measured using a visual analogue scale. The patients were also asked whether they had to change their employment as a result of the injury.

The static muscle power was examined by measuring maximum grip strength, lateral key pinch, and three-point pinch using the Jamar dynamometer and pinch gauge (Jamar, Jackson, MI). The results were correlated with the uninjured side.

A BTE Work Simulator (Baltimore Therapeutic Equipment, Hanover, MD) was used to assess dynamic muscle power. This is a reflection of the power generated by a repetitive activity and is measured in watts (W). The work output of the affected hand was compared with the nonaffected hand, with both hands working with 50% of their maximal force. The onset of fatigue was monitored. This test is indicative of the tolerance to repetitive activity and muscle fatigue. Sensitivity testing was performed using the Semmes-Weinstein monofilament aesthesiometer. The differences between the injured and uninjured sides were compared using the two-tailed Student's *t* test. A probability value of less than 5% ($p < 0.05$) was considered to be significant.

RESULTS

The average age of the patients at review was 44 years (range, 21–64). The dominant index was the most frequently injured digit. The injected material was hydraulic oil in seven patients, and grease, paint, water, and animal vaccine in two each. The average number of doctors seen before definitive treatment was 2.4 (range, 1–4). The delay between injury and operation ranged from 3 to 30 hours, with a mean of 11.7 hours. Patients had to undergo 2.8 operations on average (range, 1–16). The average debridement delay for amputees was 14.5 hours compared with nonamputees at 9.8 hours (Table 1). The difference is not statistically significant.

The average reduction in grip strength was 7.9 kg (range, 2–31 kg), or 19%, compared with the uninjured hand, which was statistically significant ($p = 0.034$). Similarly, the lateral key pinch was on average 1.8 kg (range, 0.5–8.3 kg) or 23% reduced ($p = 0.018$), and the three-point pinch was 1.7 kg (range, 0.3–3.5 kg) or 24.6% reduced ($p = 0.002$) compared with the uninjured side. Dynamic muscle power was down by an average of 2.7 W (range, 0.5–8.5 W), a decrease of 26.9% ($p = 0.02$) (Table 2).

Sensory testing could not be performed in three patients who had undergone ray amputation of the involved digit. The remaining 12 patients had different degrees of sensibility. The D2.83 Semmes-Weinstein filament is generally accepted as a cut-off reference for normal versus abnormal peripheral nerve function.[7] According to this, only one patient had normal sensation. Seven patients had diminished light touch, three had diminished protective sensation, and one had loss of protective sensation. Six cases resulted in amputation. Three of four patients who changed their occupation after the injury were amputees. The average patient satisfaction was 7 (range, 1.9–10) on the VAS.

Table 1 Details of the Patients in the Series[a]

	Follow-up (mo)	Dominance	Site	Material	No. of Doctors Seen	Delay (h)	No. of Operations	Sensibility	Amputation	Satisfaction (/100)
Case 1	84	R	R index	Grease	3	24	3	N/A	Index ray	55
Case 2	144	L	L index	Paint	1	9	2	F3.61	Proximal phalanx	100
Case 3	6	L	L middle	Grease	3	3	1	F3.61	None	82
Case 4	68	R	R thumb	Hydraulic oil	3	30	1	J4.31	None	95
Case 5	22	L	L ring	Hydraulic oil	3	10	1	D2.83	None	100
Case 6	68	L	L palm	Pig vaccine	1	5	16	F3.61	Thumb metacarpal	100
Case 7	132	L	L index	Hydraulic oil	3	5	1	K4.56	None	98
Case 8	87	R	L thumb	Chicken vaccine	2	8	2	F3.61	None	50
Case 9	80	R	L index	Hydraulic oil	2	24	4	N/A	Index ray	40
Case 10	82	L	L middle	Hydraulic oil	4	11	4	N/A	Middle ray	19
Case 11	46	L	R middle	Paint	2	14	3	J4.31	Middle phalanx	23
Case 12	35	L	L ring/little	Water	3	8	1	J4.31	None	70
Case 13	8	L	L index	Hydraulic oil	2	9	1	F3.61	None	100
Case 14	115	R	R palm	Water	2	4	1	F3.61	None	48
Case 15	126	R	R index	Hydraulic oil	2	12	1	F3.61	None	75

[a] Sensory evaluation given as the thinnest Semmes-Weinstein filament felt. D2.83 is the limit for normal sensation, F3.61 for diminished light touch, and J4.31 for diminished protective sensation. K4.56 and thicker filaments indicate loss of protective sensation (7). Satisfaction measured on visual analogue scale (0 = totally dissatisfied, 100 = totally satisfied).

Table 2 Static and Dynamic Measurements of the Patients at Follow-up

	Grip Strength (kg)		Pinch Srength (kg)		Three-Point Pinch (kg)		Muscle Power (W)	
	Injured Hand	Normal Hand	Injured Hand	Normal Hand	Injured Hand	Normal Hand	Injured Hand	Normal Hand
Case 1	22.6	31.00	8.0	16.3	10.3	10.60	6.0	6.8
Case 2	51.0	65.00	6.1	6.3	4.1	6.80	12.3	18.5
Case 3	54.0	53.50	7.1	7.8	3.6	6.60	11.4	11.2
Case 4	46.6	40.00	4.8	3.8	2.8	3.10	6.1	9.1
Case 5	45.6	49.00	7.1	8.6	4.3	3.30	6.9	9.8
Case 6	39.0	46.00	4.9	6.7	4.4	6.80	3.5	12.0
Case 7	22.9	39.60	1.4	1.6	3.8	4.10	7.8	12.5
Case 8	29.0	39.30	4.1	4.6	1.5	3.80	7.8	6.5
Case 9	19.3	4.00	1.0	4.5	1.5	4.00	2.9	10.7
Case 10	16.6	47.30	4.8	5.8	.9	3.83	4.5	12.2
Case 11	22.6	54.00	4.6	6.5	2.3	6.75	3.9	4.1
Case 12	46.6	59.60	8.8	12.5	7.6	10.00	7.6	8.4
Case 13	51.0	64.00	7.5	7.8	10.4	9.75	13.0	11.4
Case 14	46.9	38.20	15.3	20.0	10.3	12.60	7.2	7.6
Case 15	40.6	42.60	7.3	7.0	9.1	10.00	7.9	8.1

DISCUSSION

The outcome of high-pressure injection injuries of the hand is affected by many factors. The time between injury and operative treatment has been regarded as a key determinant by a number of authors. Stark et al. drew the conclusion that patients undergoing decompression earlier than 10 hours fared better.[8] They had seven "early attenders," but two of them were injuries into the palm, which are known to have better outcomes than digital injuries because of more space available for expansion. An additional two patients had thrombosed digital arteries at exploration, although these digits survived, and one had an amputation. Conversely, four of the seven late cases that were operated on at 1 day to 3 weeks after the injury had an amputation. The study of Stark et al. was limited to paint injuries, but the type of paint is unknown. Spirit- or oil-based paints are more noxious than those that are water based. Early decompression had already been attempted in 10 of 14 cases by either incising the digit (seven patients) or expressing the paint (three patients) before the patients saw the authors. This type of intervention cannot be regarded as proper treatment, although it may have reduced the pressure in the digit and disposed of at least some injected material.

Pinto et al. have reported on the outcome of 25 patients injured with a variety of materials with a mean follow-up of 10 months.[9] They came up with the lowest amputation rates in the literature (16%), and postulated that presentation after more than 48 hours precluded application of their consistent practice of aggressive early debridement and open wound packing, which they thought was responsible for the favorable results. They did not provide details of the delays encountered in the treatment of each patient. It is likely, though, that many of the late cases did well if one takes into account the average delay of 2.5 days from injury to treatment, with a wide range between a few hours and 8 days.

Gelberman et al. have not been able to confirm the relationship of the delay to the outcome. A large number of their 26 patients treated by early surgery did not do as well as expected, whereas several with later surgery recovered satisfactorily.[10] Lewis et al. reviewed a case series of HPI injuries and found that those requiring amputation had, paradoxically, a shorter interval between injury and surgery.[11]

It is difficult to draw any conclusive evidence from these studies, because there seems to be a multitude of factors in play. From the information available to us, however, it seems likely that the time factor has so far been overestimated. If the pressure is high and the injected material toxic enough to cause vascular damage, it may not be possible to salvage the digit, however early the decompression is performed. Mason and Queen considered in 1941 that "Pressure accounts for the early development of gangrene."[12] Furthermore, the tissue damage may continue even after debridement if the material is sufficiently toxic.[3] The average delay before debridement was 14.5 hours for amputees and 9.8 hours for nonamputees in our study. No statistical inference can be made from these data, as the standard deviations in both groups are very high. Some patients with later operations in our series did very well, allowing us to confirm the complexity and multifactorial involvement of these injuries. It is certainly best to perform the operation as soon as possible, but there is little evidence that this is the most important determinant on the outcome.

The nature of the injected material is probably more important. It has been noted by many authors that injuries with paints have a worse outcome than those with oil or grease.[1,5,8,10,13] There is also a distinction on the basis of paint types. Spirit-based paints cause damage by disintegration of cell membranes,[3] whereas oil-based paints cause an intense inflammatory response.[13] Latex paints in a water base are known to be least noxious. Injuries with water, air, or low-volume vaccines (e.g., chicken vaccine) may be amenable to nonoperative treatment.[14,15] Our patients were too few to be analyzed in subgroups of injected material.

The ejection pressure from the gun and the amount of injected material are yet other considerations. Pressures greater than 7,000 lb/in^2 are reported to have a 100% amputation rate.[4] However, it is usually difficult to establish these variables, except in the case of vaccines where delivery is in fixed amounts. Increasing volume is known to have an adverse effect on the outcome.[15] The unfavorable outcome of the patient injured with pig vaccine (2-mL dose) in our series confirms this, as opposed to the patient with chicken vaccine (0.2-mL dose). The site of injection can be viewed in conjunction with the volume. Digital injection injuries do worse than palmar injuries because of the limited space available for expansion.[8,13] The nondominant index finger has been reported to be a frequent site of injury because it is commonly used to wipe the tip of a blocked nozzle,[4,8] although this is not a uniform finding throughout the literature.[10] The dominant index finger was more often injured in our series.

The injury is characterized by marked limitation of joint motion, with restricted tendon excursion because of local swelling. All of our patients started immediate postoperative physiotherapy. The swelling also responded well to early application of intermittent custom-made pressure garments.

The dynamic gripping test requires coordinated, firm, repeated grip and the ability to tolerate contact with a hard surface. All these elements are necessary in daily manipulative function and simulate a person's ability to use their hand in a productive manner. This ability was reduced by an average of 26.9% on the injured side. The grip strength was reduced by 19%, the lateral key pinch by 23%, and the three-point pinch by 24.6%. Four patients had to change their occupation, and they all had a reduction of both static and dynamic parameters.

These findings emphasize the need to explain the severity of the HPI injury to the patients at the outset. They should be warned that the function of the injured hand is likely to be permanently compromised in terms of strength, power, and sensation to enable them to realistically plan for the future. Where necessary, these patients should be encouraged to consider retraining for alternative occupations to prevent them from becoming disabled.

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