ORIGINAL ARTICLE

High-pressure injection injuries to the upper extremity and the review of the literature

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ABSTRACT

BACKGROUND: High-pressure injection injuries of the hand are rare severe injuries. This study aimed to present a retrospective analysis of current and possible prognostic factors, treatment modalities and evaluation criteria.

METHODS: Ten patients who had high-pressure injection injury to their upper extremity between 2005–2018 were included in this study. All patients were evaluated for the compartment syndrome; if exists fasciotomy and wide debridement were performed. After the first debridement, the second debridement was considered within the first 24 hours.

RESULTS: In this study, 10 patients (mean age: 30) were evaluated retrospectively. The injected materials were the animal vaccine, thinner, oil, diesel, water, plastic and paint. Preoperative and postoperative mean WBC levels were 14.73 K/μL and 9.62 K/μL, respectively. Preoperative and postoperative mean neutrophil levels were 11.4 K/μL and 6.49 K/μL, respectively.

CONCLUSION: Early and serial debridement and compartment syndrome evaluation are required. Despite these cautions, amputation may occur. Material, injection force and the time elapsed are the main determinants in prognosis. Aggressive debridement is required in high-pressure injection injuries. However, the adequacy of debridement should be evaluated because it is mostly impossible to completely clean the tissue from diesel or thinner. According to the experience of 10 cases in our series, when clinical and macroscopic debridement adequacy was observed, a decrease in WBC and neutrophil levels was observed simultaneously. For this reason, WBC and neutrophil levels may be an indicator of the adequacy of debridement, although these injuries are very rare, larger series are needed for this interpretation.

Keywords: Hand; high-pressure; injection injury.

INTRODUCTION

High-pressure injection injuries of the hand are rare, leading to severe necrosis or even amputations.[1,2] The most important feature of these injuries is that the examination findings do not show a severe hand injury, only one injection site can be detected on the skin, even the pain can be minimal, making it easier to neglect.[3] Historically, Rees described finger necrosis with high-pressure fuel oil injection in 1937.[1,3] The severity of the injury is determined by the force of the injection and the type of material. The pressure to pass through the skin is 100 psi and high-pressure injection injuries have caused injuries above this injection force.[1] The type of material also significantly affects the tissue damage. The presence of water, oil, paint and organic solvents of the high-pressure injecting material is what determines both the fate of the hand and the reaction of the tissue and the extent of the damage in the tissue.

Compartment syndrome, loss of function of the extremities and amputations are the results of high-pressure injection injuries. Therefore, good history, physical examination and management of treatment are critical. Following this, emergency intervention is essential and decompression and extensive surgical debridement are critical. Follow-up or wait-and-see is not the treatment options. However, amputation rates of up to 48% have been reported, even if treated with an appropriate approach.[4] An injury with such serious con-

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sequences should be treated in hand surgery centers, as it is reported that one in every 600 traumas has injection injuries.[2]

The clinical course and pathology of this type of injury are well known.[5] However, it is often presented in the literature as case reports.[6–15] In this study, we aimed to present a retrospective analysis of current and possible prognostic factors and treatment modalities of patients who applied to our hand surgery clinic.

MATERIALS AND METHODS

Ten patients who had high-pressure injection injury to their upper extremity between 2005–2018 were included in our study. Patients were classified according to the patients' age, gender, injected material type, hand laterality and injured hand part, duration between injection injury and patient application, treatment received and the result of treatment. Ethical approval for this study was obtained from Selcuk University ethical committee with the number of 2019/363.

Surgical Management

All patients received tetanus and antibiotics prophylaxis and were evaluated clinically for the compartment syndrome; if it is diagnosed based on the physical examination, urgent fasciotomies were performed for the first step. In this surgery, wide debridement was also performed. All patients were operated urgently after their application. After the first debridement, the second debridement was considered within the first 24 hours. Wound dressings were changed twice a day. After serial debridement, the options for reconstruction (secondary wound healing, primary suturation, graft or flap surgeries) were evaluated.

Approach to the management of high-pressure injection injuries was discussed with the review of the literature.

RESULTS

In this study, 10 patients were evaluated retrospectively, all of them were male and injury types were working accidents for all (Table 1). The mean age of patients was 30 (21–50). The injected materials were the animal vaccine (n=2), paint thinner (n=2), oil (n=2), diesel (n=1), water (n=1), plastic (n=1) and paint (n=1). Eight hands of injured hands were the nondominant hands. Only two patients were injured from their dominant hands. Affected extremity regions were the index finger (n=3), palm (n=2), thumb (n=1), 3rd finger (n=1), second webspace (n=1), forearm (n=1) and on the snuffbox (n=1) anatomically. Three patients were considered as compartment syndrome and underwent a fasciotomy surgery. All patients had serial debridement. Four patients were recovered with wound dressings and secondary intention, two patients had primary suturation, two patients' defects were repaired with skin grafting and a local flap, two patients' fingers were amputated, and defects were primarily repaired. The injected materials were painted thinner and diesel for these two amputated fingers. Preoperative and postoperative mean WBC levels were 14.73 K/μL and 9.62 K/μL, respectively. Preoperative and postoperative mean neutrophil levels were 11.4 K/μL and 6.49 K/μL, respectively.

Case Examples

Case 1 – A 32-year-old male patient was admitted one hour after the high-pressure liquid plastic injection for the nondominant hand second webspace (Fig. 1). The patient was operated urgently, and surgical debridement was performed, during surgery, it was observed that the plastic material penetrated inside the skin did not spread inside the soft tissue, and the material was excised. The wound healed with secondary intention.

Case 2 – A 35-year-old male patient was admitted two hours after the high-pressure paint injection for the nondominant hand palm (Fig. 2). Considered as compartment syndrome,

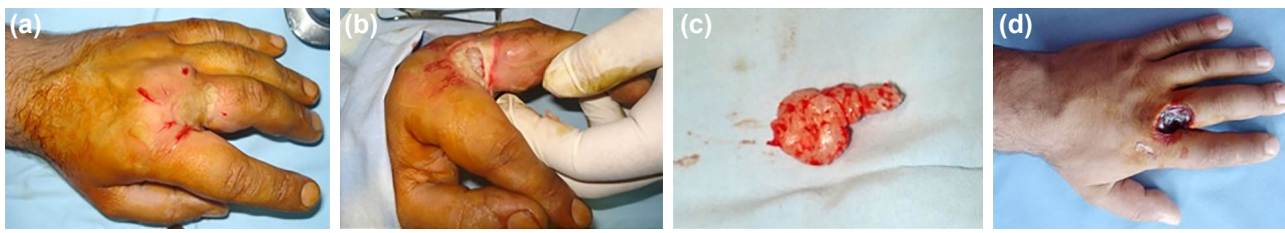

Figure 1. (a) 32-year-old male, liquid plastic injection to the nondominant hand second web [Case no. 2]. **(b)** Incision and the appearance of the liquid plastic inside the tissue. **(c)** Liquid plastic is frozen in the tissue temperature. **(d)** The tissue defect was healed with secondary intention.

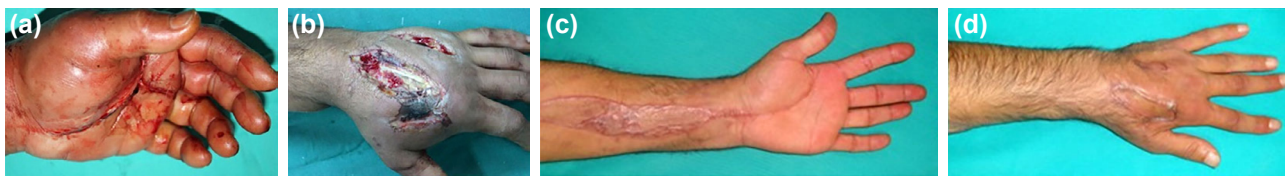

Figure 2. (a) 35-year-old male, high-pressure paint injection to the nondominant palm [Case no. 4]. **(b)** Compartment syndrome was detected and fasciotomy was performed. **(c, d)** Volar forearm and hand dorsum defects were closed with skin grafts.

Figure 3. (a) 35-year-old male, high-pressure diesel injection to the nondominant 3rd finger [Case no. 5]. The finger was ischaemic. **(b)** Wide exposure was performed in order to debride all the necrotic tissues and an irrigation system was inserted. **(c)** Within a few hours, full thickness finger necrosis. **(d)** The secondary debridement was performed and total thrombosis in the digital artery was determined. **(e)** Wide exposure was performed, all the remained tissues were necrotic in the palmar region. Palmar necrosis was debrided and 3rd finger was amputated. **(f)** Early postoperative appearance after amputation.

urgently fasciotomies and wide debridement were performed. Because of the red color of the paint, it was possible to see the area where the paint spread. After the first debridement, it was determined that the WBC was reduced from 16 K/μL to 10.8 K/μL, the neutrophil levels were reduced from 12.9 K/μL to 6.88 K/μL. Due to the continuation of the necrosis, serial debridement was performed and two weeks after the injury, the wounds were repaired with skin grafts and local flap. No complications or limitations in finger and hand movements were detected.

Case 3 – A 35-year-old male patient was admitted two hours after the high-pressure diesel injection for the nondominant 3rd finger (Fig. 3). 3rd finger was ischemic and there was no capillary refilling. Leucocyte was counted 15.9 K/μL; neutrophil was 13 K/μL, CRP was 183 and procalcitonin was 0.012. The patient was operated urgently; however, extensive thrombosis that was not suitable for any revascularization along the proper palmar digital arteries and the common palmar digital artery was detected. After the first operation, WBC was counted as 11.5 K/μL; neutrophil was 8.5 K/μL, CRP reduced to 57.8, and procalcitonin was 0.05. Despite the dramatic reduction of WBC, neutrophil, CRP and procalcitonin levels, the finger was amputated 24 hours after the trauma.

DISCUSSION

High-pressure injection injuries may occur with industrial tools and chemical injections. Thus, tissue damage may be mechanical, chemical or both. Mechanically, spreading may occur throughout the tendon sheath, deep spaces, and especially the neurovascular bundle. The direct effects of the pressure in the tissue were found by Kaufman et al.,[16] who showed that the material injected with high pressure, spread, especially along the neurovascular bundle, until the resistant tissue and after this resistance, the material has changed direction. Chemically, damage arises from the direct irritant effects of caustic materials.[17,18] Vascular occlusion after this initial injury leads to ischemia and tissue necrosis and destructive results, such as amputations. Subsequently, severe infections and severe tissue damage due to ischemia and necrosis occur.

All injuries in this study were identified as work accidents. High-pressure injections are often used in industrial areas

Table 1. Demographic features and injury-related results

No	Age	Gender	Material	Hand dominance	Effected region	Early treatment	Late term treament result
1	24	Male	Chicken vaccine	Nondominant	Thumb	Serial debridements	Healed with wound dressings
2	32	Male	Liquid plastic	Nondominant	Second web	Serial debridements	Healed with wound dressings
3	26	Male	Thinner	Nondominant	Forearm	Serial debridements	Skin grafting
4	35	Male	Paint	Nondominant	Palm	Fasciotomy, serial debridements	Skin grafting and flap
5	35	Male	Diesel	Nondominant	3rd finger	Debridements, revascularization	Amputation
6	50	Male	Oil	Dominant	Index	Fasciotomy, serial debridements	Healed with primary suturation
7	29	Male	Water	Nondominant	Snuffbox	Serial debridements	Healed with wound dressings
8	24	Male	Animal vaccine	Nondominant	Index	Fasciotomy, serial debridements	Healed with wound dressings
9	21	Male	Thinner	Dominant	Index	Serial debridements	Amputation
10	24	Male	Grease oil	Nondominant	Palm	Serial debridements	Healed with primary suturation

where water, oil, paint, various solvents and paint thinners, or even air need to be injected in various working areas; therefore, these injuries are often seen as work accidents.

The most affected area is the index finger of the nondominant hand. According to one study, the most frequent localizations of high-pressure injection injuries in the upper extremity were the index finger, long finger, palm, thumb, ring finger, respectively.[1] In our study, the most affected area was the index finger of the nondominant hand, and it was observed that three of 10 patients were injured in this anatomical region. Devices that can perform high-pressure injection are held by the dominant hand as they require control. The nondominant index finger injury is an expected result after slipping or dropping of the material, which required high-pressure injection that is occasionally held in the nondominant hand.

The degree of injury is related to the force of the injection and the type of material. While the spread of materials, such as plastic, paint and grease, is limited, the reaction gives very heavy damage to the tissue. Organic solvents are distributed in a wider area but cause a lighter reaction. In this study, the distribution of the material in tissue was found to be limited by the liquid plastic and grease. These patients showed rapid healing with wound dressings and primary suturing. However, the patient who was injured with paint thinner had no compartment syndrome and even a very limited area was affected, but the forearm defect in the patient had to be repaired by a skin graft. With these findings, it is possible to predict the degree of injury with the type of material injected. Another important form of injury is oil-based paints and industrial solvents. If the material type is oil-based paints and industrial solvents, their damage is more than water-based paints or grease damage. The rate of amputation with oil-based paints was reported as 50% in one study.[19] Amputation was not reported in water-based ones. In a review, the amputation rates of the injected material were compared and over 70% amputation rates were observed in diesel injuries. It was followed by paint thinner, oil, paint and undercoating. [18] In another study, the rate of amputation in high-pressure injection injuries with paint thinner was found to be 80% and 67% in diesel-induced cases, respectively, followed by paint, grease and hydraulic fluid.[1] In this study, amputated two fingers were amputated as a result of diesel and paint thinner injury. In these patients, vascular occlusion was detected in the early period with the injection of diesel and the injury with the paint thinner was applied at the fingertip with necrosis. It should be foreseen by the surgeon that amputation rates are very high in patients presenting with diesel and paint thinner injection injuries and the finger may not be saved despite serial and aggressive debridement. Although high-pressure injections are dangerous and destructive, air and water injections are more innocent than other materials. Amputation was not observed with air and water injections in Hogan et al.'s[18] study. In a similar literature, no amputation was reported in water and air injections.[20]

In such injuries, because the site of entry is a single point, a small perforation hole and relatively good surrounding tissue are determined. Therefore, it is easier to skip such injuries. However, the material that causes this minor wound will then cause extensive soft tissue injuries with persistent and severe pain. It is essential that a good story is taken in order not to miss them. In history, the location of the injury, the type of the injected material should be asked.

A critical point in the history should be the severity of the pressure; otherwise, a high-pressure injection injury can be considered as a simple injection injury. The impacts of an industrial type pressure pump will be more devastating than the injector of the chicken vaccine. Industrial type working pressures can reach up to 10000 psi, but the skin can exceed 100 psi pressure. Amputation rates were found to be 43% and 19%, respectively, in the injuries occurring above and below 1000 psi.[1]

Early diagnosis and aggressive treatment are critical as high-pressure injection injuries, amputations, or dysfunction of the extremity cause severe consequences.

The approach to the high-pressure injection injuries in the emergency room includes tetanus prophylaxis, broad-spectrum antibiotherapy, wound site irrigation. Prophylactic antibiotics, such as third-generation cephalosporins, are recommended to reduce future infection.[17,18] Irrigation should be done using Ringer Lactate.[18] If the injected material is a radiopaque material, the material's distribution area can be shown in the X-ray, so the proximal border of the spread material; thus, the extent of debridement can be determined. In physical examination, the neurovascular examination should be performed, and detailed anamnesis should be taken. A hand surgeon must be evaluated.
One of the main determinants of the outcome of the injury is the time from the injury to the operation.[21] According to Stark et al.'s[22] study, if the time between injury and surgery is over 10 hours, amputation rates increase significantly. The best results are obtained with debridement in the first six hours.[17]

The other important point in this study was that WBC levels were more than 12 K/μL (mean 14.73 K/μL) in the preoperative period despite the absence of any obvious clinical infection, and these WBC levels rapidly decreased to an average of 9.62 K/μL (normal intervals) with early aggressive debridement. Neutrophilia, which can be determined in bacterial infections, are also present in these patients preoperatively. In high-pressure infections, the neutrophil average is above 11 K/μL and decreases to 6 K/μL after the first debridement. Although there is no clinical appearance of neutrophilia, leukocytosis, infected content, lack of appearance, there is a reaction against this acute condition in the body. The WBC levels of the patients whose fingers were amputated were 15.9 K/μL and 12.1 K/μL, respectively. Thus, WBC levels cannot be

a prognostic factor for the high-pressure injection injuries. However, blood counts and infection markers could be used as a simple scale to monitor the effectiveness and adequacy of debridement because aggressive decreases in WBC and neutrophil levels were determined only by surgical debridement.

The intervention should be performed under operating room conditions. General anesthesia or plexus blocks are preferred. No local anesthesia or digital block should be applied to the patient. In addition, the choice of tourniquet should be based on a pneumatic tourniquet rather than a material that can push the material to the proximal levels like Esmarch.[23] In the presence of compartment syndrome, fasciotomy should be performed, and revascularization should be performed in the presence of circulatory problems. Broad and aggressive debridement should be administered and all soft tissues in the area of injury should be explored. The affected tissues should be irrigated; if possible, the limb should be removed from the entire material and removed as far as possible. The second debridement should be performed within 24 hours following initial debridement, followed by continuous irrigations and serial debridement to remove any remaining material and necrotic tissues. Wound care is important until soft tissue edema is controlled. Therefore, delayed repairs are often preferred. Defects that arise from large tissue necrosis and opened fasciotomy can be repaired in various ways. In this study, defects in patients were repaired with primary suturing, graft or local flaps. Splinting and physiotherapy are complementary to treatment.

If the amputation is performed despite the interventions, it should be taken care of not to have any chemical contamination on the other regions of the hand while amputation is being performed. The amputation decision should not be delayed or neglected; otherwise, it would be a loss of time with permanent loss of strength, loss of function and multiple procedures.[18]

According to some authors, in air, water and vaccine injections, the rules of this solid surgical debridement treatment may be stretched and fasciotomy may be performed when compartment syndrome is suspected because air and water are not caustic, irritant or toxic, requiring extensive debridement; however, they should be closely monitored as they cause dissection inside the tissue.[17]

Infection is rarely observed in high-pressure injection injuries. If there is a delay in treatment and a medium is emerging due to the presence of ischemic tissues, the probability of infection increases. In the case of infection, this is often seen as a combination of gram-positive and gram-negatives because necrotic tissue is a very good medium, in the case of infection, this is often seen as a combination of gram-positive and gram-negatives. Treatment of this possible infection is extensive and aggressive debridement and broad-spectrum antibiotics should be added to the treatment.

High-pressure injection injuries are a surgical emergency and should be recognized in the emergency department and require hand surgeon evaluation. The injected material and the pressure are the main prognostic factors that predict the amputation. The early surgical debridement, which is an important prognostic factor and under the control of the surgeon, will provide the best outcomes.

Ethics Committee Approval: Approved by the local ethics committee.

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Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZET*

Üst ekstremitenin yüksek basınçlı enjeksiyon yaralanmaları ve literatürün gözden geçirilmesi

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AMAÇ: Elin yüksek basınçlı enjeksiyon yaralanmaları ciddi, nadir yaralanmalardır. Bu yazıda, mevcut ve olası prognostik faktörlerin, tedavi yöntemlerinin ve değerlendirme kriterlerinin geriye dönük analizi sunuldu.
GEREÇ VE YÖNTEM: Çalışmaya 2005–2018 yılları arasında üst ekstremitede yüksek basınçlı enjeksiyon yaralanması olan 10 hasta alındı. Tüm hastalar kompartman sendromu açısından değerlendirildi; varsa fasiyotomi ve geniş debridman yapıldı. İlk debridmandan sonra ilk 24 saat içinde ikinci debridman yapıldı.
BULGULAR: On hasta (ort. yaş 30) geriye dönük olarak değerlendirildi. Enjekte edilen materyaller hayvan aşısı, tiner, yağ, dizel, su, plastik ve boya olarak bulundu. Ameliyat öncesi ve sonrası ortalama WBC düzeyleri sırasıyla 14.73 K/μL ve 9.62 K/μL idi. Ameliyat öncesi ve sonrası ortalama nötrofil düzeyleri sırasıyla 11.4 K/μL ve 6.49 K/μL idi.
TARTIŞMA: Erken ve seri debridmanlar ve kompartman sendromu değerlendirmesi gereklidir. Tüm önlemlere rağmen amputasyon ile sonuçlanabilir. Malzeme, enjeksiyon kuvveti ve geçen süre prognozdaki ana belirleyicilerdir. Yüksek basınçlı enjeksiyon yaralanmalarında agresif debridman gereklidir. Ancak, debridmanın yeterliliği değerlendirilmelidir çünkü dokuyu dizel veya tiner gibi materyallerden tamamen temizlemek imkansızdır. On olguluk çalışmadan edindiğimiz tecrübeye göre klinik ve makroskobik olarak debridman yeterliliği gözlendiğinde eşzamanlı olarak WBC ve nötrofil seviyelerinin de düştüğü belirlenmiştir. Bu nedenle WBC ve nötrofil seviyeleri debridmanın yeterliliği için bir indikatör olabilir, ne var ki bu yaralanmalar çok nadir yaralanmalar olsa da bu yorumu yapabilmek için daha geniş çalışmalara ihtiyaç vardır.
Anahtar sözcükler: El; enjeksiyon yaralanması; yüksek basınç.

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