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Surgical reconstruction for high-pressure injection injuries to the hand

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Abstract

Introduction High-pressure injection injuries to the hand result from injection of substances by high-pressure industrial devices. These are rare lesions with high risk of substantial long-term morbidity. Tissue defects resulting from staged debridement require skin grafting or vascularized island flap coverage. Hand therapy is an important part of the complex rehabilitation of such patients. The objective is to present complex surgical reconstruction of severe high-pressure injection injury of the hand aimed at preserving limb function. **Material and methods** Methods and results of surgical reconstruction of a patient with severe high-pressure injection injury of the hand treated at the Research Institute – S.V. Ochapovsky Regional Clinic Hospital No.1 in 2018–2019. **Results** Short-term result of surgical treatment demonstrated complete skin restoration and maximum possible preservation of underlying deep anatomical structures of the hand. Subsequent surgical interventions were aimed at restoring the hand function. **Conclusion** The restorative treatment of a high-pressure injection injury of the hand includes the earliest possible primary surgical treatment of the wound with wide revision, maximum removal of the injected substance and non-viable tissues and prevention of secondary injuries and infection in the wound. Non-free vascularized flaps, full-thickness free grafts or split-skin autografts are used for skin reconstruction. Restoration of other functionally significant structures can be considered at a long term with wounds healed and autografts completely implanted. Hand therapy is integral to the comprehensive functional rehabilitation of the high-pressure injection injuries to the hand.

Keywords: wound, hand, high-pressure injection injury, flap, skin autograft, reconstruction, hand therapy

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INTRODUCTION

Injuries to the hands caused by industrial high pressure injections have been reported since the 1930s. C.E. Rees [1] reported an injury of a motor mechanic resulting from the injection into the tissues of oil under high pressure in working with diesel engines. Despite a benign initial appearance of the involved digit with minimal bleeding at the distal tip tissue necrosis led to amputation of the finger. With introduction of different spray mechanisms, paint sprayers and fluid amplifiers into the industry in the 50^{s} of the last century, high-pressure injection injuries to the fingers and the hand began to attract the attention of various specialists much more often [2]. The injury is termed "high pressure injury", "pressure gun injury", "high pressure injection" in the English-language literature. The term "barohydrotrauma" proposed by A.V. Konychev has become widespread in Russia [3]. The hand is involved in more than 90 % of cases.

Despite the multiple industrial usages of high-pressure guns injection injuries of the hand are rare. On average 1/600 hand traumas include an injection injury under high-pressure [4]. Large hand surgery centers face an average of 1-4 injection injuries per year [5]. The injection site is the hand in most cases. Although the nondominant hand is more commonly injured [6, 7] Wieder et al. [8] reported 13 out of 25 injections on the dominant hand, with > 50 % of these injuries sustained in the index finger. The thumb is the second most commonly injured digit, followed by10 % of palm injuries. The frequency of amputations in such injuries ranges from 30 to 48 % without adequate treatment [9]. A high-pressure injection injuries often looks insignificant and quite favorable in terms of prognosis. The real extent of damage in high-pressure injection injuries is hidden behind a small and frequently painless punctiform skin lesion on the finger or the hand. The clinical effect of such damage depends on several factors, such as injection pressure, chemical toxicity of the agent, the volume of the substance and the temperature.

Pressure plays a major role in pressure injection injuries and can vary from 40 to 800 bar. A pressure of 7 bar is sufficient to penetrate the skin. At higher pressure, direct contact of the equipment with the skin is not required for infiltration of the underlying tissues. The injected fluid spreads along the neurovascular bundles through the areas with the least resistance [11]. The force of the injection leads to tissue dissection of the finger or hand, compression of neurovascular bundles and vasospasm, tissue ischemia and, as a consequence, leads to thrombosis. Stretching of tissues resulting from direct exposure to a liquid agent and edema increase hydrostatic pressure, and tissue perfusion is impaired similarly to compartment syndrome. In addition to the pressure the volume of fluid injected into the tissues is of crucial importance. The palm has a greater ability to stretch than the finger tip. An equal volume of fluid injected into both

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areas will lead to a faster development of compartment syndrome in the finger than in the palm [12, 13]. The spread of the agent would depend on different density of the tissues encountered and can continue until it meets a dense structure. Thus, the injected substance spreads along the tendon sheaths and neurovascular bundles.

The second factor is chemical damage resulting from exposure to injected fluid on tissues. Some industrial fluids have pronounced cytolytic properties leading to cell destruction, necrosis and an intense inflammatory response. Injection of water, air or small amounts of veterinary vaccines causes mild tissue damage and ends favorably even without surgical treatment. Paints and solvents are more irritating substances and have larger cytolytic properties than water, some oils or greases. That is the reason why they also have a worse outcome than other fluids [14]. Solvents have a lower viscosity compared to paints and as a consequence a faster distribution along the tissues is apparent. The difference may be based on the type of paint. White spirit based paints cause tissue damage due to disintegration of cell membranes. Oil paints lead to a more intense inflammatory effect. Latex based paints have a smaller tissue-destroying effect compared to other based paints.

H. Bekler reported the temperature of the injected substance as one of the decisive factors in the pathogenesis of injury [15].

Infection is the next factor that plays a role in the extensive destruction of tissues. It can develop immediately after injection and in delayed manner that is more common. Ischemia and necrosis contribute to the occurrence. The use of broad-spectrum antibiotics is indicated.

The fourth and only factor that the doctor and the patient can influence is the time between injury and the beginning of adequate treatment. It is considered the most significant prognostic factor [16, 17, 18] and the risk of amputation increases with greater interval between the two. Some studies report a time limit of 10 h on which amputation risk is strongly raised. Other studies showed no significant difference in prognosis if the patient is treated within the first 24 h [13]. Stark et al. [22] concluded that patients who underwent a decompression within the first 10 h had a better outcome. Pinto et al. [20] reported that the longer the time between injury and the start of adequate treatment, the higher the risk of amputation. They had to remove the finger when the patient arrived for treatment 72 hours after the injury.

Earlier publications reported a wait-and-see or conservative strategy for high-pressure guns injection injuries of the hand that led to amputations of the affected fingers in most cases [10]. The experience accumulated showed that early operational removal of injected substance can provide a satisfactory result [1].

Information about the nature of the injected substance should be collected to rule out general intoxication. Toxicologists can be involved in the treatment to inject a specific antidote. Monitoring of vital signs is mandatory. The general systemic response can be manifested as renal failure, allergic reaction or hemolysis. White spirit injection injury is associated with the highest risk of intoxication [12]. Urgent and extensive repair under general anesthesia or brachial plexus blockade is reported to be an adequate treatment for high-pressure injection injury [9, 17]. Wong et al. [21] classified all high-pressure injection injuries of the hand into mild, moderate and severe based on the nature of the fluid, the time of initiation of adequate treatment and the clinical picture on admission. Minor injuries can be treated conservatively with the use of broad-spectrum antibiotics, tetanus prevention and control of the neuro-vascular condition of the fingers. Patients with moderate to severe trauma should undergo immediate surgical repair with decompression and extensive debridement in combination with antibiotics and tetanus prevention. Preparations of the third generation of cephalosporins are considered most effective [22].

Fluid squeeze-out or relief incisions fail to prevent additional subcutaneous damage. If there is a circulatory disorder and loss of sensitivity in the finger or the entire hand on admission, immediate amputation must be discussed with the patient [12]. Function and cosmetic appearance of the hand are essential for the patient. A full thickness skin graft and pedicled flaps are used to restore the integrity of the skin [23, 24].

The injected substances and necrotic tissues should be removed with abundant irrigation with saline solution. The use of solvents is undesirable because of the cytolytic effect and additional tissue damage. The operation is performed with use of a tourniquet without exanguination of the arm with Esmarch's bandage to prevent spread of the injected agent along the tendon sheaths and neurovascular bundles [25]. Wide incisions and debridement are usually recommended for maximum removal of necrotic tissues and foreign substances. Radiological and clinical observation is also recommended to determine the timing for surgical treatment. A negative pressure wound therapy can be useful for maximum removal of foreign bodies and a better prognosis of treatment [26, 27]. Patients should be informed about the risk of amputation and late complications of severe injury. Staged surgical treatments, amputations, as well as reconstructions using flaps are necessary to save the limb [21]. There is often a need for several debridments or necrectomies, and then reconstructions using skin autografts, island or free flaps [20, 21]. Sometimes open wound management is preferable [20]. The patient should wear a palm splint after surgery. Physical therapy is essential for the hand function. Active and passive finger mobilization is provided in the first 3 weeks to be followed by intensive hand therapy and rehabilitation for a period of 6 to 12 weeks [4].

Delay in treatment may result in irreversible tissue damage, impairment of hand function and even amputation. Oleogranulomas, fibrogistiolytic tumors, squamous cell carcinoma are described as late complications in rare cases [28, 29, 30]. Studying the literature we encountered a rare occurrence of high-

pressure injection injury of the hand, a significant number of possible complications and lack of a description of the vascularized flaps that can be applied in the treatment of the pathology.

The objective was to present complex surgical reconstruction and plasty of severe high-pressure injection injury of the hand aimed at preserving limb function.

MATERIAL AND METHODS

A clinical case of a high-pressure injection injury of the hand surgically treated in the State Medical Institution "Research Institute-KKB No. 1 named after Professor S.V. Ochapovsky" is presented. The study was performed in accordance with ethical principles for medical research involving human subjects stated in the Declaration of Helsinki developed by the World Medical Association as revised in 2000 study and Order of the Ministry of Health of the RF dtd 19th June 2003 No. 266 on Clinical Practice Guidelines in the Russian Federation. Written informed consent was obtained from all patients for publication of the findings without identifying details.

RESULTS

A 28-year-old patient L. suffered an injury to his left hand working on a machine injecting plastic heated to 200 °C into a melting mold. The patient was taken to the trauma department of the city hospital by an ambulance team and underwent primary surgical treatment including wide opening of the wound, removal of frozen plastic and excision of non-viable tissues. The patient was transferred to the Research Institute of the Regional Clinical Hospital No. 1 for specialized treatment after 3 days (Fig. 1–2). The patient underwent a staged surgical debridement next day (4 days after injury), (Fig. 3). Necrotized tendons of extensors and flexors of the 3rd, 4th fingers, interosseous and lumbrical muscles were excised. Wound defects of the hand were simultaneously closed with non-free vascularized flaps: the posterior flap of the forearm was moved to the dorsum without compromising major vessels of the limb (Fig. 4 and 5), and allowed for defect closure on the palmar aspect of the hand with a non-free "radial" flap (Fig. 6 and 8).

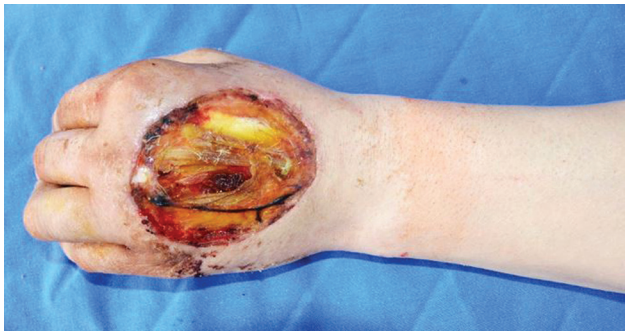

Fig. 1 Appearance of the dorsum on admission to the hospital

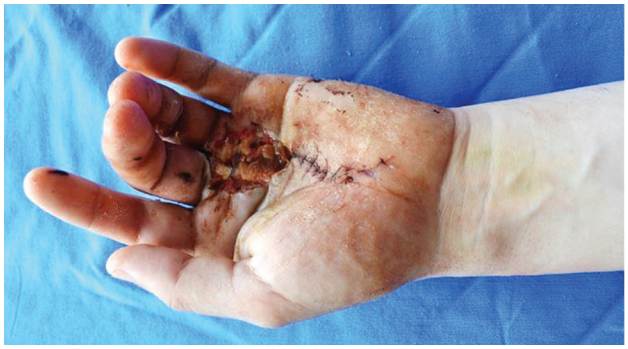

Fig. 2 Appearance of the palm on admission to the hospital

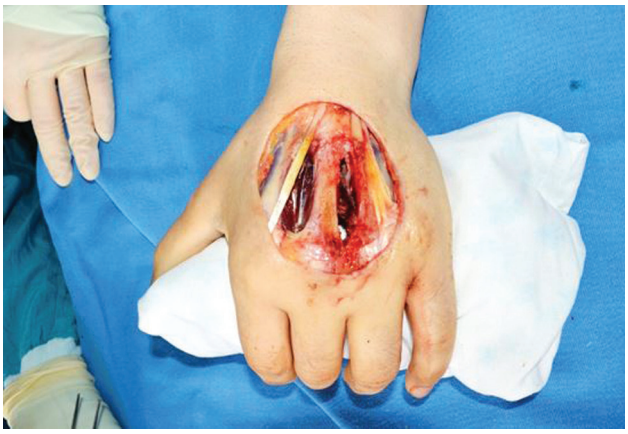

Fig. 3 Appearance of the hand after debridement

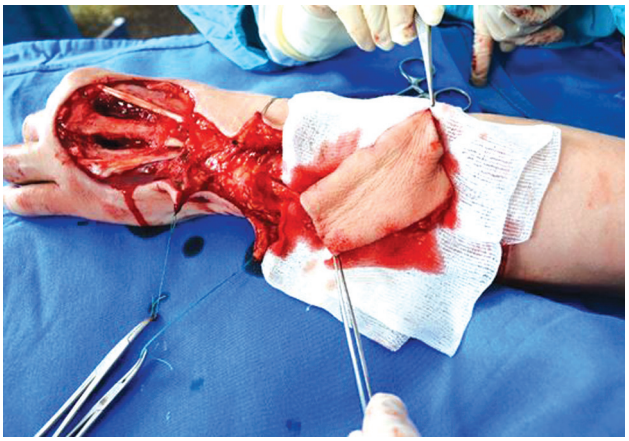

Fig. 4 A vascularized skin-fascial flap raised on the posterior aspect of the forearm

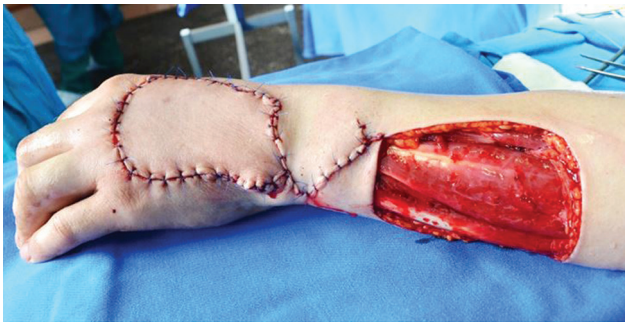

Fig. 5 Defect of the dorsum closed with vascularized forearm flap

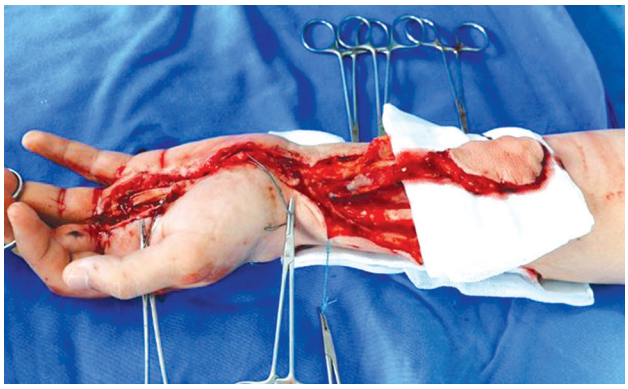

Fig. 6 A vascularized skin-fascial flap formed on the radial vascular bundle of the forearm

The donor defects of the forearm were covered with free full-thickness skin autografts 1 mm thick cut off by a rotator electrodermatoma from the lateral surface of the left shoulder. The plasty for the resulting wound defect was performed with a split autograft 0.25 mm thick with a perforation index of 1:4. The ChitoPran biological wound dressing was used for the plastic area to reduce the healing time (Fig. 7–9).

The limb was immobilized with a plaster splint for 3 weeks after the operation. Starting from the seventh day after the operation, a course of hand therapy aimed at preserving the full range of passive and active movements in the fingers of injured hand was performed under the supervision of a specialist. Hand therapy was produced throughout the restorative treatment of the patient and included plasty of the extensor tendons of the 3rd, 4th fingers with free non-vascularized autografts from the tendons of the long extensors of the 4th, 5th toes of the left foot. A two-stage plasty of the tendons of the deep flexors of the 3rd, 4th fingers consisted of sequential implantation of silicone endoprostheses and the subsequent replacement with free non-vascularized autografts of the tendons of the long extensors of the 4th, 5th toes of the right foot. Each intervention was supplemented by mandatory step-by-step degreasing of the survived radial flap. Rehabilitation of the hand allowed for the hand function maximally regained (Fig. 10, 11) and the patient could return to the job.

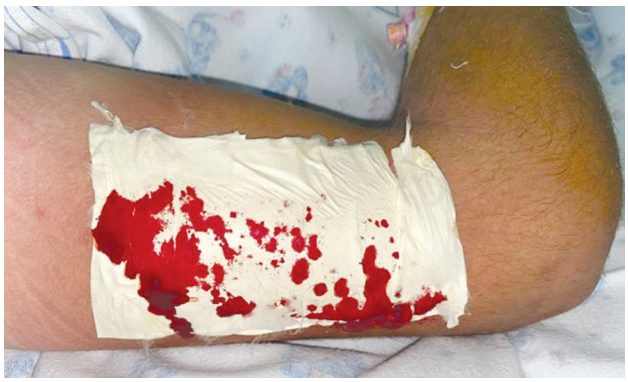

Fig. 7 The donor wound with autograft harvested and covered with Chitopran biological wound dressing

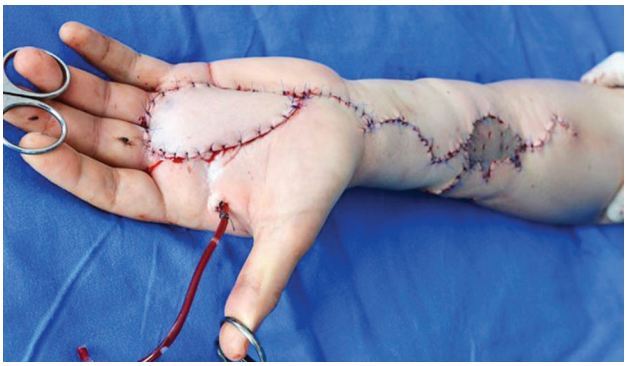

Fig. 8 Defect closure on the palmar aspect of the hand with a non-free "radial" flap

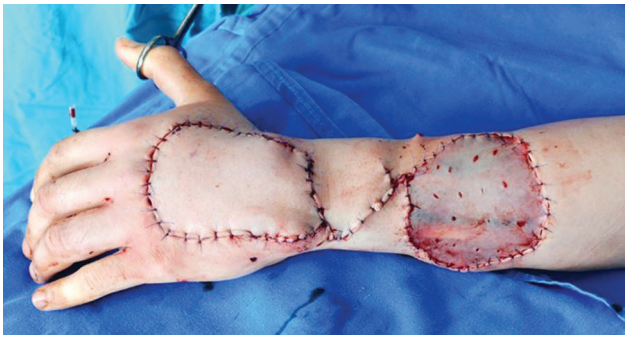

Fig. 9 Donor defect of the forearm covered with free full-thickness skin autograft

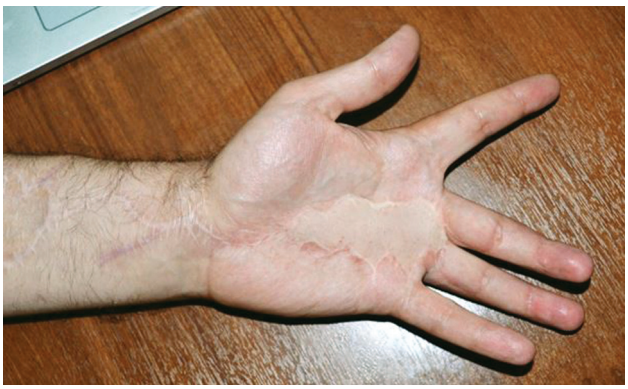

Fig. 10 Appearance of the hand at 1 year of injury (extension of the fingers)

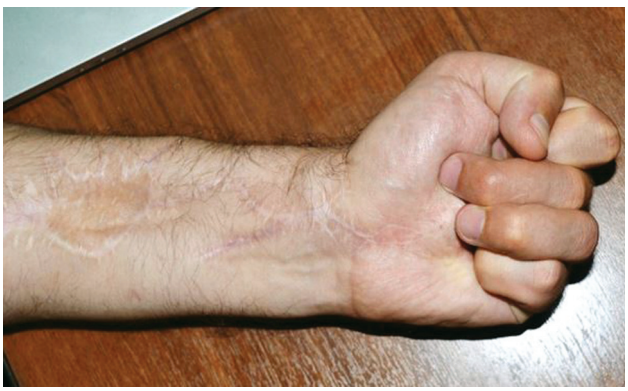

Fig. 11 Appearance of the hand at 1 year of injury (flexion of the fingers)

DISCUSSION

A high-pressure injection injury of the hand rarely seen in everyday practice can lead to serious consequences up to the loss of a finger or the hand with untimely and non-radical surgical care. The treatment includes a wide surgical exploration of the wound with exposure of the leakages of the injected substance and decompression of the neurovascular bundles. Imaging modalities can be employed for accurate preoperative planning. Computed tomography can be used on admission, and MRI can be utilized later to examine the limb. Abundant irrigation of the wound with saline solution is essential to remove toxic products and tissue discharge [27].

We have not found clear indications for the preferred use of split skin autografts or vascularized flaps in the available literature. Therefore, we support the concept generally accepted in plastic surgery [31]: vascularized flaps is a good option in absent inflammation of the wound and exposure of structures such as nerves, vessels, tendons. The priority use of techniques are those that do not compromise major vessels, such as the dorsal flap of the forearm we used. The use allowed us to raise the island skin-fascial radial flap of the forearm to reconstruct the palmar surface of the hand without decompensation of blood circulation. The flap on the radial vascular bundle appears to be preferable for reconstructive surgery in a trauma or burn unit because its use does not require special microsurgical equipment of the operating room and thorough microsurgical training of the operating surgeon. Split or full-thickness non-vascularized skin autografts are successfully used to close superficial defects and granulating wounds. A thin split skin autograft can be employed for a wound of a functionally significant area with a risk of infectious complications in some cases. Late reconstruction of scarry deformity with plasty using a vascularized flap is a safer technique for the scenario. Reconstruction of other lost structures, such as the tendons of the digital flexors and extensors is performed in the next stages with adequate soft tissue cover restored and may be accompanied by procedures to degrease the flap. Hand therapy and rehabilitation is also an important component of the rehabilitation for patients with high-pressure injection bone injury. The hand should be immobilized with a plaster splint for the first 5–7 days. With decreased edema and inflammation, a rehabilitation aimed at prevention of contractures and restoration of the range of passive and, if possible, active motion in the fingers and the wrist can be initiated with the help of a specialist.

CONCLUSION

High-pressure injection injury of the hand is a severe injury that requires emergency surgical treatment and a comprehensive approach. The treatment includes a wide surgical exploration of the wound with exposure of the leakages of the injected substance and decompression of the neurovascular bundles, maximum removal of foreign bodies and non-viable tissues, abundant irrigation of the wound with saline solution. The wound is not sutured and is treated in an open manner or with the use of negative pressure therapy. The patient should be informed about the possibility of primary or delayed amputation. Anesthesiology and resuscitation service is essential for a possible resorptive toxic effect of the injected substance. Subsequent staged surgical treatments are aimed at removing the remaining leakage of the injected substance, non-viable tissues, preventing infection of the wound and preparing it for plastic closure. Restoration of the skin is considered with minimal risk of infection and with no necrotic and non-viable tissues, no inflammation in the wound. Non-free vascularized flaps are practical for plastic surgery of deep defects and exposed vessels, nerves and tendons and such functionally important areas as the palm surface, finger joints. Free non-vascularized full-thickness or split skin autografts are used in other cases. Reconstruction of other lost functionally significant structures, such as the tendons of the fingers, is produced with adequate soft-tissue cover of the hand regained. Hand therapy and rehabilitation aimed at prevention of contractures of the hand joints, scarry adhesions, restoration of the range of passive and active motion and the working capacity of the hand as an entity is an important component of the treatment of patients with high-pressure injection trauma. The cohort of patients is to be treated in the regional trauma and orthopaedic centers with available services of different medical specialists including hand surgeons, traumatologists, plastic surgeons, toxicologists, emergency physician, purulent-septic surgeons, rehabilitologists and hand therapists. The patient in our series received a severe high-pressure injection injury and could return to normal work without significant functional loss as a result of timely and comprehensive surgical treatment.

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