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Hand

Optimal Irrigant in High Pressure Paint Injection Injuries of the Hand

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Background: High pressure injection injury to the hand with paint leads to amputation rates near 48%. Historically, authors utilized saline irrigation alone, but have high reoperation rates. We conducted a cadaveric study to determine the ideal detergent for effective paint removal from the soft tissue.
Methods: Two cadaveric hands were amputated from the same cadaver. The left and right hand digits were injected with flat white latex-based paint and flat white oil-based paint, respectively. Each digit received a longitudinal incision and was scrubbed for 120 seconds with 50 mL of a randomly assigned detergent and no detergent (saline) as the control. After achieving a lather, each finger was cleansed with 50 mL saline before being evaluated by two blinded hand surgery faculty. Reviewers assessed the washouts as adequate or inadequate, in order to generate a Kappa statistic and measure inter-rater reliability prior to ranking each digit (1 through 5) (ie, 1 = most paint-free soft tissue).
Results: The two hand faculty had an inter-rater reliability of 0.70. Both reviewers ranked povidone-iodine 10% or Johnson & Johnson shampoo as the best irrigant for latex-based paint. In oil-based paint, povidone-iodine 10%, Johnson & Johnson, & Techni-care were ranked as top three. All reviewers reported detergents were better than saline alone.
Conclusions: The addition of detergent created an irrigant that removed both latex- and oil-based paint better than normal saline alone. Based on these results, surgeons treating high-pressure injection injury should consider using Povidone-Iodine 10% or Johnson & Johnson baby shampoo for latex- or oil-based paint.
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INTRODUCTION

High pressure injection injuries (HPII) to the hand are a form of occupational trauma occurring with the use of industrial strength pressure injectors. About 60% of these injuries involve high pressure injection of oil or paint, grease, and various cleaning agents.[1–3] These injuries can be deceptively benign in appearance but are associated with amputation rates of up to 48%.[4] The cytotoxicity of oil-based paint and paint thinners present additional challenges to the hand surgeon, with amputation rates of 58%.[5] Tissue necrosis and ischemia secondary to compartment pressure, direct tissue damage from the injected material, and secondary acute inflammation are factors involved in the high amputation rates. The mainstay for management of these high pressure paint injection injuries is urgent decompression, surgical debridement, and copious irrigation. However, there is no literature germane to detergent selection for the removal of paint. Historically, most authors have advocated for the use of normal saline irrigation; others have endorsed the addition of postoperative betadine whirlpools.[6,7] However, no studies have been performed to evaluate the ideal detergent use in high pressure paint injection injuries. We conducted a cadaveric study to determine the ideal detergent for effective paint removal.

MATERIALS AND METHODS

This study received a waiver of institutional review board approval by the University of California, Davis. Cadaveric hand specimens for testing were made available through the University of California, Davis Anatomical Materials

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Program (Fig. 1). Funding of specimens was provided by an educational grant via Integra LifeSciences. The goal of this experiment was to determine which widely available detergents are most efficacious in irrigating and debriding both latex- and oil-based paint. Two cadaveric hands were amputated from the same cadaver, and each digit was injected with 3 mL of paint (using a 10 mL syringe and 18-gauge needle) to simulate high pressure paint injection injury. The left and right hands were injected with flat white latex-based paint and flat white oil-based paint, respectively. Each digit was injected at the radial aspect of the proximal phalanx shaft, to mimic the tracking of paint along the neurovascular bundle, as described in the literature, and then allowed to sit inside the soft tissue for 1 hour[1] (Fig. 2).

The right hand injections were delayed by 30 min, to standardize how long the soft tissue was exposed to the paint (1 hour), before being washed out. One hour after paint injection, each digit underwent a central, volar, longitudinal incision from the metacarpophalangeal joint to the distal interphalangeal joint, with a #15 blade. Skin flaps were then created and retracted using 3-0 nylon suture, to facilitate proper exposure of the fingers' soft tissue. Each digit was then scrubbed for exactly 120 seconds with an E-Z Scrub 160 brush, using 10 mL of normal saline, and 50 mL of a randomly assigned detergent including no detergent (normal saline control), povidone-iodine 10% (PVP prep) (Medline, Northfield, Ill.), Johnson & Johnson baby shampoo (New Brunswick, N.J.), Castile soap (Aplicare, Meriden, Conn.), and Techni-Care surgical scrub (Care-Tech Laboratories, St. Louis, Mo.) (Tables 1, 2). After 120 seconds of achieving a proper lather, the finger and subsequent lather was cleansed with a 50 mL flush of normal saline from a Tumi syringe. Each digit was then photographed (see Figs. 3, 4); photographs were reviewed by two attending hand surgeons, who were both blinded to detergent use. Reviewers were asked to assess the washout of each digit as either adequate or inadequate, to generate a Kappa statistic and measure inter-rater reliability of the two blinded attendings. Secondarily, for each hand, reviewers ranked each digit (1 through 5), with a rank of 1 designating the most efficacious washout (ie, the most paint-free soft tissue).

Takeaways

Question: What irrigant removes paint (oil or latex) from the soft tissues of the hand most effectively after high pressure injection?

Findings: Oil-based paint is best removed with povidone iodine and Johnson & Johnson baby shampoo. Latex-based paint is best removed with povidone iodine, Johnson & Johnson baby shampoo, and Techni-care surgical scrub. Saline is the least effective.

Meaning: High pressure injection injury with latex- or oil-based paint should be irrigated with betadine (povidone iodine) or Johnson & Johnson baby shampoo. Detergent-based irrigants are more effective than saline alone.

RESULTS

The soft tissues of both cadaver hands were analyzed by each double-blinded hand faculty member and evaluated for adequacy of washout (Table 3). The two hand attendings had an inter-rater reliability measurement of 0.70, which indicated that they agreed substantially on the quality of each irrigated finger.

Oil-based Paint

In the right hand that was injected with oil-based paint, evaluator one found that PVP prep, followed by Johnson & Johnson baby shampoo achieved a washout superior to the other three irrigants used in the experiment. Similarly, evaluator two found that Johnson & Johnson baby shampoo worked superiorly in cleansing the digits' soft tissue

Fig. 1. Experimental setup of both the left and right hand of the same cadaver specimen before the injection of latex- and oil-based paint.

Fig. 2. Two researchers inject 3 ml of flat white latex-based paint into the radial aspect of each digits' proximal phalanx (see left hand).

of oil-based paint, while ranking PVP prep second. Both evaluators felt that saline achieved a washout worthy of a third place ranking, with Castile soap and Techni-Care scrub achieving the least adequate results (Table 4).

Latex-based Paint

In the left hand digits that were injected with latex-based paint, both evaluators differed greatly on which irrigant achieved the most optimal washout. However, each evaluator felt that all the irrigants achieved a better result than saline alone, coming in at number five in both of their rankings. Evaluator one felt that Techni-Care scrub removed latex paint the best, ranking it number one, followed by PVP prep, Johnson & Johnson baby shampoo, and Castile soap, respectively. However, evaluator two ranked PVP prep number one, followed by Johnson & Johnson baby shampoo, Techni-Care scrub, and Castile soap, respectively (see Table 5). Regardless of individual evaluator rankings, PVP prep achieved a washout worthy of a first and second place ranking, in both oil-based and latex-based paint injuries.

Table 1. Random Irrigant Assignment Based on Right Hand Digits: Oil-based Paint

Right Hand: Oil-based Paint	Irrigant
Thumb	J&J baby shampoo
Index finger	Castile soap
Long finger (middle)	Techni-care scrub
Ring finger	Povidone iodine
Small finger	Saline

Table 2. Random Irrigant Assignment Based on Left Hand Digits: Latex-based Paint

Left Hand: Latex-based Paint	Irrigant
Thumb	Castile soap
Index finger	Saline
Long finger (middle)	Techni-care scrub
Ring finger	Povidone iodine
Small finger	J&J baby shampoo

DISCUSSION

We performed a cadaveric study, comparing the relative efficacy of various detergents in removing both latex- and oil-based paints. The optimal irrigant in a HPII with paint is one that is tailored to the chemical properties of the injected agent. As per current recommendations, a HPII is managed with IV antibiotics (typically a first- or third-generation cephalosporin or gentamycin), tetanus toxoid, urgent surgical decompression, irrigation, and debridement.[6–10] Our study aimed to optimize the approach to washout for high pressure paint gun injuries by exploring the efficacy of various irrigants that are readily found and available in most hospitals. Many options exist when considering the various soaps, scrubs, and other detergents found in the standard hospital setting. However, literature regarding HPII often only supports the use of normal saline and/or lactated ringers when irrigating and debriding these traumatic wounds.[1,11] Interestingly, Failla & Linden found saline lavage inadequate due to solubility issues.[7] Furthermore, paints tend to bind to fat lobules within the subcutaneous tissues of the finger. They proposed the idea of developing an antidote that could ideally be applied to the soft tissues of an injured finger, before operative intervention either topically or via injection.[12] Until such time as specific antidotes are created, utilization of easily available detergents in the hospital setting is the current standard. Our study helps delineate the more efficacious detergents to use based on the type of paint injected. We have shown that the use of detergent is more effective than normal saline alone for irrigation. Oil-based paint injuries are better cleared from the soft tissue using either Johnson & Johnson baby shampoo or PVP prep. Latex-based paint injuries should use either Johnson & Johnson baby shampoo, Techni-Care scrub, or PVP prep during irrigation and debridement. Interestingly, saline was ranked as the least efficacious irrigant in the hand containing latex paint. This finding alone suggests that literature reporting saline as the standard of care likely leads to suboptimal washouts and further contributes to reoperation and other associated morbidities.

Detergent-containing irrigants likely performed more effectively than saline due to the presence of surfactants. Johnson & Johnson baby shampoo contains sodium laureth sulfate, both a popular foaming agent and surfactant.[13] However, Medline advertises the presence of surfactants in all of their scrub preparations, including PVP

Fig. 3. Photographs of right hand digits that were injected with oil-based paint, followed by decompression, irrigation, and debridement with randomly assigned irrigants. Status post irrigation and debridement of the thumb (J&J baby shampoo, A), index finger (Castile soap, B), middle finger (Techni-care scrub, C), ring finger (povidone iodine, D), and small finger (saline, E) of the right hand status post injection of oil-based paint.

prep.[14] Surfactants are amphiphilic molecules that have hydrophobic and hydrophilic parts.[15] When added to liquids, they reduce the surface tension of water, thereby increasing its spreading and wetting properties.[15] When detergents are added to oil-containing liquids such as paint, surfactants help place the oils in suspension, and subsequently pull the oil into the detergent solution.[16] Additionally, water tends to rupture the chemical bonds on the surface of both oil and latex-based paint via a hydrolytic effect.[17] The dissociation of paint through these interactions allows for surfactants in the detergent to bind resins, pigments, and other dispersed chemicals.[18]

Although there has been concern amongst past literature regarding antiseptic solutions and their potential for tissue cytotoxicity,[19–21] none of the surfactant-containing solutions utilized in our study mimicked the solutions in the aforementioned research except for povidone-iodine, which has since been supported by both animal and in vivo wound healing studies, noting no consistent cytotoxicity or inhibitory effects on wound healing for concentrations up to 10%.[22–24] Furthermore, intraoperatively available sterile povidone-iodine is often at a concentration of 3%, which showed no significant reduction in cell viability even in the literature reporting concern for adipose stem cells.[21]

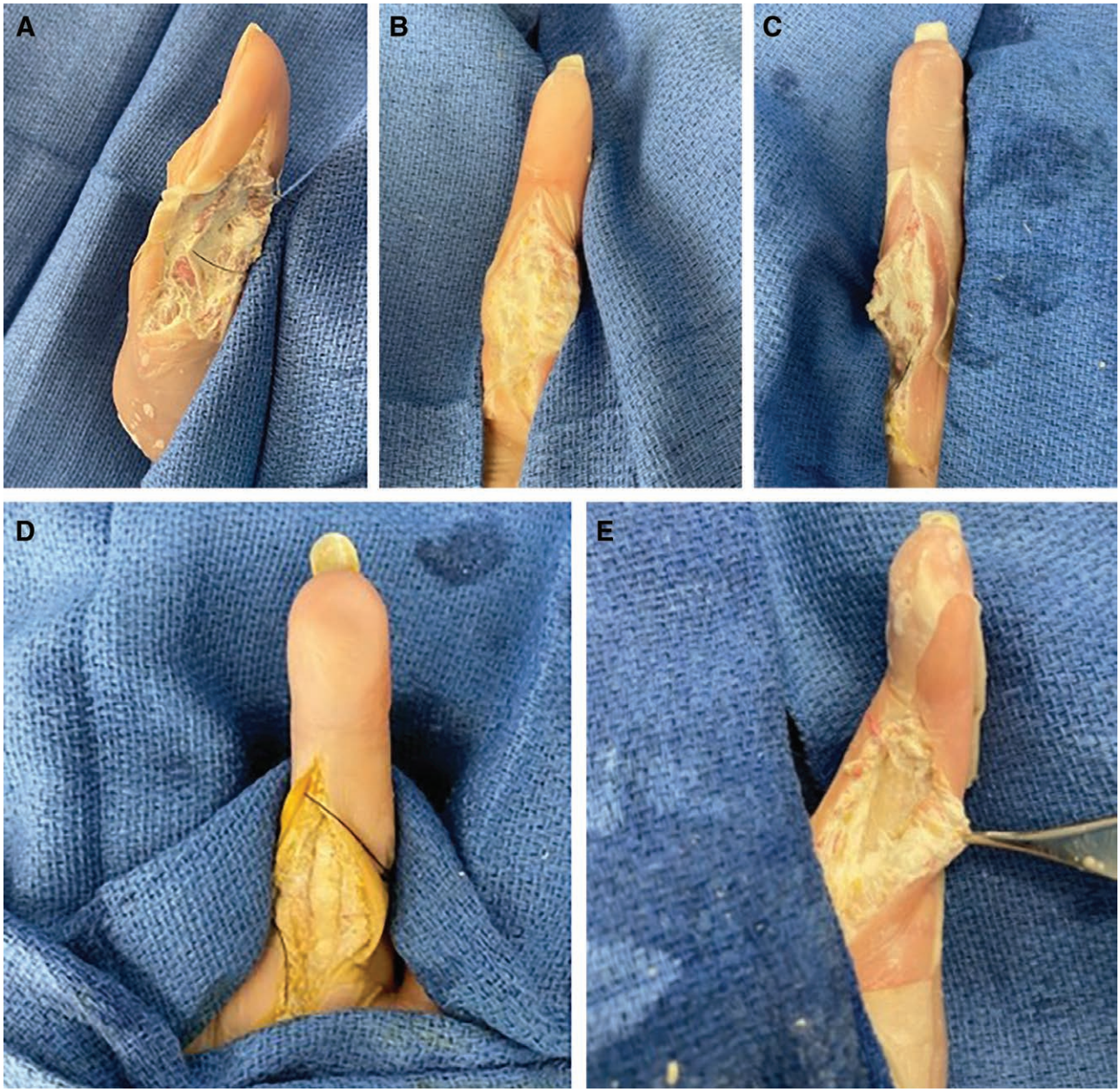

Fig. 4. Photographs of left hand digits that were injected with latex-based paint, followed by decompression, irrigation, and debridement with randomly assigned irrigants. Status post irrigation and debridement of the thumb (Castile soap, A), index finger (saline, B), middle finger (Techni-care scrub, C), ring finger (povidone iodine, D), and small finger (J&J baby shampoo, E).

In addition to decompressing the finger to prevent and circumvent the effects of compartment pressure, it is also important to prevent the acute inflammation that occurs secondary to the tissues reaction to chemical injury and foreign material. This can continue until all foreign material is removed.[25] Chemically induced inflammation can lead to vasospasm and ischemia, with worsening tissue necrosis despite urgent and adequate surgical decompression. To reduce the risk for continued tissue necrosis and amputation, it is imperative that all foreign material is removed at the earliest instance. Although meticulous surgical debridement under surgical or even operating microscope magnification can be performed, it risks damage to the neurovascular bundles, tendons and ligaments. Utilizing an effective detergent for the type of paint used can circumvent these issues.[12] Although the benefits of achieving an optimal washout is obvious in the acute setting of a HPII (ie, preventing infection, re-operations, and amputations), it can also prevent the chronic changes associated with retained paint material such as formation of oleogranulomas, foreign body granulomas, and even fibrohistiocytic tumors.[25–27]

Our study suggests detergents are superior to saline washout alone, and the use of normal saline in high pressure latex-based paint injection injuries should thus be reserved for cases in which all other alternative

Table 3. Evaluation of Washout Adequacy, for Each Digit on Each Hand, Based on Gross Soft-tissue Appearance (See Comparison of Both Evaluators)

	Left Hand					Right Hand				
Digit	T	IF	LF	RF	SF	T	IF	LF	RF	SF
Evaluator 1	I	I	A	A	I	A	A	A	A	A
Evaluator 2	I	I	I	A	I	A	I	I	A	A

T, Thumb; IF, Index Finger, LF, Long Finger; RF, Ring Finger; SF, Small Finger; A, Adequate; I, Inadequate.

Table 4. Comparison of Evaluator Rankings for Irrigant Efficacy in Debriding Oil-based Paint

Right Hand: Oil-based Paint Irrigant Ranking	Evaluator 1	Evaluator 2
1	Povidone iodine	Johnson & Johnson
2	Johnson & Johnson	Povidone iodine
3	Saline	Saline
4	Castile soap	Techni-care scrub
5	Techni-care scrub	Castile soap

Table 5. Comparison of Evaluator Rankings for Irrigant Efficacy in Debriding Latex-based Paint

Left Hand: Latex-based Paint Irrigant Ranking	Evaluator 1	Evaluator 2
1	Techni-care scrub	Povidone iodine
2	Povidone iodine	Johnson & Johnson
3	Johnson & Johnson	Techni-care scrub
4	Castile soap	Castile soap
5	Saline	Saline

irrigants are unavailable. Castile soap received the second worst efficacy designation and should also be avoided. Alternatively, one of the top three irrigants (including PVP prep, Techni-Care scrub, and Johnson & Johnson baby shampoo) should be considered with the final choice being based on individual surgeon preference. Our study has limitations, including the limited number of cadaver hands used. Secondly, from a technical standpoint, the white paint used in the injection has a lower contrast to tissue and may have affected detection rates. Similarly, PVP prep efficacy may have been overstated owing to its propensity to stain tissue a tan color, although it did appear to grossly displace paint more effectively than other irrigants during the experiment. And finally, non-viable cadaveric tissue may react differently than normal viable tissue and may not be directly translatable to the clinical setting. Acute inflammation, progression of tissue necrosis, amputation rates, and reoperation rates all affect final clinical outcomes.

In conclusion, we recommend using either Johnson & Johnson baby shampoo or PVP prep for oil-based paint injuries and either Johnson & Johnson baby shampoo, Techni-Care scrub, or PVP prep for latex-based paint injuries. Larger studies involving higher sample numbers, more evaluators and the addition of emulsification studies should be performed. Furthermore, clinical studies are required to elucidate the ideal irrigants and detergents in real-life scenarios. Our study takes an important albeit small step toward an evidence-based approach to the treatment of these injuries, hopefully reducing reoperation rates, amputation rates, and secondary morbidities. In addition, studies looking at emulsification tests for specific offending agents can help us to further isolate the optimal irrigant combination based on solubility.

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REFERENCES

1. The Orthopedic Knowledge Network. High-pressure injection injuries of the hand. Available at http://www.wheelessonline.com/ortho/high_pressure_injection_injuries_in_the_hand. Accessed November 15, 2020.
2. Zamkowski M, Ropel J, Baczkowski B, et al. High pressure injection injury of the thumb. Case Study. *Ortop Traumatol Rehabil.* 2015;17:543–552.
3. Gelberman RH, Posch JL, Jurist JM. High-pressure injection injuries of the hand. *J Bone and Joint Surg.* 1975;57:935–957.
4. Dailiana HZ, Kotsaki D, Varitimidis S, et al. Injection injuries: seemingly minor injuries with major consequences. *Hippokratia.* 2008;12:33–36.
5. Schoo MJ, Scott FA, Boswick JA. High pressure injection injuries of the hand. *J Trauma.* 1980;20:229-238.
6. Bekler H, Gokce A, Beyzadeoglu T, et al. The surgical treatment and outcomes of high-pressure injection injuries of the hand. *J Hand Surg Eur Vol.* 2007;32:394–399.
7. Failla JM, Linden MD. The acute pathologic changes of paint-injection injury and correlation to surgical treatment: a report of two cases. *J Hand Surg Am.* 1997;22:156–159.
8. Mirzayan R, Schnall SB, Chon JH, et al. Culture results and amputation rates in high-pressure paint gun injuries of the hand. *Orthopedics.* 2001;24:587–589.
9. O'Reilly RJ, Blatt G. Accidental high-pressure injection-gun injuries of the hand; the role of the emergency radiologic examination. *J Trauma.* 1975;15:24–31.
10. Pappou IP, Deal DN. High-pressure injection injuries. *J Hand Surg Am.* 2012;37:2404–2407.
11. Pinto MR, Turkula-Pinto LD, Cooney WP, et al. High-pressure injection injuries of the hand: review of 25 patients managed by open wound technique. *J Hand Surg Am.* 1993;18:125–130.
12. Hogan CJ, Ruland RT. High-pressure injection injuries to the upper extremity: a review of the literature. *J Orthop Trauma.* 2006;20:503–511.
13. Gandhi I, Siva R, Ramamurthy K. Analysis of the foam generated using surfactant sodium lauryl sulfate. *Int J Concr Struct Mater.* 2010;4:55-62.
14. Medline Industries. Povidone iodine scrub solutions. Available at http://punchout.medline.com/product/Povidone-Iodine-Prep-Solutions/Skin-Scrub/Z05-PF07446?question=&index=P2&indexCount=2. Accessed November 15, 2020.

15. Britannica. *Surfactant*. Available at https://www.britannica.com/science/surfactant. Accessed November 15, 2020.
16. Zavenir Daubert. Aqueous cleaners: how they remove grease and oil? Available at http://www.zavenir.com/blog/aqueous-cleaners-how-they-remove-grease-and-oil/. Accessed November 15, 2020.
17. Tator KB. *Coating Deterioration. ASM Handbook. Volume 5B: Protective Organic Coating*. Vancouver, Canada: ASM International; 2015.
18. Bhairi SM, Mohan C.. *Detergents: A Guide to the Properties and Uses of Detergents in Biological Systems*. San Diego, Calif.: EMD Biosciences; 2007.
19. Franz T, Vögelin E. Aseptic tissue necrosis and chronic inflammation after irrigation of penetrating hand wounds using Octenisept. *J Hand Surg Eur Vol*. 2012;37:61–64.
20. Müller G, Kramer A. Comparative study of in vitro cytotoxicity of povidone-iodine in solution, in ointment or in a liposomal formulation (Repithel) and selected antiseptics. *Dermatology*. 2006;212 (Suppl 1):91–93.
21. Kim BS, Ott V, Boecker AH, et al. The effect of antiseptics on adipose-derived stem cells. *Plast Reconstr Surg*. 2017;139:625–637.
22. Bigliardi PL, Alsagoff SAL, El-Kafrawi HY, et al. Povidone iodine in wound healing: a review of current concepts and practices. *Int J Surg*. 2017;44:260–268.
23. van Meurs SJ, Gawlitta D, Heemstra KA, et al. Selection of an optimal antiseptic solution for intraoperative irrigation: an in vitro study. *J Bone Joint Surg Am*. 2014;96:285–291.
24. Vermeulen H, Westerbos SJ, Ubbink DT. Benefit and harm of iodine in wound care: a systematic review. *J Hosp Infect*. 2010;76:191–199.
25. Saadat P, Turla S, Vadmal M. Fibrohistiocytic tumor of the hand after high pressure paint gun injury: 2 case reports. *J Hand Surg*. 2005;30A:404-408.
26. Stefanato CM, Turner MS, Bhawan J. High-pressure paint-gun injury of the finger simulating giant cell tumor of tendon sheath. *J Cutan Pathol*. 2005;32:179–183.
27. Ştefănescu RL, Bordeianu I. High-pressure injection injury of the finger – a case presentation. *Clujul Med*. 2013;86:74–76.