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Dissemination pathways in high-pressure injection injuries of the hand: an experimental animal model

Elin yüksek basınçlı enjeksiyon yaralanmalarında dağılım yolları: Deneysel hayvan modeli

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Amaç: Yüksek basınçlı enjeksiyon yaralanmaları, el işlevlerinde ileri derecede kayıplara, hatta amputasyonlara neden olmaktadır. Bu çalışmada klinik uygulamalarda gözlemlediğimiz nörovasküler yayılımın deneysel çalışma ile gösterilmesi amaçlandı.

Çalışma planı: Çalışmada ortalama 200 gr ağırlıkta 10 adet erişkin Yeni Zelanda tavşanı kullanıldı. Ksilazin hidroklorid ve ketamin anestezisi altında, üçlü musluk bağlantı sistemi yardımıyla 1 ml siyah çini mürekkebi 4 atmosfer basınç altında enjektör iğnesiyle her iki üst ekstremite üçüncü parmak pulpasından uygulandı. İntrakardiyak enjeksiyonla deneklerin yaşamı sonlandırıldı. Toplam 20 adet üst ekstremite transhumeral kesildi. Elde edilen amputatlar %10'luk formalin solüsyonu içinde tespit edildi. Dekalsifikasyonu takiben amputatlardan parmak, bilek distal ve proksimalinden çeşitli seviyelerde örnekler alındı. Doku kesileri hematoksilen-eozin ile boyandıktan sonra incelendi.

Sonuçlar: Parmak seviyesinden yapılan transvers kesitlerde tüm örneklerde çini mürekkebinin öncelikle pulpada cilt altında toplandığı görüldü. Tüm örneklerde bilek distalinde üçüncü parmağın tendon kılıfları ile birlikte damar sinir yapılarının da çini mürekkebiyle boyandığı görüldü.

Çıkarımlar: Çalışmamızın bulguları, elin yüksek basınçlı enjeksiyon yaralanmalarında, literatürde belirtilen dokulara ek olarak, damar sinir paketlerinin de öncelikle ve ciddi şekilde etkilendiğini göstermektedir.

Anahtar sözcükler: İş kazası; debridman; parmak yaralanması/etyoloji/fizyopatoloji; el yaralanması/etyoloji; basınç; tavşan.

Objectives: High-pressure injection injuries of the hand may compromise the function of the hand or even result in amputations. Based on our clinical observations, we aimed to demonstrate neurovascular dissemination in an animal model.

Methods: Ten adult New Zealand rabbits with a mean weight of 200 g were used. Under xylazine-ketamine anesthesia and using a triple connection system, the rabbits were injected one milliliter of black Indian ink in the third finger tip of the upper limbs at 4 atmospheric pressure. The rabbits were sacrificed via intracardiac injections for transhumeral amputation of all the upper limbs. All amputations were fixed in 10% formalin, decalcified, and specimens obtained from fingers and distal and proximal regions of the wrist were stained with hematoxylin and eosin for histopathologic examination.

Results: Transverse sections of the third finger showed subcutaneous deposition of Indian ink particularly in the pulp in all the specimens. In addition, all specimens from the distal wrist showed penetration into fascia, tendon sheaths, and neurovascular bundles of the third finger.

Conclusion: Our results suggest that, in addition to the tissues mentioned in the literature, neurovascular bundles are primarily and seriously affected by high-pressure injection injuries of the hand.

Key words: Accidents, occupational; debridement; finger injuries/etiology/physiopathology; hand injuries/etiology; pressure; rabbits.

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Injection injuries are more frequently seen in emergency rooms with the increased usage of high pressure injection pistols in the industry. Due to relatively small initial insertion sites, and minor swelling of the adjacent peripheral tissue, they can be overlooked and undertreated.

Clinical course and pathology of these injuries with squeal requiring serious interventions as amputation have been well defined. Proper and efficient management of these patients depends on satisfactory debridement. The first prerequisite of this approach is the determination of affected tissues. The injected material reportedly infiltrates via tendon sheaths.[1,2] Our observations in 14 patients suggested intense accumulation of injected material around tendon sheaths, vascular structures and nerves (unpublished data).[3] We intended to investigate whether this accumulation is the result of spread through tendon sheaths or neurovascular structures constitute another important pathway of infiltration. The presence of loose adipose tissue with partially relatively lower resistive properties in fingers, and around neurovascular structures is well known. Injected material under high pressure can probably find its way through a potential cavity. To investigate our hypothesis, we planned an experimental animal study.

Material and method

In this study 10 adult New Zealand rabbits weighing approximately 200 g were used.. Anesthesia was achieved with 5 mg/kg xylocaine hydrochloride IM and 35 mg/kg ketamine IM. With a three stopcock system 1 mL black indian ink was administered with a syringe needle under 4 atmosphere pressure into the pulps of the 3. digits of both upper extremities. To obtain high pressure injection air within 50 mL injector was compressed at a rate of 1: 4. The required pressure was calculated according to the formula volume (mL) x pressure (mm Hg) and monitored with a manometer. A 4 atmosphere pressure was attained. At this pressure, indian ink rapidly infiltrated into tissues.

Rabbits were sacrificed with intracardiac injections. Twenty pieces of upper extremities were excised trans humeral. The amputated samples were fixed in 10 % formaldehyde solution. After decalcification various samples were taken from the digits, proximal and distal parts of ankles of the amputated extremities. Tissue cuts were stained with hematoxylene- eosin. With staining easy identification of spread of injected indian ink into tissues was intended.

Results

In pathologic anatomical examinations, determination of pathways of spread of the injected material and tissues infiltrated with ink were mainly emphasized. In all transverse sections done from digits, accumulation of indian ink was seen priorly within the pulps and subcutaneous tissue (Figure 1).

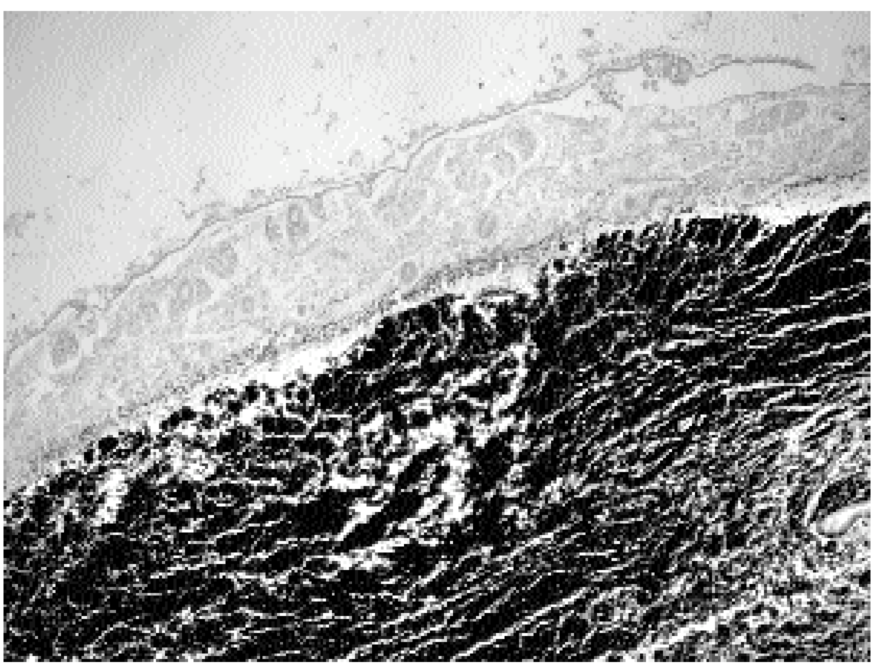

Figure 1. Indian ink accumulated within subcutaneous tissue (H-e x 40).

Table 1. Pathways of spread of injected materials in high- pressure injection injuries of hands: Experimental animal model

	Pulp	mutual nerves and arteries of 2. and 4. digits	3. region FDS FDP	m.palmaris longus	5. region FDS FDP	Median nerve	Radial artery	Ulnar artery	Ulnar nerve	m. flexor carpi ulnaris
Involved/total number of samples	20/20	20/20	20/20	8/20	16/20	4/20	4/20	6/20	1/20	1/20
Percentage (%)	100	100	100	40	80	20	20	30	5	5

FDS: m. flexor digitorum superficialis; FDP: m. flexor digitorum profundus

In all samples, involvement of distal part of the wrist, tendon sheaths of the 3 digits together with neurovascular structures in other words nervous branches of median nerve innervating 2. and 3. digits was seen. In this region we observed intense involvement of the subcutaneous tissue same as seen in the digital pulps.

When sections taken from proximal part of the ankle joints were examined, 16 out of 20 samples (80%) densely concentrated ink stains were detected within sheaths of m. flexor digitorium superficialis and profundus In addition, involvement of tendon of m.palmaris longus in 8 (40%) extremities were seen. In 6 of these 8 samples (30%) m. flexor digitorum was also stained. In 4 samples (20 %) surrounding porous adipose tissues of median nerve, and radial nerve were stained. In 6 extremities (30 %) involvement of ulnar artery and accompanying veins was observed, while only one section (5 %) demonstrated ulnar nerve involvement. In the same sample the observation of dense infiltration of m. flexor carpi ulnarıs sheath was evaluated as contamination. In two (10 %) samples any trace of ink was not found in the proximal part of the ankles which suggested inadequacy of the injection pressure (Table 1).

In sections some of the peripheral veins were filled with indian ink. Muscles, tendons, and subcutaneous tissue were completely intact, neurovascular bundle capillaries localized around major veins and arteries were full of ink (Figure 2).

Discussion

A pressure of 7 bars (700 kN/m2) applied on the skin impairs cutaneous integrity.14 Most of the injection pistols are operated at and over this pressure. In these types of industrial injuries the material easily diffuses into subdermis, and from there spreads into tissues. Finger pulps are rich in porous

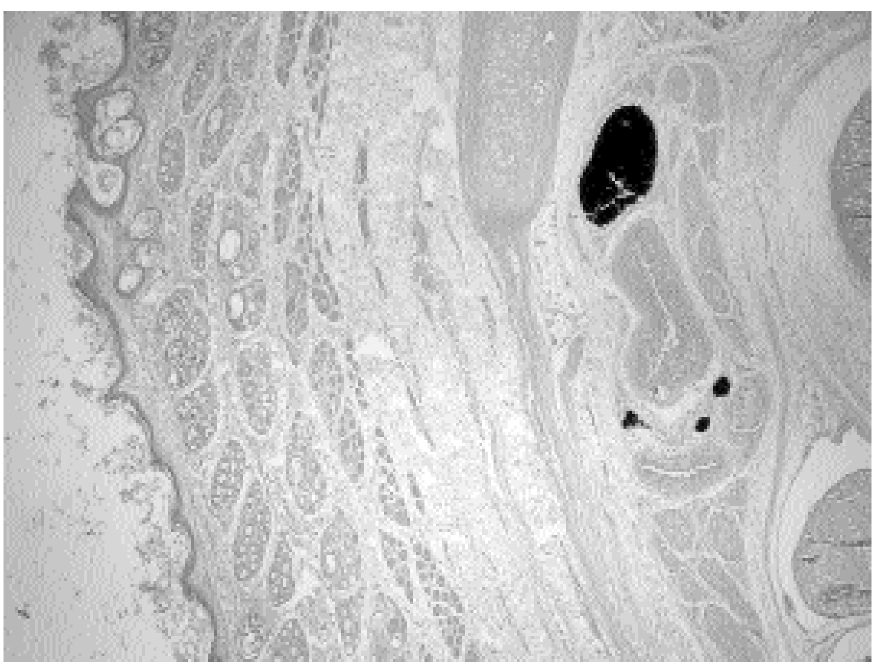

Figure 2. Uptake of ink within veins accompanying ulnar vein and artery (H-E x 100)

adipose tissue cells. Since they were subjected to injection material at maximal pressures, naturally in all of our samples accumulation of ink was detected within digital pulps and subcutaneous tissue. The outcome of injection traumas are determined by the type of the injected material, the site of injection, the degree of soft tissue involvement, timing of the treatment and the extent of the surgical intervention.[1, 5, 6] Damage incurred is the result of deterioration of circulation within tissue due to high pressure , chemical irritation of the material, and various mechanism as inflammation and infection.[7] Wong et al.[6] categorized injection traumas as mild, moderate, and serious and emphasized the necessity of early and adequate debridement.

In cases where surgical management is required, decompression, removal of all foreign materials and necrotic tissue from the environment, and irrigation of the wound with abundant amounts of serum are fundamental measures to be taken. In injection injuries exploration, debridement, and meticulous removal of foreign materials carry utmost importance.[2,8,9] Debridements are maintained till complete cleaning of the wound is achieved. Contaminated and death tissues are sources of infections. [10]

In our opinion the extent of soft tissue debridement is the critical issue in injection injuries. Inadequate debridement does not achieve anticipated benefit, and cause persistence of potential risks arising from contamination with foreign materials. Uncontrolled and extensive debridement compromises circulatory functions further. Unduly large or inadequate debridement can cause iatrogenic neurovascular injuries, and circulatory disorders due to chemical irritation. Acknowledgement of the mechanism of spread of injected material is very important with respect to planning of debridement.

In our study we observed the spread of indian ink not only through tendon sheaths, but also via fascial planes. Simultaneous involvement of profound and superficial flexors in 16 (80%) subjects indicates the importance of this pathway. However, it was noteworthy that some portion of the injected material infiltrated through tendon sheath, while the other portion spread within fascial planes outside the tendon sheath (Figure 3). Especially this finding suggest that injected material courses through the lesser resistive pathway.

Venous structures and capillaries coursing adjacent to the arteries were filled with ink. Spread of ink through neurovascular bundles as we detected previously was also observed in model extremities. Neurovascular spread of the injected material occurred through small diameter veins. Veins were especially infiltrated owing to their relatively lower intravenous pressures, and more vulnerable outer layers.

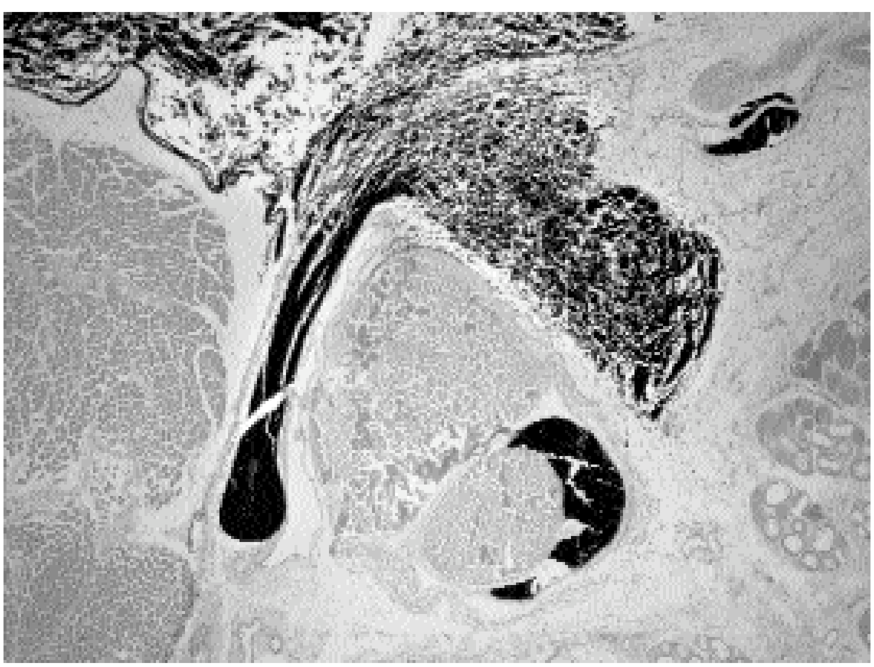

Figure 3. Spread of indian ink through sheaths and fascial tissues of deep and superficial flexor muscles (H-E x 200)

Generally we detected extensive subcutaneous depositions, and involvement of fascial planes, tendon sheaths and veins within neurovascular bundles. Under the light of these findings we can say that after high-pressure injection injuries, injected material accumulates firstly within subcutaneous tissue of the injection site, subsequently it spreads through tendon sheaths, fascial planes, and venous components of neurovascular bundles. Tissue resistance is thought to be the determinative factor in the preference of the pathway. In addition to tendon sheaths, perimuscular porous fatty tissue, and more importantly periarterial veins of neurovascular bundles are pathways of material spread.

Our findings demonstrate that in high-pressure injection injuries of the hand, in addition to the affected tissues cited in the literature, neurovascular bundles are particularly and seriously damaged, and in these types of injuries involvement of neurovascular bundles should be taken into account with respect to circulatory compromise.

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