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Klinik Çalışma

Unusual hand frostbite caused by refrigerant liquids and gases

Soğutucu gaz ve sıvıların neden olduğu lokalize el donukları

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BACKGROUND

The refrigerant liquids and gases used widely in industry, farming and medicine for their cooling properties may cause severe frostbite. Despite their widespread use, only a few reports on frostbite of the hand involving these liquids and gases have been published. In this study, the circumstances accompanying these injuries, several adjunctive therapies and preventive measures are discussed.

METHODS

A retrospective analysis of hand frostbite injuries was conducted between June 2005 to June 2009 in a burn care center in Istanbul, Turkey. Seventeen patients (13 men, 4 women) were treated for hand frostbite injuries due to contact with refrigerant liquids and gases.

RESULTS

There was a preponderance of male patients (76.5%). Ages ranged from 22 to 52 years (mean age, 30.82 years). Eleven patients were treated conservatively. The hospital stay for treatment of their burns ranged from 16 to 52 days, with a mean stay of 30 days.

CONCLUSION

Frostbite injuries of the hand are uncommon and their etiologies vary. Thus, the low incidence of these injuries and limited experience in handling rare cases of this nature may lead to misjudgments in treatment that can have grave consequences. Decreasing the exposure time is an important first step in the treatment approach. After exposure to gas, quick delivery of the patient to a burn center is essential.

Key Words: Cryogenic burns; cold injury; frostbite; hand burns; liquid nitrogen; refrigerant.

AMAÇ

Endüstri, tarım ve tıp alanında yaygın olarak kullanılan soğutucu sıvılar ve gazlar soğutma özellikleri nedeniyle elde şiddetli lokalize donuklara neden olabilir. Bu sıvı ve gazların yaygın olarak kullanımına rağmen, lokalize el donuklarını bildiren sadece birkaç olgu yayınlanmıştır. Bu çalışmada, el donuklarının tedavisi ve alınacak önlemler tartışıldı.

GEREÇ VE YÖNTEM

Bu geriye dönük çalışmada, Haziran 2005 ve Haziran 2009 tarihleri arasında İstanbul'daki yanık merkezine başvuran, soğutucu gaz ve sıvılara temas nedeniyle elde lokalize donuğu olan 17 hasta (13 erkek, 4 kadın) değerlendirildi.

BULGULAR

Çalışmaya dahil edilen hastaların %76,47'si erkekti. Hastaların ortalama yaşı 30,82 (dağılım, 22-52 yaş) olarak hesaplandı. Toplam 17 hastanın 11'i konservatif olarak tedavi edildi. Hastaların hastanede kalış süresi ortalama olarak 30 gün (dağılım, 16-52 gün) olarak hesaplandı.

SONUÇ

Elin lokalize donukları nadir olup, bu yaralanmaların etyolojisi çeşitlidir. Bu nedenle tedavi yaklaşımında bazı karmaşalar yaşanmaktadır. Tedavide, ilk yaklaşım maruz kalınan soğutucu gaz ve sıvıdan hastanın bir an önce uzaklaştırılması ve en yakın yanık merkezine hastanın nakledilmesidir.

Anahtar Sözcükler: Kriyojenik yanıklar; soğuk yaralanması; soğuk ısırığı; el yanıkları; sıvı nitrojen; dondurucu.

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Frostbite may be defined as the acute freezing of tissues when exposed to temperatures below the freezing point of intact skin. It is most commonly observed in the extremities and is usually seen in those between the ages of 30 and 49 years. The refrigerant liquids and compressed gases may cause frostbite when they are sprayed on the skin. The severity of frostbite is related to the temperature gradient on the skin surface and the duration of exposure.[1]

The refrigerant liquids and gases, such as chlorofluorocarbons (CFCs), liquid oxygen (LOx, LOX or Lox), liquefied petrol gas (LPG), liquid nitrogen, and liquid helium, which are used in different industries, farming, medicine, and chemical engineering, may cause severe frostbite on the hands.[2-6] The frostbite may cause cellular destruction and arterial vasoconstriction, leading to disordered vascular flow patterns and damage to the microcirculation.[2,3,7] The outcome is vascular thrombosis and dermal necrosis.[7]

The initial wound is hyperemic and edematous, without apparent tissue necrosis. The appearance of the superficial tissue is often an unreliable indicator of the viability of the underlying tissue. The injury may be more severe because the refrigerant agents penetrate through the skin more rapidly and deeper. As a result, in the care of frostbite injury, patience in allowing demarcation of nonviable tissues is recommended, which may take as long as two to three months. Therapy consists of tissue rewarming, prolonged watchful waiting and often delayed amputation.

To date, despite widespread use of refrigerant liquids and gases, few hand contact frostbite cases have been reported in the English literature.[2-6] Thus, the low incidence of these injuries may lead to misjudgments in management. The aim of this paper was to present our experience with frostbite injury to the hands due to contact with refrigerant liquids and gases.

MATERIALS AND METHODS

A retrospective analysis of hand frostbite injuries was conducted between June 2005 to June 2009 in Gulhane Military Medical Academy, Department of Plastic and Reconstructive Surgery, and Burn Center, which is tertiary burn care center in Istanbul. Seventeen patients (13 men, 4 women) were treated for hand frostbite injuries due to contact refrigerant liquids and gases. The data of these patients were obtained and were based on the analysis of medical records. Age and sex of the patients, mechanism of injury, site of frostbite area, and treatment regimen data were collected.

RESULTS

During this four-year period, 1670 burn patients were admitted to the burn center. Seventeen of them had hand frostbite injuries due to refrigerant liquids and gases. Characteristically, most of the injuries occurred at night. The characteristics of the hand frostbite injuries and patients are outlined in Table 1. There was a preponderance of male patients (76.5%). Ages ranged from 22 to 52 years (mean age, 30.82 years).

The mean interval between injury and primary operation was 38 days. Eleven of those patients were treated conservatively. The remaining six were operated: five patients had graft operation and one patient

Table 1. Patient data

No	Age	Sex	Cause of frostbite	Burn areas	The mean length of stay (days)	Follow- up (month)
1	22	Male	Liquid argon	Left hand	25	14
2	25	Female	Liquid nitrogen	Left & Right hand	32	8
3	38	Male	Freon gas	Right hand	16	8
4	52	Male	Propane gas	Left & Right hand	19	6
5	24	Female	Liquid helium	Right hand	25	3
6	26	Male	Liquid argon	Left & Right hand	44	14
7	26	Female	Liquid ammonia	Right hand	32	12
8	39	Male	Liquid oxygen	Right hand	25	10
9	42	Male	Butane gas	Left hand	34	6
10	25	Male	Freon gas	Right hand	52	16
11	27	Male	R 22 gas	Left & Right hand	26	8
12	36	Female	Liquid argon	Left & Right hand	25	14
13	38	Male	Liquid sulfur dioxide	Right hand	34	3
14	26	Male	R 22 gas	Right hand	31	10
15	22	Male	Liquid nitrogen	Right hand	24	8
16	29	Male	Liquid oxygen	Right hand	38	6
17	27	Male	Ethylene gas	Left & Right hand	32	11

Fig. 1. Appearance of frostbite burn caused by freon gas.

Fig. 2. Four days after the injury.

had partial finger amputation. The hospital stay for treatment of their burns ranged from 16 to 52 days, with a mean stay of 30 days. Postoperatively, range of motion exercises were performed to prevent contractures. The follow-up period ranged from 3 to 16 months.

Case 10- A 25-year-old man admitted to our burn care unit with frostbite involving the right hand. He reported that the frostbite was due to contact with the air conditioner gas called freon while he was trying to repair the air conditioner. While he was working, a freon gas leak occurred. He held his right hand through the hole to prevent the gas leak. The gas emission towards his right hand lasted for 30 seconds. Immediately after the exposure, the skin had turned white and cold. Afterwards, he had felt numbness and increasing pain in his hand. The initial physical examination demonstrated second-degree frostbite on the palm of the hand (Fig. 1). All the fingers were severely edematous. After 96 hours, the capillary circulation of the fingers was poor (Fig. 2). For this reason and the late onset of therapy, we decided to treat the patient with hyperbaric oxygen. HBOT was repeated daily for 14 days. After the first course of the treatment, we observed rewarming of the injured fingers and pink color at the borders of the affected parts. Remarkable improvement in the frostbite area was seen in daily consultation. Bacterial cultures obtained at the first debridement revealed the presence of *Staphylococcus epidermidis*. The patient was treated with intravenous antibiotics at the initial debridement. Burn areas were dressed every day. The burns healed gradually over eight weeks. Range of motion exercises were performed to prevent contractures. At his last follow-up at 16 months, his fingers showed good healing with a good range of movement (Fig. 3).

Case 16- A 29-year-old man admitted to our burn care unit with frostbite involving the right hand. Frostbite injury due to contact with LOx occurred while he was transporting the liquid oxygen to a storage container of a military aircraft. The emission of the liquid toward his gloved right hand was sustained for a period of 30-60 seconds. The protective gloves could not insulate his hand from accidental contact. The initial physical examination demonstrated second-degree frostbite on the fingers (Fig. 4a). The capillary circulation of fingers was clinically adequate. All the fingers were well perfused. After 24 hours, the capillary circulation of the second finger of the right hand was poor. Escharotomy of the second finger was performed (Fig. 4b). Parenteral antibiotics, low molecular weight dextran in saline (60 ml/h) and heparin infusion (5000 units IV stat and 1000 units/h) were started. Dressings of the burn areas were changed every day. On the 26th day, the wound on the second finger of the right hand was covered with split-thickness autograft (Fig. 4c). No complication was observed during his postoperative course and he was discharged on postoperative day 12. At his last follow-up at six months, he had a well-healed graft with a good range of movement of his right hand (Fig. 4d).

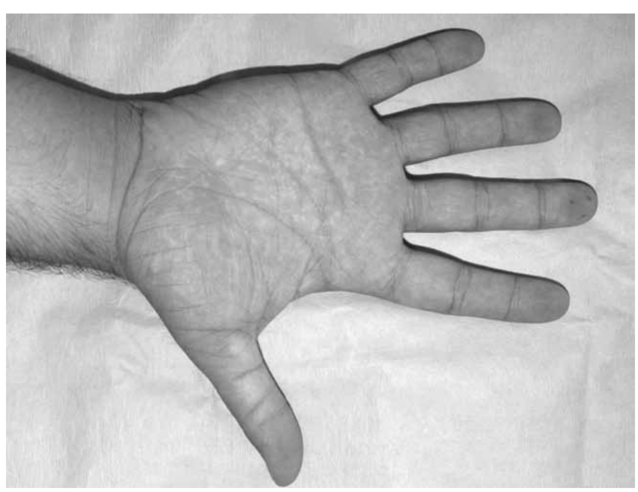

Fig. 3. Sixteen months after the frostbite, burns are healed.

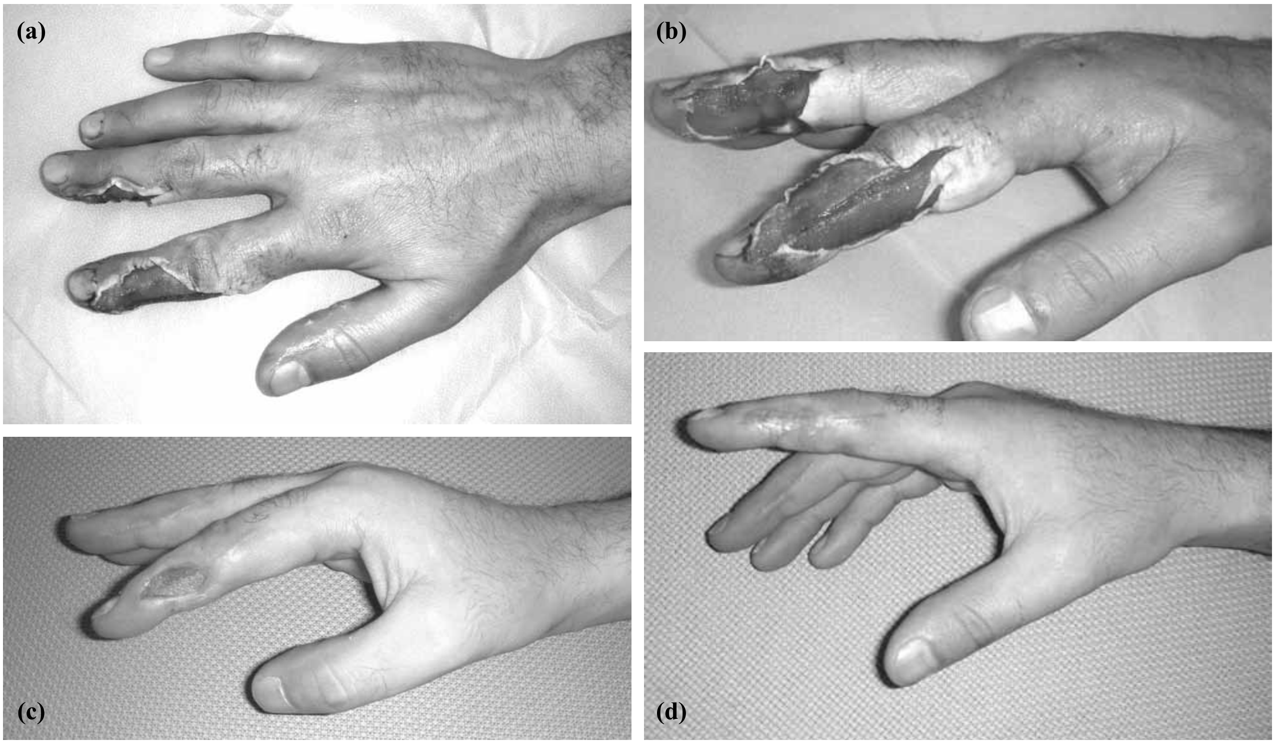

Fig. 4. **(a)** Second-degree frostbite on the fingers. **(b)** Escharotomy of the finger. **(c)** The non-healing wound on the second finger. **(d)** Six months after the frostbite, burns are healed.

DISCUSSION

The refrigerant liquids and compressed gases may cause frostbite when sprayed on the skin. Contact frostbite is common in young workers and typically involves the hands. The upper extremities, the fingers in particular, are more susceptible to cold exposure, as the vascular structures are smaller and narrower and the tissue coverage is thinner in the upper than in the lower extremities.[7]

The extent of injury caused by liquid agents may be determined by the surface area of exposed tissue, the volume of liquid agent on the skin and the duration of exposure. The mechanism of refrigerant agents is unlike frostbite in that the damage occurs within seconds.[2,3] However, there are some controversial discussions over the duration of exposure that may lead to such severe tissue damage. The appearance of the superficial tissue is often an unreliable indicator of the viability of the underlying tissue. The injury may be more severe than that caused by a thermal burn because the refrigerant liquids and gases rapidly and deeply penetrate through the skin.

The pathophysiology of frostbite is thought to have two distinct mechanisms: direct cellular damage at the time of exposure to the cold and post-thaw arterial vasoconstriction, leading to disordered vascular flow patterns and damage to the microcirculation. The intracellular electrolyte concentration increases dramatically. This leads to intracellular dehydration with an increase in intracellular electrolytes, proteins and enzymes that lead to cell death. Generation of oxygen free radicals, production of prostaglandins and thromboxane A2, release of proteolytic enzymes, and generalized inflammation are the underlying mechanical effects of these injuries. In addition, vascular endothelial damage leads to intravascular thrombosis and reduced blood flow. The outcome is vascular thrombosis and dermal necrosis.[7-9] The treatment of frostbite is directed toward reversing the pathologic effects of ice-crystal formation, vasoconstriction and the release of inflammatory mediators; therefore, rapid rewarming and anti-inflammatory agents are still the main components of treatment protocols.

There is little information available in the medical literature that reports on emergency treatments for frostbite injuries from refrigerant liquids and gases. The first treatment step is to remove the patient from danger and minimize the duration of exposure. Unlike with thermal burn, the agent will continue to burn until the substance is inactivated or removed from the area. In the first-aid treatment, any clothing that has been splashed or soaked with refrigerant agents should be removed immediately. The contaminated skin must be promptly washed using soap or mild detergent and water. For frostbite, immediate rewarming in a water bath between 40°C to 42°C is recommended.[2,3] Adherence to this narrow temperature range is important; rewarming at lower temperatures is less beneficial to tissue survival, while rewarming at higher temperatures may compound the injury by producing a burn wound. Rewarming should be continued for 15 to 30 minutes until thawing is complete. Active motion during rewarming is helpful, but massage should be avoided.

The adequate prophylactic treatment of frostbite for infection and thrombosis, prevention of compartment syndrome, burn area care, and surgical debridement play a significant role. The edema has been found to inhibit the skin's own streptococcicidal properties. For this reason, penicillin is the prophylactic antibiotic of choice in many centers, although some authors reserve antibiotics for specific infectious complications.[7] Thus, prophylactic antibiotic use is controversial and usually not recommended unless signs of infection develop.

The best frostbite treatment results have been achieved with methods that improve microcirculation, since vein and capillary thrombosis is main cause of tissue damage. HBOT may be used successfully in frostbite therapy. Good results have been reported in the treatment of problem wounds and frostbite by HBO.[10] The effect of HBOT on damaged tissues is complex. HBOT diminishes microorganism proliferation, activates antimicrobial agents and the immune system, and significantly improves pO_2 in reversibly damaged peripheral tissues.[11] HBOT should be performed between days 4 and 10 after injury, resulting in "pinking" of the affected areas according to the Marx-schema for problem wounds (2, 4 bar, total time at depth: 90 min, alternations of 100% O_2 and air breathing). The increasing local tissue oxygen tension with HBO treatment improves and maintains the viability of the adjacent tissue. Therefore, vascular and cellular regeneration occurs more quickly and is more efficient.[12]

Heparinization for the prevention of thrombosis is still controversial. In the first few days after thawing, thrombosis is seen to occur in the superficial dermal plexus. For this reason, heparinization has been used to prevent intravascular thrombosis. Pentoxifylline shows some beneficial effects in animal models but it is not an accepted therapeutical agent.[13] In the past, aspirin has been given as a systemic anti-thromboxane agent. However, the correct dose of aspirin for thromboxane inhibition has not been established. Aspirin inhibits the synthesis of prostaglandins, including some prostaglandins that are beneficial to wound healing. For these reasons, aspirin has been superseded by ibuprofen for this application.[14,15] Inhibitors of the prostaglandin synthesis of inhibitors of free radicals such as superoxide dismutase are promising agents for the future.

Reconstruction has no role in the acute phase of frostbite. Escharotomy or fasciotomy may be indicated in the early phase if circulation is impaired or compartment syndrome develops. Attempts at aggressive debridement in the early phase of frostbite and amputation may compromise viable tissue. The only indication for early operative intervention is to ameliorate a constricting eschar or to drain a subeschar infection that has not responded to topical antimicrobials. If tissue injury progresses to gangrene, amputation and coverage may be required. Thus, in the care of frostbite injury, patience in allowing demarcation of nonviable tissues is recommended, which may take as long as two to three months. Surgery should be delayed until the area is thoroughly demarcated.

Prevention is the best strategy for reducing the morbidity and mortality of frostbite. The first step is increasing the awareness of the personnel and health care professionals of the risk of these injuries. The eyes are the most sensitive to the extreme cold of the liquid and vapors of cryogenic liquids. The recommended personal protective equipment for handling cryogens includes a full face shield over safety glasses, leather gloves, long sleeve shirts, and trousers. In addition, safety shoes are recommended for people involved in the handling of containers. Most of these injuries can be prevented by taking adequate precautions and educating the involved persons.

In conclusion, even brief contact with refrigerant liquids and gases may result in severe frostbite injury. Decreasing the exposure time is an important first step in the treatment approach. After exposure to gas, quick delivery of the patient to a burn center is essential. Prevention of severe edema and compartment syndrome is necessary in frostbite treatment due to refrigerant liquids and gases. and the importance of a close monitoring of such cases due to the potential for deep tissue damage that may cause compartment syndrome is stressed.

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