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The management of white phosphorus burns

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Abstract

Phosphorus burns are a rarely encountered chemical burn, typically occurring in battle, industrial accidents, or from fireworks. Death may result even with minimal burn areas. Early recognition of affected areas and adequate resuscitation is crucial. Amongst our 2765 admissions between 1984 and 1998, 326 patients had chemical burns. Seven admissions were the result of phosphorus burns. Our treatment protocol comprises 1% copper sulfate solution for neutralization and identification of phosphorus particles, copious normal saline irrigation, keeping wounds moist with saline-soaked thick pads even during transportation, prompt debridement of affected areas, porcine skin coverage or skin grafts for acute wound management, as well as intensive monitoring of electrolytes and cardiac function in our burns center. Intravenous calcium gluconate is mandatory for correction of hypocalcemia. Of the seven, one patient died from inhalation injury and the others were scheduled for sequential surgical procedures for functional and cosmetic recovery. Cooling affected areas with tap water or normal saline, prompt removal of phosphorus particles with mechanical debridement, intensive monitoring, and maintenance of electrolyte balance are critical steps in initial management. Fluid resuscitation can be adjusted according to urine output. Early excision and skin autografts summarize our phosphorus burn treatment protocol. © 2001 Elsevier Science Ltd and ISBI. All rights reserved.

Keywords: Chemical burn; White phosphorus; Hypocalcemia; Copper sulfate

1. Introduction

Chemical burns caused by white phosphorus are quite different to thermal burns. Such burns are typically caused by combat mortar rounds, accidents involving fireworks, or accidents in agricultural plants. Such injuries combine the heat of chemical combustion with the corrosiveness of phosphoric acid as the phosphorus is oxygenated and hydrated in tissues. With chemical burns, several factors in addition to intensity and duration of exposure to heat may determine the depth of a burn, including the concentration of the agent and its reactions with tissues. These factors differ among agents. Phosphorus has several allotropic forms, namely white, red, and black, with the yellowish discoloration often seen in white phosphorus due to impurities. When exposed to air, white phosphorus spontaneously oxidizes to phosphorus pentoxide and hydrolyzes in water to form potentially corrosive phosphoric acid, capable of producing chemical injury in tissues. Adherence of phosphorus to clothing and skin will often cause thermal injury because white phosphorus ignites spontaneously if the temperature exceeds 34°C [1,2]. The complexity of injury seen with phosphorus burns can extend to the damage caused by grenades going off in the hands of soldiers. Both phosphorus particles and grenade fragments embed themselves in the wound. If the temperature is high enough, spectacular smoke will sometimes be seen as phosphorus particles exposed to the air, ignite. Systemic effects including hypoproteinemia, hematuria, oliguria, generalized petechiae, icterus, acute yellow atrophy of the liver, seizures, impaired glycogenolysis, hypocalcemia, and ischemic-like ECG changes can arise quickly [3,6].

General principles of treatment include identification of chemical agents as well as prompt, appropriate first

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Table 1
Patients having respiratory failure[a]. Demographic data of patients.

No.	Sex	Age	Site involved	Degree/TBSA (%)	Operation	Complication
1	M	21	Face Extremities	II (11)III (17)	Deb. + STSGAK amputation Fasciotomy	Stump infection
2	M	25	Face Chest wall Trunk	III (39)	Fasciostomy Tracheotomy	Expired
3	M	23	Face	II–III (6)	Deb. + STSG	
4	M	22	Face	II–III (3.5)	Change dressing	
5	M	18	Neck Face Extremities	II–III (15)	Deb. + STSG	
6	F	17	Face Neck Chest wall Both arms	II–III (9)	Deb. + STSG	
7	M	21	Face Extremities	II (11)III (11.5)	Fasciotomy Deb. + STSG Biological dressing	

[a] STSG: split-thickness skin graft; Deb.: debridement.

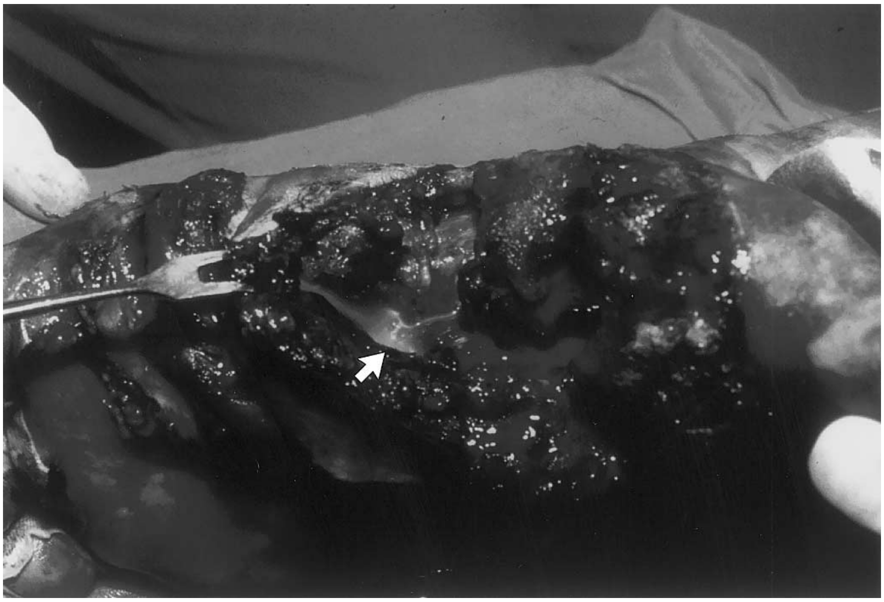

Fig. 1. The ongoing combustion of phosphorus over web space of hand with smoke generated (arrow) in the air.

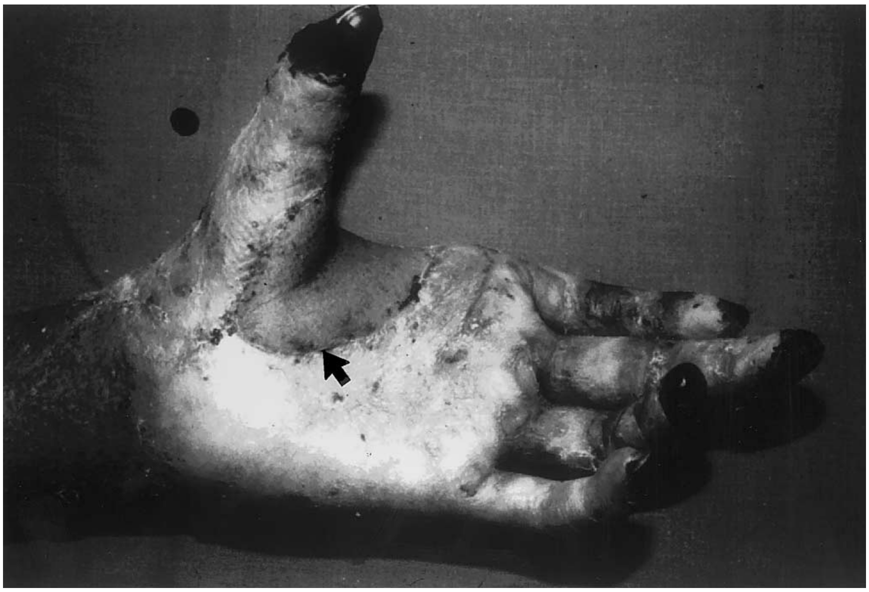

Fig. 2. The first web space was reconstructed with groin flap (arrow), and the fingers' tips were left self-reepithelization in several months.

Fig. 3. After application of 1% copper sulfate solution for staining of the phosphorus particles retained on the skin (arrow).

aid. We have reviewed our phosphorus burn patients between 1984 and 1998 to refine the protocols for systemic treatment and wound care.

2. Materials and methods

Seven patients with phosphorus burns were admitted to the Tri-Service General Hospital burns center over the period spanning January 1984 to December 1998. Of the seven, six were male, and all had suffered from hand grenade, firebomb, or other munition explosions. Thermal injury usually produced lesions over the extremities and face with the depth of burn varying between superficial second degree to third degree and the surface areas burn ranged between 7.5% and 39% (mean 17.6%). All seven patients had facial involvement and the accident had occurred during work. The treatment protocol followed the procedures mentioned in the abstract. Phosphorus particles were removed with mechanical debridement after identification with 1% copper sulfate solution, then irrigating the wounds with copious normal saline or distilled water. Patients underwent fluid resuscitation after reaching hospital with the amount adjusted according to urine output, ranging between 50 and 100 ml/h. Nasotracheal intubation with mechanical ventilation support was indicated as patient had respiratory failure (Table 1).

3. Results

Using our treatment protocol, three patients had fasciotomies performed to prevent compartment syndrome. One patient, who sustained inhalation injury died of respiratory failure even after the attempts at resuscitation. Of the seven patients, five required skin grafts for resurfacing of burns, when wounds had not healed within 14 days of presentation [7]. All donor sites healed without complication. Three patients had associated fractures of the extremities, and one required an above knee amputation after infectious complications, and the infected stump underwent repeated debridements to allow wound closure.

Hypocalcemia was a commonly encountered electrolyte disturbance and was corrected with intravenous 10% calcium gluconate infusion. The six surviving patients recovered well and were followed up for at least 2 yr with reconstructive procedures to correct scar problems.

Fig. 4. The whole face revealed generalized swelling with fish-mouth appearance after phosphorus flame burn, and nasotracheal intubation was used for keeping airway patent.

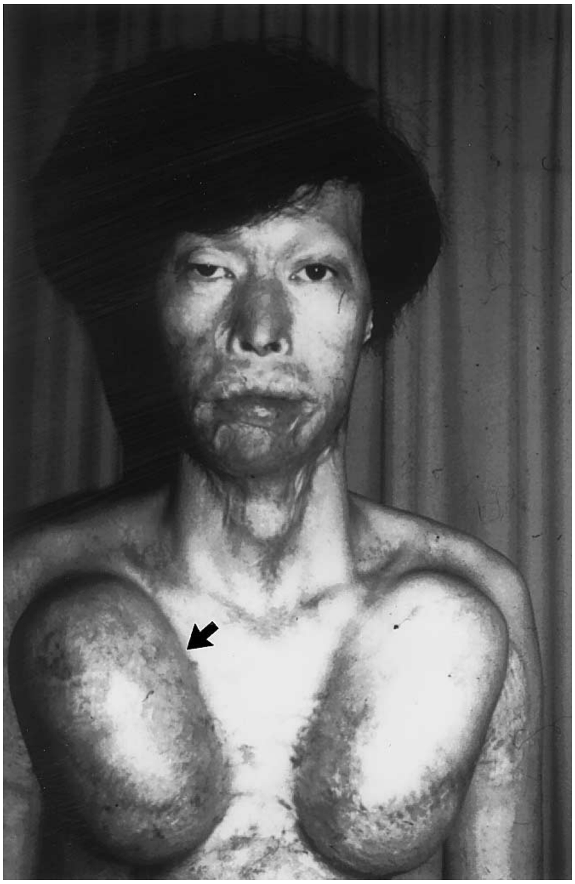

Fig. 5. Tissue expanders were used for full-thickness skin banking for later on scar revision procedure over low neck and chin (arrow).

4. Case reports

4.1. Case 1

A 21-year-old man sustained a hand grenade explosion injury to his face and extremities, where it produced open wounds. Black–blue discoloration was seen over the wound bed after 1% copper sulphate was used to identify remaining particles of phosphorus. There was a white smoky appearance over the wound bed due to continuing combustion of the phosphorus particles (Figs. 1 and 3). Combustion was controlled by cool saline soaked gauze and the burning phosphorus particles were promptly removed. The hand was then covered with a groin flap to allow for first web space restoration (Fig. 2). The gangrene of distal phalanges of thumb, middle, and ring fingers was managed with conservative treatment (Fig. 3). The wounds healed up after tulle gras dressing without further debridement.

4.2. Case 2

A 21-year-old soldier suffered an accident in a munitions dump, where an incendiary bomb had exploded. The patient's face sustained deep second and third degree burns. An endotracheal tube was introduced to maintain airway patent (Fig. 4). Surgery commenced once the patient had been stabilized. The affected areas of the face were resurfaced with thick split-thickness skin graft. Skin grafts were also used over the affected portions of the neck region. Tissue expander methods were used for skin banking over flushing area for dealing with problems arising from post-burn scarring over low chin and face (Fig. 5). Jobst garments were used routinely for post-operative care. The normal appearance of the right eyebrow was restored with composite grafts using hair transplants cropped from the temporal region (Fig. 6). The patient has since resumed work after retirement from military service.

5. Discussion

Phosphorus exists in three main allotropic forms: white, black, and red. White phosphorus has a melting point of 44°C, and ignites around 30°C. When exposed to air in darkness, greenish light is emitted and white fumes with a garlic-like odor are released. Its oxides, (P_2O_3 and P_2O_5), produce phosphoric acid in contact

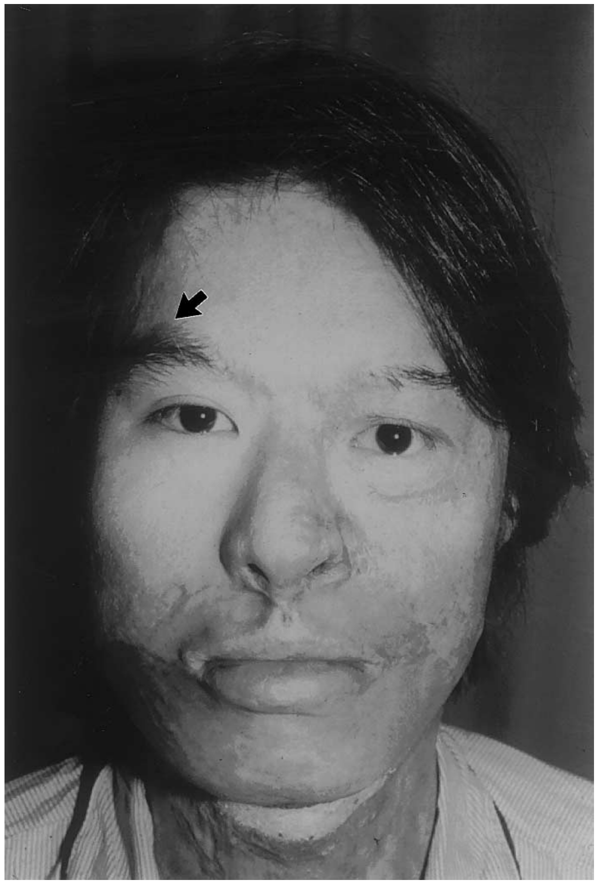

Fig. 6. The low chin and perioral were resurfaced with full-thickness of skin graft as an aesthetic unit, and right eyebrow was restored normal appearance by composite hair graft (arrow).

with tissue fluid, and phosphoric acid promotes the combustion process [4,5]. Burning phosphorus is easily extinguished with water, but re-ignites after drying, producing smoke. A lethal human dose is in the order of 50–100 mg [2].

White phosphorus is commonly used as an incendiary in the manufacture of ammunition. Consequently, the military population has an increased risk of injury from white phosphorus. The initial treatment of white phosphorus burn consists of prompt removal of contaminated clothing followed by immediate irrigation with water. Phosphorus will keep burning if exposed to air, hence the need for prompt removal of gross particles from the skin and clothes. Lavaging of cutaneous wounds with water or saline is indispensable, as it can stop combustion, lower the temperature of burnt areas, and dilute any phosphoric acid that may have formed. For these reasons, saline-soaked pads should be used for wound coverage, even when transporting the patient or moving the patient into theatre for emergency removal of white phosphorus contamination [8–10].

Several treatment protocols have been proposed for phosphorus burn. The main goal is always prompt removal or neutralization of active phosphorus from the burn site. Our protocol for the management of phosphorus burn includes the application of 1% copper sulfate solution, which on contact with phosphorus forms copper phosphate ($CuPO_3$), allowing both easy identification of retained white phosphorus particles and impeding further white phosphorus oxidation [4]. Excess copper sulfate should be removed immediately by water irrigation to prevent the systemic effects of copper intoxication, which include vomiting, diarrhea, hemolysis, hematuria, oliguria, hepatic necrosis, and cardiorespiratory collapse [11]. Eldad described the toxic effects of prolonged exposure to copper sulphate emulsion or solution used on wounds [10]. Consequently, copious irrigation with water is an essential part of the protocol.

The systemic effects of phosphorus burns include calcium-phosphorus shifts, which are believed to be due to absorption of phosphorus compounds from the burn area. Those burnt can rapidly develop hypocalcemia and hyperphosphatemia, which have been shown to be the major cause of sometimes fatal cardiac arrhythmias. Abnormalities seen on the electrocardiogram include prolongation of the QT interval, bradycardia, and ST-T wave changes. Excision of the burned wounds within one hour of injury does not improve survival, suggesting that metabolic changes may occur earlier. The dehydrating effects of phosphorus pentoxide can be ignored since 6.06 mg of phosphorus as phosphorus pentoxide combines with only 2.18 mg of water to form acid, which is negligible. Other complications include deep-lying shrapnel fragments in soft tissues. They are usually contaminated with the phosphorus particles, which will react continuously with tissue fluid. Removal of stained phosphorus particles on the wounds is essential for prevention of further ignition, absorption into the circulation and possible systemic effects [8,13].

The smoke generated is the result of combustion or oxidation, and is strongly irritant to mucosal surfaces, where it combines with water to form phosphoric acid. Ensuring airway patency was particularly important in patients rescued from phosphorus explosions occurring in close confinement. Patients should be assessed for life-threatening injuries as soon as a pertinent history is obtained, and fiberoptic bronchoscopy should be performed if there is a history of smoke exposure and symptoms or signs suggest the possibility of inhalation injury. More fluid is given in our burns unit for initial resuscitation after inhalation injury than in cases without inhalation injury, with the amount of fluid titrated by urine output and ranging between 0.5 and 1.0 ml/kg/h. The goal is to achieve the minimum requirements for fluid therapy in the postburn shock stage [15]. Phosphorus induced systemic intoxication and hypocalcemia can be reversed with intravenous infusion of 10% calcium gluconate solution, but intensive monitoring of electrolytes is still necessary [12].

Phosphorus burns have aspects that differ from other burns and are often combined with explosion injury. The retention of shrapnel fragments often produces associated injuries of nerves, tendons, or open fractures. The first priority of reconstruction should be restoration of function, followed by cosmetic considerations. Consequently, skin grafts are not always appropriate, as flaps may allow better preservation and restoration of function. For example, groin flaps can be used to cover exposed digital nerves, arteries, and thenar muscle groups [14]. Doing this also allows the first web space to be maintained after burns to the hands. Finger tips with compromised circulation after severe burns can be left to auto-amputate. Although this can take several months, the patient is able to begin rehabilitation more quickly providing the flexor digitorum profundus is uninvolved (Fig. 2).

In our experience, porcine skin is a good biological dressing for wounds. Porcine heterografts provide a physiological environment at the wound surface that seems to be conducive healing processes [16,17], and has been shown to augment defences against bacteria [18]. The adherence of porcine skin to the wound is probably related to collagen content rather than viability. Such grafts enable the lesion to be closed in preparation for the graft.

In summary, after emergency resuscitation has occurred, management of the cutaneous injury with 1% copper sulfate solution should be followed by irrigation with saline and prompt removal of phosphorus particles. In some cases, debridement of the damaged area or amputation should be carried out if the injury is life-threatening. Intravenous fluid resuscitation is essential even for limited phosphorus burns, as they can quickly produce serum electrolyte disturbances. Close monitoring of ECG traces and serum calcium and phosphorus levels in the 48 h following injury is crucial. Only once the patient has been stabilized should closure and resurfacing of the affected area with skin grafts be undertaken.

References

[1] Obermer E. Phosphorus burn. The lancet 1943;1:20.

[2] William TS, Captain MC, Arnold ID, Moncrief JA. White phosphorus burn and massive hemolysis. J Trauma 1967;7:476–84.

[3] Ben Hur N, Giladi A, Neuman Z. Phosphorus burns – a pathophysiological study. Br J Plast Surg 1972;25:238–44.

[4] Ben Hur N, Giladi A, Applebaum J, Neuman Z. Phosphorus burn The antidote: a new approach. Br J Plast Surg 1972;25:245–9.

[5] Ben Hur N, Ben Hur N, Shani J, Appelbaum J. Phosphorus burn in primates: a conclusive experimental study of a new specific therapy. Burns 1978;4:246–53.

[6] Thomas EB, Thomas JW, Thomas GN. Sudden death after phosphorus burn. Ann Surg 1971;174:779–84.

[7] Engrav LH, Heimbach DM, Walkinshaw MD, Marvin JA. Excision of burns of the face. J Plast Reconst Surg 1986;77:744–9.

[8] Mendelson JA. Some principles of protection against burns from flame and incendiary munitions. J Trauma 1971;11:286–94.

[9] Mozingo DW, Smith AA, McManus WF, Pruitt BA, Mason AD. Chemical burns. J Trauma 1988;18:642–7.

[10] Eldad A, Simon GA. The phosphorus burn – a preliminary comparative experimental study of various forms of treatment. Burns 1991;17:198–200.

[11] Chuttani HK, Gupta PS, Gulati S, Gupta DN. Acute copper sulfate poisoning. Am J Med 1965;39:849–54.

[12] Hu A. Intravenous drop of calcium gluconate for phosphorus burns. Chung Jua Cheng Hsing Shao Shan Wai Ko Tsa Chih 1993;9(4):254–6.

[13] Curreri PW, Asch MA, Pruitt BA. The treatment of chemical burns: specialized diagnostic, therapeutic, and prognostic considerations. J Trauma 1970;10:634–42.

[14] McGregor IA, Jackson IT. The groin flap. Br J Plast Surg 1972;25:3–16.

[15] Dai NT, Chen TM, Cheng TY, Chen SL, Chen SG, Chou GH, et al. The comparison of early fluid therapy in extensive flame burns between inhalation and noninhalation injuries. Burns 1998;24:671–5.

[16] Tung YW. The phosphorus burn – a case report. J Plas Reconst Surg (ROC) 1998;7:345–54.

[17] Burleson R, Eiseman B. Effect of skin dressings and topical antibiotics on healing of partial-thickness wound. Surg Gynecol Obstet 1973;136:958–60.

[18] Burleson R, Eiseman B. Mechanisms of antibacterial effect of biologic dressing. Ann Surg 1973;177:181–6.