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Review

Chemical burns: Pathophysiology and treatment

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ABSTRACT

Chemical burns continue to pose a variety of dilemmas to the clinician managing such cases. Assessment of burn depth is often difficult and the decision whether to excise the wound early is not always clear-cut. In this updated review, common agents are classified and the basic principles of management and specific recommendations are examined. The complications arising from exposure to these chemicals and the supportive measures needed during treatment are also described.

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1.   Introduction

A wide variety of chemicals may cause cutaneous and ocular burns and systemic effects either by absorption or inhalation, requiring in most of the cases medical and/or surgical treatment. Given the nature of the agents involved and the type of injuries (depth, lung injury, eye involvement, etc.) they produce a relevant loss of working time. Long-term sequelae are, unfortunately, not uncommon.

More than 25,000 chemicals are commonly used in the industry, agriculture, house cleaners and others, and many of them have been identified as having the potential to cause burns. This makes chemical burns an important risk in the household and in the industrial setting. Knowledge of the potential harm of these agents is very low in the domestic setting, whereas in the industry it is often underestimated. In the past years, an increase has been detected in using chemical agents in aggressions involving domestic violence, mainly to women, spraying them on the face and body, with the subsequent important and disfiguring burn sequelae, but the criminal use of chemicals to assault others is not uncommon [1,2]. On the other hand, the international instability in some areas of the world with a lot of armed conflicts has increased the use and the threat of chemical weapons. There are reviews in the last years that have shown a predominance of injuries due to white phosphorous [3]. The variety of chemical agents is so vast that a short review cannot describe all the agents and their treatments, but we can provide general principles for the treatment of chemical injuries. The fact that they only represent near the 3% of all burns must not underscore these principles. They are present with an important morbidity (near 55% of them require surgery), commonly involve cosmetic body like face, thorax and hands, and in some series they carry approximately 30% of burns death [4]. Cutaneous chemical burns can present a variety of dilemmas to the clinician managing such cases. Assessment of burn depth is often difficult and the decision whether to excise the wound early is not always clear-cut. In this review, common agents are classified; the basic principles of management, and specific recommendations are examined. The complications arising from exposure to these chemicals and the supportive measures needed during treatment are also described (Figs. 1–5).

2.   Pathophysiology

The body has very few specific protective and repair mechanisms for thermal, electrical, radiation and chemical burns. Denaturation of proteins is a common effect of all type of burns. However, chemical injuries have some important differences when compared to thermal burns. Chemical injuries are more likely produced by longer (minutes) exposure to chemicals, and this exposure may still be continuing in an emergency room in contrast with thermal injuries, which are typically produced by very short-term exposure (seconds) to intense heat that is relatively quickly stopped.

There are also some important biochemical differences between them. The structure of biological proteins involves not only a specific amino acid sequence, but also a three-dimensional structure dependent on weak forces, such as

Fig. 1 – Patient who tried to remove a tattoo with a chemical product.

hydrogen bonding or van der Waal's forces. These three-dimensional structures are key elements for the biological activity on the proteins, and are easily disrupted by external factors. Application of heat or chemicals, especially pH disturbances, can cause the structures to fall apart. In thermal injuries, there is a rapid coagulation of protein due to irreversible cross-linking reactions, whereas in chemical burns the protein destruction is continued by other mechanisms, mainly hydrolysis. These mechanisms may continue so long as traces of the offending agent are present, especially in

Fig. 2 – 40% T.B.S. burns caused by a chemical product. The ABC of Trauma and Secondary Assessment and all general principles of Trauma and Burn Care apply to chemical burns.

Fig. 3 – Formic acid burn. (a and b) Early copious water irrigation was established for an hour. Both cornea were affected and were immediately explored by an ophthalmologist. (c) After 2 weeks treatment with topical silver sulphadiazine cream, the frontal, nasal and periorbital areas, where the eyelids are specially affected, have not still epitelized. (d) Although these areas were grafted, and a temporal tarsorrhaphy was kept in place for 2 weeks, the patient developed an ectropion in the four eyelids.

deeper layers. In addition, chemical agents may act in a systemic fashion if their components are circulated throughout the victim, with potential toxicity.

The severity of a chemical burn injury is determined by:

(a) concentration,
(b) quantity of burning agent,
(c) duration of skin contact,
(d) penetration and,
(e) mechanism of action.

Chemical injury is classified either by the mechanism of action on skin or by chemical class of the agent.

3. Mechanisms of action

There are six mechanisms of action for chemical agents in biological systems [5].

(1) *Oxidation*: The protein denaturation is caused by inserting an oxygen, sulphur, or halogen atom to viable body proteins (sodium hypochlorite, potassium permanganate, and chromic acid).

(2) *Reduction*: Reducing agents act by binding free electrons in tissue proteins. Heat may also be a product of a chemical reaction, thereby causing a mixed picture. The agents more likely to be encountered are hydrochloric acid, nitric acid and alkyl mercuric compounds.

(3) *Corrosion*: It causes protein denaturation on contact. They tend to produce a soft eschar, which may progress to shallow ulceration. Examples of corrosive agents are phenols, sodium hypochlorite, and white phosphorous.

(4) *Protoplasmic poisons*: They produce their effects by causing the formation of esters with proteins or by binding or inhibiting calcium or other organic ions necessary for tissue viability and function. Examples of ester formers are formic and acetic acids, while inhibitors include oxalic and hydrofluoric acids.

(5) *Vesicants*: They produce ischaemia with anoxic necrosis at the site of contact. These agents are characterized to produce cutaneous blisters. They include mustard gas, dimethyl sulfoxide (DMSO), and Lewisite.

(6) *Desiccants*: These substances cause damage by dehydration of tissues. The damage is often exacerbated by heat production, as these reactions are usually exothermic. In this group we find sulphuric and muriatic (concentrated hydrochloric) acids.

Fig. 4 – Hydrofluoric acid burns. These are very corrosive and penetrating. (a and b) In this patient, the finger affected was treated with subcutaneous infiltration of calcium gluconate beneath the nail. (c and d) The nail was removed after infiltration, and the outcome 2 months later.

4.   Type of chemicals

This classification is based on the chemical reactions that the chemical agent initiates. This method of classification is less accurate than describing how they coagulate the proteins. The ability to influence pH is one of the most important characteristics of an injurious chemical agent. Its concentra-

Fig. 5 – Sulphuric acid burn. Brown discoloration is typical.

tion also plays an important role in the reactivity. Although the mechanisms of action for individual acids or alkali may differ, the resulting wounds are similar enough to include them in these different groups as a whole [4].

We consider four classes: acids, bases, and organic and inorganic solutions.

1. Acids are proton donors. They release hydrogen ions and reduce pH from 7 down to values as low as 0. Acids with a pH less than 2 can produce coagulation necrosis on contact with the skin [4]. A better predictor than pH alone is the amount of alkali needed to raise the pH of an acid to neutrality [6]. This may reflect the strength of the acid involved.
2. Bases are proton acceptors. They will strip hydrogen ions from protonated amine groups and carboxylic groups. Alkalis with a pH greater than 11.5 produce severe tissue injury through liquefaction necrosis [6]. Liquefaction loosens tissue planes and allows deeper penetration of the agent [4]. For this reason, alkali burns tend to be more severe than acid burns.
3. Organic solutions act dissolving the lipid membrane of cells and disrupting the cellular protein structure.
4. Inorganic solutions damage the skin by direct binding and salt formation. It should be noted that all of these reactions

Table 1 – Extracted from [7].	
Points of chemical burns treatment	
(1) Removal of chemical	Remove particulate debris, brush off dry chemical,
(2) Dilution	Copious high-density shower with tap water (20–30 min), do NOT immerse.
(3) Examination of burn	The extent of burn is normally deeper than seems externally
(4) Systemic toxicity	Remember metabolic changes. Call toxicology centre for information
(5) Ocular contact	Water lavage continuously. Ophthalmology consultation
(6) Inhalation injury	In aerosol chemical products. Administer O_2, consider intubation. Bronchoscopy for diagnosis

may be accompanied by exothermy, which contributes to tissue injury [4].

5. General principles of management

The ABC of Trauma, Primary and Secondary Assessment and all general principles of Trauma and Burn Care apply to chemical burns. However, there are also some relevant measures of first aid that must be remembered when considering chemical burns. Key points in the treatment of chemical burns are summarized in Table 1. Extracted from [7].

First aid measures for chemical burns involve several aspects such as:

- removal of the chemical agent,
- treatment of the systemic toxicity if any and side-effects of an agent,
- general support,
- special considerations for specific agents if appropriate,
- local care of the burn (if it is relevant at this stage, depending on the nature of the chemical involved, i.e., fluorhydric acid).

A thorough history is necessary to ascertain the responsible agent and a prompt treatment is essential to minimize the tissue damage. Material Safety Data Sheets are mandated to be available for all chemicals present in the workplace, which can be valuable resources for potential systemic toxicity and side-effects of an agent.

5.1. Removal of the chemical agent

It cannot be overemphasised that the duration of the chemical's contact with the skin is the major determinant of injury severity. Chemical burns are characterized by ongoing tissue destruction for as long as the inciting agent

is present [8–10]. Because of this, the immediate removal of the agent is very important. This requires removal of involved clothing and a thorough irrigation with water at the scene of the accident. It should be repeated when the patient arrives at the burn centre or hospital. Irrigation should be copious, and to the floor or in a special tank for runoff water, avoiding placing the patient into a tub, which could spread the injurious agent to previously unexposed tissue and increase the damage. The ANSI Z-358.1-1998 standard is a consensus standard for emergency water decontamination equipment for the skin and eyes [11]. It specifies the characteristics that emergency showers and eyewash stations have to accomplish. Lavage dilutes and removes the chemical agent in contact with the skin, and helps to correct the hygroscopic effects that certain agents have on tissues [12]. It has less pronounced effects on changes in tissue pH [13]. Early and copious water irrigation has been shown to reduce the severity of burn and length hospital stay [14]. No measure of adequacy of lavage has been developed, but when possible, monitoring of the lavage solution pH will give a good indication of lavage effectiveness and completion. Periods of 30 min to 2 h of lavage may be necessary to produce pH between 5 and 11.

Although copious water lavage should be used for virtually all chemical burns, there are a few notable exceptions. Some chemicals create significant exothermy when combined with water, and other chemicals are insoluble in water [8]. Phenol is insoluble in water and should first be wiped off the skin with sponges soaked in solublizing agents such as 50% polyethylene glycol [10,15]. Dry lime contains calcium oxide, which reacts with water to form calcium hydroxide, an injurious alkali. Therefore, dry lime should be dusted off the skin prior to lavage [14]. Muriatic acid and concentrated sulphuric acid produce extreme heat when combined with water. These agents should be neutralized with soap or lime water before lavage [5,14] (Table 2). Extracted from [7].

Table 2 – Extracted from [7].	
Important exceptions in chemical burns treatment	
NO Irrigation with water	Phenol: wipe off with 50% polyethylene glycol sponges before lavage Sulphuric and muriatic acids: soda lime or soap wash. Chlorox: milk, egg white or 1% sodium thiosulphate wash, then irrigation.
Antidotes	Hydrofluoric acid: subeschar injection of 10% calcium gluconate until pain is relieved, up to 0.5 ml/cm^2. Monitor calcium and magnesium White phosphorus: lavage with 1% or 2% copper sulphate, immerse in water (note toxicity of copper sulphate)

5.2. Neutralizing agents

This is one of the most controversial points of discussion in the chemical burns treatment. Some authors have shown that dilution, not neutralization, is the key point of therapy because it is very efficacious for acid and alkali exposures [10,12,14]. However, theoretically neutralizing solutions should effectively remove the active chemical from a wound and provide relief from further injury. Control of the quantity of the neutralizing agent is the key difficulty. Problems associated with its use include exothermic reactions causing further thermal damage and delay of hydrotherapy while the neutralizing agent is sought. It is also important to remember that neutralizing agents can themselves cause toxicity. Still, in some cases when the appropriate antidote is known, there is some benefit in its use [16]. Its use has been also recommended after an initial copious water decontamination followed by neutralization and then a second decontamination with copious amount of water [17]. However, despite the ready availability of water decontamination, large numbers of persons have skin/eye splash exposure each year and many develop burns [18] despite early water decontamination which gives a word of caution when water decontamination is used without further treatments.

Another approach used in European workplaces for a number of years is active skin/eye decontamination with Diphoterine. Diphoterine is a water-soluble powder manufactured by Laboratoire Prevor, Valmondois, France, and provided for use dissolved in water and sterilized by autoclaving. The rinsing and diluting effects of an equal volume of water (in the commercial preparations) are most likely retained. It is a polyvalent (actively binds multiple substances), amphoteric, hypertonic, chelating molecule with active binding sites for acids, bases, oxidizing agents, reducing agent, vesicant, lachrymators, irritants, solvents, etc. Its use has recently shown to prevent or decrease the severity of burns, to rapidly decrease pain, and has resulted in fewer requirements for medical or surgical burn care other than initial decontamination and less work time [19,20]. Ongoing prospective research in been carried out in order to produce evidence based results that may improve outcomes in chemical burns.

5.3. General support, estimation of the burns and local care

General principles of trauma management are followed (ABC). Conventional thermal burn formulas for resuscitation are used when necessary, monitoring the urine output to assessment of adequacy of end organ perfusion and hence resuscitation [2]. Disturbances of pH are the major systemic complication. Blood gas and electrolyte analysis should be performed until metabolic stability has been assured.

Any patient having a copious lavage to adequately dilute chemical exposure is in potential risk for hypothermia. It is important to avoid this complication maintaining the room temperature between 28 and 31 °C and the lavage water temperature as near the body temperature as possible.

Clinical assessment of the depth and extent of a chemical burn is difficult because of the unusual tanning and local anaesthetic properties of some agents. Sometimes a significant deep burn may appear deceptively superficial [1,7].

Following lavage and debridement of blisters, chemical burns will be treated with the same principles as for thermal burns. We can cover them with chemotherapeutic agents, creams or dressings. Early excision and grafting of non-viable tissue is advocated as soon as possible [2].

The eye is often involved in chemical burns [1]. Even very small volumes of a strong corrosive fluid can produce significant damage. In these cases an ophthalmologist must be consulted immediately [21]. Authors recommend that irrigation with water must start as soon as possible and for long periods of time (0.5–1 h) [1]. Recent in vitro experiments on corneal cell cultures [22], however, have shown that water decontamination could have a deleterious effect on cells, with hypo-osmolar effects increasing the cell volume with resultant lysis from increased intracellular osmotic pressure. New active decontamination modalities should be critically evaluated. A case report of an ocular splash with delayed Diphoterine rinsing [23] suggests that Diphoterine induces corneal healing improvement as it stops the activity of the involved chemical product.

5.4. Systemic toxicity and inhalation injury

Physicians must be aware of any possible toxicity from systemic absorption of the agent. Hydrofluoric acid toxicity includes hypocalcaemia and ventricular fibrillation [24]. Formic acid absorption can produce intravascular haemolysis, renal failure and narcotising pancreatitis [25]. Systemic toxicity is less common in other agents, although physicians caring for the victims must be always aware of this possibility. Liver dysfunction may appear also in organic agents and in chemical diluted in hydrocarbures.

Respiratory injuries may also occur in chemical burns when aerosolised chemical or smoke is inhaled. They are managed like smoke inhalation injuries, with airway protection and oxygen therapy, by mechanical ventilation with positive end-expiratory pressure and aggressive chest physiotherapy [7]. Prognosis is very poor in moderate to severe cases with rapid progression to respiratory distress syndrome.

6. Specific agents

There are several agents, most of them used in the industry, that have the potential to cause harm when in contact, inhaled, or ingested by humans. However, current practice in emergency departments and burn centres points out that few toxics and chemicals warrant further study in order to explore their potential to cause burns and their specific treatment. In most, if not in all of the agents, the common and general rules of treatment for chemical burns do apply. Physicians are always warned that after initial stabilization and treatment, contact with the Official Office or Body for Toxicology should be sought in case of uncommon agents.

The following list is an approach to the most specific agents found in usual practice.

6.1. Cement burns

Cement is widely used throughout the world. Its use extends from amateurs to professionals, and is probably the do-it-yourself work the main cause for the increased incidence of cement burns seen in our units [26].

There are many constituents of cement. Calcium oxide accounts for 65% by weight in the most common mixtures, and acts both as a desiccant and an alkali. Injury results from the action of the hydroxyl ion [27], originated when calcium oxide is exposed to water, becoming calcium hydroxide.

Wet cement damages skin in three ways [28]:

(1) *Allergic dermatitis*: It is caused by the reaction to its hexavalent chromate ions. Irritation from the sand and gravel within cement can similarly cause dermatitis.
(2) *Abrasions*: The gritty nature of the coarse and fine aggregate in the cement is responsible for these lesions.
(3) *Chemical Burns*: This are the most significant injuries related to cement. The alkalinity of cement causes liquefaction necrosis.

The onset of injury is insidious. The patient may be initially unaware of the problem until several hours later [26]. The anatomic location most frequently involved is the lower extremity and our experience proves that they are commonly deep injuries.

General treatment of these injuries consists first of all in removal of all of the cement-soaked clothing including footwear. Next, burned areas should be cleaned with sterile water and dressed with topical antibacterial cream. The lesion is periodically evaluated in order to make a decision whether surgical excision and skin grafting is necessary.

We must remember, however, that there are two other locations where cement can produce severe injuries. Cement burns can be particularly devastating if they involve the eyes in a worker not wearing protective glasses. On the other hand, calcium oxide dust may aerosolise and become an irritant to the respiratory tract.

Some studies document that most patients who suffer cement burns ignore the potential of wet cement to cause injury [28]. Information and use of adequate protective materials are essential in the prevention of cement burns.

6.2. Hydrochloric acid/muriatic acid

This type of burn is less frequent than other acid burns like sulphuric acid. In contact with the skin, hydrochloric acid denatures the proteins into chloride salts. The management consists in quickly and continuous water irrigation of the affected skin to avoid severe damage associated with low pH that can appear on subcutaneous tissues [13,29]. It is also important to remember the pulmonary damage (upper airway oedema, pulmonary inflammation) that hydrochloric acid can produce if its fumes are inhaled.

6.3. Hydrofluoric acid

Hydrofluoric acid (HF) is a highly dangerous substance, yet it is used in a variety of industries and household settings [30]. In view of the widespread use of HF, a large population is at risk of potential harmful exposure [31].

HF is the inorganic acid of elemental fluorine. It is manufactured from the reaction between fluorspar (calcium fluoride) and sulphuric acid to produce HF gas, which is then cooled and stored as a colourless liquid [32]. Its has a vast array of uses, including frosting, etching and polishing glass and ceramics, removal of metal castings, cleaning stone and marble, and in the treatment of textiles [2,33].

Hydrofluoric acid causes severe burns and systemic effects, even in cases where cutaneous damage does not appear to be so dramatic. Tissue damage is caused by two mechanisms. First, the hydrogen ions cause superficial burns. Second, the fluoride penetrates down to the deeper tissue, causing liquefactive necrosis of the soft tissue. Free fluoride ions dissociated from HF have a strong reactivity with calcium and magnesium salts by making neutralizing salts with these two ions. This behaviour of fluoride ions interferes with cellular metabolism, thereby inducing cell death and liquefactive necrosis topically, and causing systemic hypocalcaemia and hypomagnesaemia [30,32,34]. Fluoride ion is also a metabolic poison and inhibits the Na–K ATPase allowing efflux of potassium as well [2,35]. These electrolyte shifts at nerve endings are thought to be cause of the extreme pain associated with HF burns [36].

Hydrofluoric acid burns are classified based on the concentration of the exposure according to the system developed by the National Institutes of Health-Division of Industrial Hygiene [37]. Concentrations greater than 50% cause immediate tissue destruction and pain. Concentrations of 20–50% result in a burn becoming apparent within several hours of exposure. Injuries from concentrations less than 20% may take up to 24 h to become apparent.

The most frequent injuries occur in the digits. Other exposures include skin contact elsewhere, ocular injuries, inhalation and ingestion. The clinical presentation of an HF burn depends on the route of exposure, concentration of the acid, duration of the contact and the penetrability or resistance of the tissue exposed. Subungueal tissue is particularly susceptible [32].

The systemic effects may have a wide variety of cardiac, respiratory, gastrointestinal and neurological presentations. The predominant pattern depends on the route of absorption. The systemic symptoms typical of hypocalcaemia or hypomagnesaemia are generally absent. Serum calcium levels and electrocardiogram are important monitors of patient status [38]. Once cardiac arrhythmias develop, they are hard to restore to normal rhythm. The fluoride ion may be acting as a metabolic poison in the myocardium to promote the irritability. The typical electrocardiography change is Q–T interval prolongation. The fluoride ions can be removed by haemodialysis or cation exchange resins [35,39].

Treatment includes four phases:

- hydrotherapy,
- topical treatment,
- infiltration,
- and intra-arterial infusion.

The first treatment of chemical burns should be thorough and copious lavage to clean the wound of unreacted surface

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chemicals and dilute them if they are already in contact with the skin [40,41].

This should be started immediately and prolonged for maximal effect. Copious washing is particularly important in HF burns since the properties of the acid derive in part from complex ions which are not present at concentration below 10%, i.e., convert it into a chemically less dangerous form.

The second phase of the treatment aim is to inactivate the free fluoride ion by promoting the formation of an insoluble fluoride salt. With this concept, several different topical treatments have been tried:

(a) *Magnesium compounds*: in practice, however, much of their reported use is anecdotal and they have generally been ineffective, probably as a result of the poor skin penetration by the magnesium ion [42].
(b) *Quaternary ammonium compounds*: high-molecular-weight quaternary ammonium compounds such as Hyamine 1622 or Zephiran are still widely used. Several mechanisms may inactivate the fluoride ion by these agents:
  a. exchange of ionised chloride for fluoride to produce a non-ionised fluoride complex;
  b. direct alteration of the permeability of tissue cell membranes,
  c. reduction of the surface tension, promoting better contact between the aqueous fluid and tissue components, and;
  d. as a secondary effect they also control invasive microorganism infection.
  (c) Several objections have been raised to these compounds. The iced solutions often cause discomfort for the patient after 15–20 min. There is also the question of toxicity, since it is estimated that a fatal dose of Hyamine is 1–3 g, which is equivalent to 50–150 ml of a 2% solution. Theoretically 4 g of Hyamine would be required to neutralize only 1 ml of a 20% HF solution, which questions its real efficacy in these types of injuries.
(d) *Calcium gel*: The advantages of the gel are that it is easy and painless to apply and may be self-administered [2]. There are however some disadvantages of this agent: large quantities may be required for treatment. It may leave a noticeable stain, especially in coloured patients. However its principal limitation is the non-permeable quality of the skin to the calcium. This can be overcome by direct infiltration into the tissue.
(e) Infiltration of calcium gluconate into the subcutaneous tissues beneath the involved skin from peripheral sites (dose of 0.5 ml of 10% calcium gluconate per cm^2) until it is painless. The indications of nail removal in hand burns are likewise contentious. HF passes easily through nails where it can cause severe damage to the delicate subungueal tissues [42].

Intra-arterial infusion: another method of improving the delivery of the calcium ion to the tissues has been the development of arterial infusion of calcium solutions to the extremities [43]. This is of particular value in digital burns involving highly concentrated HF where large amounts of fluoride ion need to be neutralized.

Systemic infusions of calcium and magnesium ions may be required in massive absorptions of acid to overcome its toxicity. The efficacy, still, is controversial, probably due to the severity of the clinical picture, which may be fatal in many cases despite treatment.

6.4. Phosphorus

Different sources of phosphorous have been claimed in literature to produce burns and it should be bear in mind, especially when dealing with industrial accidents. However, the military use of this product makes this environment the most frequent setting. White phosphorus ignites in the presence of air and burns until the entire agent is oxidized or the oxygen source is removed. Because of that, irrigation with water is the most important point of treatment with the removal of macroscopic clusters of phosphorus in contact with the patient. The application of a 0.5% copper sulphate solution impede oxidation and turn the particles black, making easier the identification and removal. Alteration of calcium, phosphorus or cardiac changes can occur. Ocular complication can be serious and disabling [44].

6.5. Strong alkali

Lime, sodium hydroxide and potassium hydroxide are present in household-cleaning solutions and are a common aetiology of chemical burns in oral ingestions in the context of suicide attempts. They are capable of deep penetration, and tissue destruction continues long after the initial exposure [45]. In household environments, the burns are usually small, but extensive alkali burns can happen in industrial settings and can be life threatening due to the large BSA burn injury involved [8]. Systemic effects can also occur due to substantial absorption of the chemical. Alkali injury to the eye is particularly devastating, because of the quick corneal penetration of these compounds. They can produce scarring, opacification of the cornea and perforation.

The mechanism by which strong alkali injuries are caused involves three factors [3]:

1. Saponification of fat is an exothermic reaction producing a significant amount of heat, which causes severe tissue damage. Destruction of fat allows an increase in water penetration of the alkali into the burn eschar, destroying the natural water barrier that lipids provide.
2. Extraction of considerable water from cells causes damage due to the hygroscopic nature of alkalis, causing extensive cell death and damage to tissues.
3. Alkalis dissolve proteins of the tissues to form alkaline proteinates, which are soluble and contain hydroxyl ions (OH^-). These ions cause further chemical reaction which initiate deeper injury of the tissue (liquefaction necrosis).

All clothes should be removed and the dry residues of alkali like lime should be brushed away, followed by prompt washing with large volumes of running water. The heat caused by the reaction of alkalis with tissues is diluted by the action of water, preventing further damage. Washing is presumed to cause:

- dilution and elimination of a chemical substance,
- attenuation of the chemical reaction,
- suppression of any raised tissue metabolism;
- anti-inflammatory action,
- suppression of the hygroscopic action; and
- return skin pH levels to normal [14].

There is no consensus, though, of the ideal duration of this hydrotherapy. Common practice calls for continuous water washing until the alkali is totally removed from the burn wound, but it is very difficult to establish this fact merely by wound inspection. In practice, we recommend continuous irrigation of 2 h or more (if small zones are affected) with rest periods of 4 h. It is very important to perform strict control of the body temperature during the hydrotherapy, and to apply this treatment in suitable cleaning tanks with a continuous water drain (this is especially true in large BSA burns).

Water cannot eliminate the chemical product from the deeper layers of the burn wound. Because of that, and when general status of the patient is stable, tangential excision of deep burns must be done with immediate coverage with skin autografts or temporary dressings. Otherwise, the damage of tissues may be progressive and the chance of infection can produce deeper lesions with time.

6.6. Sulphuric acid

Sulphuric acid is one of the agents most often involved in acid burns [3,7]. Sulphuric acid burn can occur in work environments, but it is also frequently seen in accidents at home and as a result of altercations. In most cases, the non-work related sulphuric acid burns are caused by drain cleaners [46].

Sulphuric acid and its precursor, sulphur trioxide, are strong acids and cause injury by causing dehydration damage and by creating excessive heat in the tissue. It produces coagulation necrotic eschars with thrombus formation in the lesion's microvasculature [5].

There is siginificant controversy in the literature about the management of this kind of burn, especially in terms of the concentration that may produce permanent damage. On the other hand, many research studies have been perform in the animal setting [13,47]. Because of careful extrapolation between animal skin and man must be done, these studies do not give much information about the treatment of human sulphuric acid burns.

Immediate copious irrigation after removing all contaminated clothes and the early excision of deep burns are the main points universally accepted, but further studies are needed to improve early treatment of sulphuric acid burns.

Nitric acid has similar characteristics, although it is much less common (mostly in industrial setting). Nitric acid burns may appear more superficial than those caused by sulphuric acid, although they can be deceptive, so caution should be exercised when dealing with this type of burn [48].

6.7. Vesicant chemical warfare agents

These agents were historically used during the trench warfare of World War I. They can produce deep skin burns and include the classic agents Lewisite (L) and sulphur mustard (SM) [49]. Skin lesions resulting from exposure to SM differ from thermal burns in that signs and symptoms may be delayed for up to 24 h after exposure depending on the dose of the inflicting agent. Damage tends to be partial thickness and spontaneous healing rates are significantly slower. Skin lesions resulting from exposure to L or SM vapour may progress to from large bullae that may require intensive medical management and surgical intervention [50]. They affect all epitheliums, including skin, eyes and respiratory epithelium. Symptoms described after exposure to mustard gas include burning eyes and a feeling of suffocation associated with burning throat [2]. Severe cutaneous SM lesions can take several months to heal. This lengthy healing process may be due to problems in cell replication due to cell damage, and to a damage of the dermis that may not provide a satisfactory matrix over which the new epidermal cells can spread. Blister aspiration and/or deroofing, epidermal removal, physical debridement, irrigation, topical antibiotics and sterile dressings have been the main courses of action in the medical management of cutaneous SM burns. Casualties generally experience multiples sites of injury, with the ultimate severity of lesion at any particularly site dependent upon the dose of the agent, ambient temperature and the moisture level in the skin [51–53].

7. Conclusions

Chemical burn injuries represent a small portion of total burn injuries. However, they are unique injuries which need a special attention and management because of their huge human and economic impact.

It is important to point out the importance of prevention, especially in working environments. Respecting the security rules and having showers and devices for eye irrigation are mandatory by consensus standards.

Patients must be treated by specialized practitioners and referred to a Burn Centre as soon as possible.

The gold standard for treatment is still copious irrigation with water, except in some chemical agents. New chemical neutralizers that are not only sterile, but also chelating, polyvalent, amphoteric, non-toxic, hypertonic and water-soluble, should also be kept in mind but they still require more clinical testing.

Conflict of interest statement

All authors declare that there are no conflicts of interest or commercial interest with the products, companies, or treatments cited in this article.

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