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Symptoms and treatment of hydrogen fluoride injuries

D. Peters *, R. Miethchen

University of Rostock, FB Chemie, Buchbinderstr. 9, D-18051 Rostock, Germany

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Abstract

Accidents with hydrogen fluoride are causes of the most hazardous injuries in laboratories. The effects of HF on human tissues are substantially different from those of ordinary acids. Therefore, the paper deals with the symptoms, first-aid and medical treatment of lesions caused by skin contact, inhalation or ingestion of HF. Furthermore, selected cases of accidents with hydrogen fluoride are reported to exemplify the unique dangers of such events. Some proper protection measures are also described.

Keywords: Symptoms; Treatment; Hydrogen fluoride injuries

1. Introduction

The accidental release of hydrogen fluoride is one of the most hazardous events in laboratories due to the physicochemical properties of HF (Table 1) and its specific attack on living tissues. There are two main reasons for a special paper on the symptoms and treatment of hydrogen fluoride injuries. On the other hand, chemists who only seldom work with HF and HF-containing or -releasing reagents, respectively, are often not aware of the potential dangers of hydrogen fluoride contact. As we noticed in discussions with colleagues, it is often unknown that even solutions of only 20 wt.% or less HF can cause severe lesions. On the other hand, a lot of first aid manuals deal with hydrogen fluoride only briefly or in connection with mineral acids and first-aid measures reported are often insufficient for HF lesions. Moreover, special treatment is necessary as will be described in this paper. Some cases of accidents are reported to underline this. As far as we know, the last comprehensive review in the chemical literature on the treatment of HF injuries was published in 1973 [1]. Subsequently, the only reports have been in medical journals which are normally outside the attention of chemists who are the objective of this paper.

Hydrogen fluoride immediately forms aggressive pungent clouds with moisture. Anhydrous HF can react explosively on contact with water. However, anhydrous HF in the liquid or vapour state and concentrated aqueous hydrogen fluoride are not the only HF sources [2–5]. There are some HF-containing fluorinating reagents (e.g. $Et_3N \cdot 3HF$, Olah's reagent pyridine $\cdot$ 9HF) which may liberate hydrogen fluoride. Inorganic fluorides (e.g. NaF and KHF_2 can release hydrogen fluoride when treated with mineral acids or heated. Certain fluorides (e.g. NH_4F and NH_4HF_2) are hygroscopic and form acidic aqueous hydrogen fluoride solutions. Certain other fluorides can also form HF, e.g. the reaction of SF_4, BrF_3 or CoF_3 with water yields hydrogen fluoride amongst other products. Thus, if the potential release of hydrogen fluoride is expected proper protection and first-aid measures in handling and performing reactions of fluorides or fluorine-containing compounds should be taken.

2. Effects of hydrogen fluoride on living tissues

Anhydrous, concentrated and even dilute aqueous hydrogen fluoride solutions are highly corrosive towards living tissues [7–10]. Inhalation, ingestion or skin contact with HF are exceedingly hazardous. The lowering of serum calcium (hypocalcemia) is one of the most serious consequences of severe exposure to HF and should be considered in all instances of inhalation, ingestion and when skin burns exceed 160 cm^2. As a consequence of hypocalcemia, cardiac arrhythmia (ventricular fibrillation) may occur.

2.1. Skin contact

HF quickly penetrates the skin, destroys deep tissues and can result in acute–threatening liver, kidney and metabolism disorder due to resorptive binding of fluoride to calcium and magnesium ions. HF burns may be characterized by a long

* Corresponding author.

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Table 1
Physicochemical properties of HF [4–6]

	Anhydrous HF	Hydrofluoric acid (70.0 wt.%)	Hydrofluoric acid (40.0 wt.%)
Boiling point (°C)	19.5	65.8	111.7
Melting point (°C)	−83.4	−81	−44.0
Vapour pressure of HF (Torr)	364 (at 0 °C)	117 (at 20 °C)	21 (at 20 °C)
Density (g cm^{-3})	1.015 (at 0 °C)	1.230 (at 20 °C)	1.135 (at 20 °C)
Viscosity (cP)	0.26 (at 0 °C)		0.95 (at 24 °C)
Surface tension (mN m^{-1})	10.2 (at 0 °C)		
Hammet function H_0	−11.7	−6.0	−2.0

latent period and tend to be deep and slow healing. Unlike other acids which are rapidly neutralised, the destruction process caused by hydrogen fluoride can continue for days. Serious effects can occur even if only small skin areas are exposed. Death has been reported after exposure to concentrated hydrogen fluoride causing burns of as little as 2.5% [7] and 8% [11] of body surface area. For animals exposed to liquid HF, the following LD_0 data (LD_0 = lowest reported lethal dose) have been published: 112 mg kg^{-1} (frog, subcutaneous) and 500 ml kg^{-1} (mouse, dermal) [12].

Contact with small amounts of HF and the accompanying death of tissue is frequently without any pain at the beginning and the appearance of the first symptoms can be delayed. The latent period may be up to 24 h, especially if the HF concentration is less than 20 wt.%. Reddening and cauterisation of the skin, followed by a white, marble-like colouring are the first symptoms of an HF burn. Larger amounts of hydrogen fluoride result in the formation of blisters. Deep penetration through the upper layer of the skin results in liquefaction and necrosis of deeper soft tissues. Experiments with rats confirm the hypothesis that HF blocks the enzymatic systems involved in cutaneous respiratory exchanges [13]. In the case of sufficient exposure, decalcification and corrosion of the underlying bone may be observed. Such deeper lesions are extremely painful due to immobilisation of tissue calcium, resulting in an excess of potassium-ensuring nerve stimulation and nerve-ending irritation.

The penetration of hydrogen fluoride into the capillary cleft between the nail body and the nail bed is especially hazardous because the acid cannot be removed by irrigation with water. In consequence, the nail has to be extracted if there is no response to direct calcium gluconate injections into the nail bed. Two accidents show the potential dangers caused by small amounts of HF.

Case 1 [14]: A drop of concentrated HF splashed on to the finger nail of a patient. The finger was insufficiently washed. The exposed point turned gradually to a white–yellowish colour, but no further visible changes were observed. Pain occurred 7 h later which continued for about 30 h. Examination of the tissue under the nail then showed that a pea-sized area had already been destroyed by necrosis requiring surgical treatment.

Case 2 [14]: HF had dropped on to the finger of a patient. Insufficient treatment resulted in the amputation of the exposed finger. Chemical analysis of this finger gave a fluoride content of as little as 0.16 mg.

2.2. Inhalation

Acute symptoms of hydrogen fluoride inhalation may include coughing, choking, chest tightness, fever, chills and cyanosis (bluish skin colouring). Exposure to HF vapour can cause pulmonary oedema and hemoptysis. HF burns of the oral mucosa and the upper airway may cause severe swelling. The threshold values of HF in the air for occupational exposure to humans (MAC values – airborne limits of permitted concentrations of hazardous chemicals) are different in industrialised countries and range from 2–3 mg m^{-3} (e.g. Germany MAC value, 2 mg m^{-3}; UK short-term limit, 2.5 mg m^{-3}; US ceiling limit, 2.6 mg m^{-3}) [12,15]. Concentrations above 50 ppm are extremely dangerous. The LD_0 value for humans (inhalation) is 50 ppm in 30 min. This is, of course, an estimated value. Various LC_{50} (inhalation) have been published for animals: mouse (342 ppm in 1 h); monkey (996 ppm in 1 h); and rat (1744 ppm in 1 h) [12]. There are also sub-acute data available for male albino pigs: inhalation of repeated doses of 5 mg of hydrogen fluoride for 4 d increased plasma cholesterol levels and reduced isocitrate dehydrogenase activity leading to an accumulation of citric acid [12]. The presence of HF vapours in the air can be detected by the pungent smell with an olfactory limit of 0.11–0.3 mg m^{-3} [16,17]. The following case describes a severe accident.

Case 3 [18]: A 49-year-old man was splashed with an acid mixture (70%–80% sulphuric acid and 10% hydrofluoric acid). He had superficial burns on the head (face, neck, throat) and on his lower legs (about 8% of body surface). However, inhalation of HF fumes caused severe burns of the upper respiratory tract. Despite adequate, rapid and intensive medical treatment, several complications including lung

problems occurred and the patient died 4 weeks after exposure due to respiratory insufficiency.

2.3. Ingestion

Ingestion of hydrogen fluoride or inorganic fluorides may cause severe HF burns to the mouth, oesophagus and stomach. Systemic effects (hypocalcemia) as well as cardiac dysrhythmias can also occur [19]. Patients who have ingested hydrogen fluoride very often die. Two cases are described below.

Case 4 [20]: A patient had ingested hydrofluoric acid from a drinking glass (mistaking it for water). The adult did not respond to medical treatment and died only 90 min after the accident due to severe acidemia and hypocalcemia resulting in refractory asystole.

Case 5 [19]: A 70-year-old woman ingested up to 50 g of a 8% hydrofluoric acid solution. Recurrent ventricular fibrillation with concurrent hypocalcemia and hypomagnesia complicated the treatment. However, aggressive administration of calcium and magnesium prevented further heart disrhythmias. This is the first report of survival from ventricular fibrillation after HF ingestion and shows the role of correcting calcium and magnesium levels.

2.4. Long-term effects

There are reports on the long-term effects after exposure to HF in some cases. After the release of about 24 tonne of hydrofluoric acid, an epidemiological study [21,22] of the community exposed in Texas (USA) has shown that long-term effects must be assessed as those causing health problems which continued for at least 2 years after the accident. A door-to-door survey of 10 811 individuals in the community showed a strong dose relationship between exposure and symptoms shortly after the accident and 2 years later on. Despite substantial health improvements, problems (such as behavioural sensitisation, recall bias, breathing and eye symptoms) that continued for at least 2 years were reported for some patients. The following case report gives an example of long-term effects.

Case 6 [18]: A 38-year-old patient had inhaled hydrogen fluoride fumes for a short period. Only a patchy flush was found on his face, neck, throat and lower legs. After appropriate medical treatment (cf. next section), the kidney and liver parameters returned to normal but 4 d after the accident some parts of the oral cavity were still slightly reddened and showed individual erosion. One year after the accident, the patient still complained of fits of coughing, hoarseness, pain in the nasopharynx and several nose bleeds.

3. First-aid measures

An accident caused by HF, even if it only appears minor or if only contact is suspected, must always be treated as a serious accident. After first-aid measures, medical treatment is always required and strongly recommended, even if the accident seems to be trifling. The most important initial point is the recognition that an HF injury may have occurred [7,9]. The rapidity of the first aid can reduce the severity of lesions. Thus, in the case of serious accidents, delays in first aid and treatment or improperly treated lesions may result in permanent damage, disability or even death (see the cases described).

Because medical treatment of hydrogen fluoride exposure is so specialised and differs from that of other mineral acid exposures, not all physicians may be aware of appropriate measures. Thus, the following statement related to HF burns was published in 1991 and is still true: "Unfortunately the particularity of this percutaneous intoxication is often misunderstood" [9]. Hence, it is recommended that prior arrangements be made with a local clinic. Thus, rapid and appropriate treatment by the staff of this clinic will be ensured in the case of an HF accident. For the staff of emergency ambulances, guidelines should have already been prepared and handed out. Thus, emergency physicians will be aware of the unique complications and treatment of these injuries. The transportation of the victim to the prepared local clinic and the proper treatment there should generally give favourable results and healing.

The following measures should be taken after skin contact, inhalation or ingestion with hydrogen fluoride [7,8,17]:

Skin contact

As the most important measure, the exposed skin should be irrigated immediately (within the first minute after HF exposure) with large amounts of clear flowing water, if necessary under a safety shower. Further measures are as follows:

- Brush off the exposed skin area with cool and clear water (at least 15 min).
- Remove contaminated clothing while flushing with water.
- After thorough washing, immediately massage the exposed skin with calcium gluconate gel until the pain disappears or dab with wet compresses soaked with a 20% calcium gluconate solution (50 ml per 15 × 15 cm compress).

An alternative treatment of HF burns of the skin is the treatment of the exposed skin with an iced, aqueous solution of a quaternary ammonium compound (e.g. Hyamine® or Zephiran®. However, these compounds should not be applied to the face or other sensitive parts due to their irritating nature.

Eye contact

- Irrigate intensively and copiously with clear gently flowing water alone (whilst irrigating, hold the eyelids completely open to allow thorough flushing of the eyes).
- Avoid rubbing the eyes.
- Calcium gluconate solutions should not be used.
- Immediate treatment should be effected by an ophthalmologist.

Inhalation

- Move the victim to fresh air.

- Treat with dexamethason aerosol (inhalation of five strokes every 10 min, until the arrival of an emergency physician) immediately after the accident.
- Oxygen should be administered if victim has breathing difficulties.

Ingestion

- The victim should drink copious amounts of water or 1% calcium gluconate solution in small sips (but do not give anything to an unconscious person).
- Do not stimulate vomiting or give emetics or backing soda.

In addition, the victim should be kept warm, quiet and lying down. Treatment for shock may also be required.

4. Clinical treatment

Further medical treatment of HF burns by a physician may include topical, subcutaneous or intra-arterial administration of calcium gluconate injections [8,9,23]. Thus, solutions of 10% calcium gluconate are injected around, beneath and into the HF burns. If subcutaneous injections are used, the amount injected initially should be small and not exceed 0.5 ml cm^{-2} of affected skin. A small-gauge needle should be used and the burned area should be injected through multiple sites. Local anaesthetics should not be applied since they mask pain relief which is an important indication of the adequacy of treatment. Injections must be continued until continuous pain relief is observed (normally within 24 h, but sometimes up to 2–3 d). Furthermore, surgical removal of destroyed tissue may be necessary. There are reports in the literature which describe the use of intra-arterial injections or infusions of calcium salts to treat burns of the limbs (e.g. hand and digits) which do not respond to other methods [9,24,25].

Severe eye burns require rapid treatment by an ophthalmologist [26]. Delays may result in scarring or blindness. Irrigation of the eye with a 1% calcium gluconate solution (prepared from 1 10% calcium gluconate and saline solution) has been successful.

Direct inhalation of HF vapour or inhalation by any exposure of HF to the face or upper body areas may result in airway irritation, chemical pneumonitis or pulmonary oedema. Patients who inhale hydrogen fluoride should be monitored for at least 24 h. It has been reported that pulmonary oedema may be delayed for up to 2 d. Respiratory problems require immediate treatment with 100% oxygen [27]. Therapy may cover treatment with dexamethason aerosol and high intravenous doses of Prednisolon® [17]. The following principles should be followed in the case of HF inhalation:

- maintain oxygenation (intubation or tracheostomy may be necessary, monitoring arterial blood gases);
- monitor and correct serum calcium levels (give calcium gluconate intravenously, continuous electrocardiogram monitoring);
- reduce bronchospasm and counteract HF pulmonary effects (use appropriate bronchodilators, consider calcium gluconate solution by nebuliser);

Table 2
Example of a first-aid package

• calcium gluconate vials, 20 wt.%	50 × 10 ml
• calcium gluconate gel	3 × 50 ml
• calcium effervescent tablets (e.g. Sandoz fortissimum®)	2 × 10 tablets
• dexamethason-spray (e.g. Auxilosan® spray with dexamethason-21-isonicotinat)	3 × 20 ml
• compresses 15 × 15 cm	50 pieces
• medical oxygen	1 cylinder

- control pulmonary oedema (high doses of parenteral steroids may be necessary, administer appropriate diuretics);
- monitor other functions (kidney, liver and heart function) and relieving anxiety.

Patients exposed to HF by contact, inhalation and ingestion should be monitored and treated for hypocalcemia. Even HF burns covering less than 2.5% of body surface area can severely lower calcium serum levels [7]. If necessary, 10 ml of a 10 wt.% aqueous solution of calcium gluconate may be given intravenously. Hypomagnesemia may also occur, although it is usually less severe than hypocalcemia. Secondary infections should be treated by antibiotics at the first signs.

For details of clinical medical treatment one should refer to the literature [7–9] and contact special trained clinical physicians, the medical divisions of suppliers of hydrogen fluoride or national intoxication services and regulations.

5. Protection

The preceding description of hydrogen fluoride effects demonstrates the necessity of proper protection and extreme caution while handling anhydrous hydrogen fluoride, aqueous solutions of HF or other hydrogen fluoride sources. A very well exhausting hood should always be used. All operations in the laboratory should be undertaken with rubber cuff gloves, rubber apron and face shield. Handling larger amounts of high concentrated HF (> 60 wt.%) or anhydrous hydrogen fluoride requires additional protection: total-body coverall, second pair of rubber gloves as well as helmet with face shield and neck-guard. The protecting equipment should be carefully inspected before handling hydrogen fluoride. The rubber gloves should be especially checked for hair cracks. Flowing water, respirator and first-aid equipment (Table 2) should be immediately accessible while handling HF. The laboratory staff must be periodically instructed about protection, first aid as well as safety and emergency regulations.

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