Chapter 104: Hydrofluoric Acid and Fluorides

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FIGURE 104–1.

HISTORY AND EPIDEMIOLOGY

Hydrofluoric acid has been known for centuries for its ability to dissolve silica. The Nuremberg artist Schwanhard is given credit for the first attempt in 1670 to use HF vapors to etch glass. Today, hydrofluoric acid (HF) is widely used throughout industry. In addition to glass etching, HF is used in brick cleaning, etching microchips in the semiconductor industry, electroplating, leather tanning, rust removal, and the cleaning of porcelain. From 2011 to 2015, the American Association of Poison Control Centers (AAPCC) reported 2,761 single-substance exposures to HF and 6 deaths (Chap. 130). The hands are the commonest part of the body injured. Exposures to HF often occur as unintentional occupational hazards. The actual number of work-related poisonings from HF appears difficult to quantitate because of limitations in International Classification of Diseases (ICD) medical coding and the lack of notification of regional poison control centers by worksites.

Hydrofluoric acid is also the commonest cause of fluoride poisoning, although other forms of fluoride, including sodium fluoride (NaF), ammonium bifluoride (NH₄HF₂), and sodium or zinc fluorosilicate, also produce significant toxicity. Historically, NaF was used as an insecticide, rodenticide, an anthelmintic for swine, and a delousing powder for poultry and cattle. Ammonium bifluoride is mainly used in industrial inorganic chemistry, especially in the processing of alloys and in glass etching. Other fluoride salts are widely used in, for example, the steel industry, drinking water, toothpaste additives, electroplating, lumber treatment, and the glass and enamel industries.

The widespread use of HF and fluoride-containing compounds results in significant toxicity. In 1988, an oil refinery in Texas released a cloud of hydrogen fluoride gas that resulted in 939 people seeking hospital treatment and 94 of these patients requiring admission. The petroleum industry has since been plagued by similar HF incidents. In 2015, Washington State reported one death and 48 occupational HF burns associated with car and truck washing between 2001 and 2013. Sodium fluoride was responsible for the poisoning of 263 people and 47 fatalities when it was mistaken for powdered milk and unintentionally combined with scrambled eggs. Following ingestion, this and other fluoride salts are converted to HF in vivo, resulting in significant fluoride toxicity.
CHEMISTRY

Hydrofluoric acid is synthesized as the product of gaseous sulfuric acid and calcium fluoride, which is subsequently cooled to a liquid. Aqueous HF is a weak acid, with a pKₐ of 3.17; as such, it is approximately 1,000 times less dissociated than equimolar hydrochloric acid, a strong acid. Hydrofluoric acid generally ranges in concentrations from 3% to 40%, for use in both industry and the home. Anhydrous HF is highly concentrated (>70%) and used almost exclusively for industrial purposes. Hydrofluoric acid has unique properties that can cause life-threatening complications following seemingly trivial exposure.

Sodium fluoride is commonly synthesized by the reaction of sodium hydroxide (NaOH) with HF, with subsequent purification by recrystallization. Sodium fluoride is highly water soluble and readily dissociates. To synthesize ammonium bifluoride (NH₄HF₂), ammonium fluoride (NH₄F) is first formed by the reaction of ammonium hydroxide (NH₄OH) with HF. Ammonium fluoride is then converted to bifluoride by dehydrating the aqueous solution.

Fluorine is the most electronegative element in the Periodic Table of the Elements owing to its relatively large number of protons in the nucleus compared to its molecular size, and the minimal amount of screening or shielding by inner electrons. Other halides possess lesser electronegative properties. Consequently, the corresponding anion of fluorine, the fluoride ion (F⁻), is a weak base because it possesses only a limited ability to donate its electrons. Liberation of the fluoride ion from the previously mentioned compounds is believed to be the major determinant of toxicity.

PATHOPHYSIOLOGY

Exposures to HF occur via dermal, ophthalmic, inhalation, oral, and rectal routes. A permeability coefficient of $1.4 \times 10^{-4}$ cm/sec allows HF to penetrate deeply into tissues prior to dissociating into hydrogen ions and highly electronegative fluoride ions. These fluoride ions avidly bind to extracellular and intracellular stores of calcium (Ca²⁺) and magnesium (Mg²⁺), depleting them, and ultimately leading to cellular dysfunction and cell death. The alteration in local calcium homeostasis causes neuroexcitation and accounts for the development of neuropathic pain. Furthermore, ischemia related to calcium dysregulation–mediated localized vasospasm is likely an additional contributory factor to the development of pain.

Formation of insoluble calcium fluoride (CaF₂) is proposed as the etiology for both the precipitous fall in serum calcium concentration and the severe pain associated with tissue toxicity. There are several theories regarding the actual fate of calcium and fluoride ions in tissues. In vitro evidence suggests that fluorapatite is formed in the presence of phosphate and hydroxyapatite, which is a more likely pathway for disposition of the fluoride ion. Fluorapatite, like calcium fluoride, is insoluble and its formation contributes to the clinical findings recognized following HF toxicity.
Fluoride also binds magnesium and manganese ions and there is in vitro evidence that this interferes with many enzyme systems. In the anhydrous form, the high concentration of hydrogen ions in HF also produces a caustic burn similar to that caused by strong acids (Chap. 103). The minimal lethal oral dose in humans is approximately 5 to 10 g of NaF.5

**CLINICAL EFFECTS**

**Local Effects**

**Dermal**

The extent of tissue injury following dermal exposure is determined by the volume, concentration, and contact time with the tissues. Following dermal exposure, the concentration of HF is directly related to the onset of pain at the contact site.31,56,90 High concentrations (>20%) cause immediate pain with visible tissue damage.84 Exposure to household rust-removal products (6% and 12% HF) is often associated with a typical latency of several hours, before pain develops.31,85,95,96 The initial site of injury typically appears relatively benign despite significant subjective complaints of pain. Over time, the tissue becomes hyperemic, with subsequent blanching and coagulative necrosis. As calcium complexes precipitate, a white discoloration of the affected area appears74 (Fig. 104–1). Ulceration is dependent on the concentration and duration of contact.27,48,57 If more than 2.5% of the body surface area (BSA) is burned with highly concentrated HF, life-threatening systemic toxicity should be expected.20,71,73,84,90 Small body surface area exposures to low concentrations (<20%) typically do not result in life-threatening systemic toxicity, although fatalities have resulted with dermal exposures to concentrated HF covering less than 5% body surface area.89

**FIGURE 104–1.**
Severe injury to the fingers resulted from exposure to hydrofluoric acid. Note the arterial line in place for administration of calcium. (Used with permission from the Fellowship in Medical Toxicology, New York University School of Medicine, New York City Poison Center.)
Gastrointestinal

Intentional ingestion of concentrated HF (or other fluoride salts) causes significant gastritis yet often spares the remainder of the gastrointestinal tract. Patients promptly develop vomiting and abdominal pain. Although systemic absorption is rapid and almost invariably fatal, there is at least one report of a patient who ingested a low concentration (8%) of HF and suffered multiple episodes of ventricular fibrillation but was successfully resuscitated. Following HF ingestion, patients often present with altered mental status, airway compromise, and dysrhythmias.

Ophthamlic

Hydrofluoric acid results in more extensive injury to the eye than most other acids. Ophthamlic exposures from liquid splashes or hydrogen fluoride gas rapidly denudes the corneal and conjunctival epithelium, and lead to stromal corneal edema, conjunctival ischemia, sloughing, and chemosis. Fluoride ions penetrate deeply to affect anterior chamber structures. The effects are usually noted within one day. Other possible findings include corneal revascularization, recurrent epithelial erosions, and, sometimes, keratoconjunctivitis sicca (dry eye) develops as a long-term complication with subsequent corneal ulcers.

Pulmonary

Patients with inhalational exposures present with a variety of signs and symptoms depending on the concentration and exposure time. Thirteen oil refinery workers exposed to a low-concentration HF mist experienced minor upper respiratory tract irritation. By contrast, in a mass inhalational exposure to HF,
throat burning and shortness of breath were among the more common chief complaints. Some of these patients developed hypoxemia and hypocalcemia and had altered pulmonary function tests. Stridor, wheezing, rhonchi, and erythema and ulcers of the upper respiratory tract were described. Eye pain was also noted, reinforcing the fact that ophthalmic injury often accompanies inhalational and/or dermal exposures.

**ASSESSING SEVERITY OF SYSTEMIC EFFECTS**

Significant systemic toxicity occurs via any route of exposure because of the ability of HF to penetrate tissues. The potential for systemic toxicity is an important consideration in management necessitating rapid decontamination and treatment. Fatal exposures to HF by any route share the similar features of hypocalcemia, hypomagnesemia, and, in many cases, hyperkalemia as preterminal events. In some circumstances, the hypocalcemia severely disrupts the coagulation cascade, resulting in significant anticoagulation, even on postmortem examination.

Fatalities from HF occur as a result of either sudden-onset myocardial conduction failure or ventricular fibrillation. Although the evidence regarding the mechanism of myocardial irritability is inconclusive, electrolyte disturbances that lead to ventricular dysrhythmias including ventricular fibrillation are the most likely primary cause of death in patients with severe systemic fluoride poisoning. Although one postmortem human case reveals significant structural myocardial injury, interestingly, histologic abnormalities of the myocardium do not occur in canine models of HF poisoning.

Systemic fluoride toxicity results in hypocalcemia, by mechanisms not fully elucidated. Fluoride causes calcium ions to accumulate intracellularly, leading to an efflux of potassium ions into the extracellular space. One in vitro study performed with human erythrocytes demonstrated that fluoride inhibition of Na⁺,K⁺-ATPase and Na⁺,Ca²⁺ exchange leads to an increase in intracellular calcium. The subsequent hyperkalemia alters the automaticity and resting potential of the heart, leading to fatal dysrhythmias (Chap. 15). Dogs treated with quinidine, a potassium efflux blocker, are protected from lethal doses of intravenous NaF. Likewise, amiodarone, which also blocks potassium efflux has demonstrable efficacy in both in vitro and in vivo models of fluoride toxicity. However, efficacy in humans has not been studied. Furthermore, the mechanism of toxicity is likely much more complicated. A child with systemic fluoride toxicity, who was appropriately replenished with calcium, and had normal electrolytes still experienced nonfatal ventricular fibrillation. Perhaps this is because serum potassium, calcium, and magnesium concentrations only partly represent tissue concentrations. Furthermore, HF directly impairs myocardial function. Rabbits exposed to topical HF over 2% of their total body surface area developed focal necrosis of myocardial fibers, as well as significant elevations in cardiac enzymes that persisted for almost 5 days after injury.

Assessing Severity of Clinical Exposures. Historical and clinical features of an exposure usually determine which HF exposures are life-threatening. All oral and inhalational exposures are potentially fatal, as should
burns of the face and neck, regardless of HF concentration. Inhalational exposure should be assumed for all patients with skin burns of greater than 5% body surface area, any exposure to HF concentrations greater than 20%, and head and neck burns. Despite this, hydrofluoric acid concentrations greater than 20% have potential for significant toxicity in any patient, even if only a small surface area is exposed. As a general rule, patients who experience severe pain within minutes of contact are most likely exposed to a very high concentration of HF and their condition should be expected to rapidly deteriorate. Some otherwise well-appearing patients have a precipitous demise without any clinical manifestations of hypocalcemia. Furthermore, it is possible that systemic toxicity will occur following seemingly minimal exposure. A 36-year-old man was exposed to 20% HF over a 3% BSA and subsequently developed hypocalcemia, hypomagnesemia, and cardiac arrest 16 hours later. A 2-year-old girl ingested some “fingers full” of an ammonium bifluoride glass etching cream and had prolonged hypocalcemia refractory to calcium gluconate up to 24 hours after ingestion. Consequently, patients will require prolonged electrolyte and cardiac monitoring following significant fluoride exposures.

**DIAGNOSTIC TESTING**

No monitoring or testing is required for uncomplicated small BSA exposures to low concentrations of HF. Diagnostic testing for systemic fluoride poisoning is currently based on monitoring of serum electrolytes. Calcium, magnesium and potassium concentrations should be serially monitored. As systemic toxicity progresses, a metabolic acidosis will likely develop necessitating a venous or arterial blood gas analysis. Serum fluoride concentrations are not readily available in a clinically relevant time frame. Although a serum fluoride concentration of 0.3 mg/dL was reported as fatal, one patient survived with a serum fluoride concentration of 1.4 mg/dL. Electrocardiographic findings of both hypocalcemia (prolonged QT interval) and hyperkalemia (peaked T waves, etc) are often reliable indicators of toxicity (Chap. 15). In fact, ECG findings of peaked T waves from hyperkalemia preceded the onset of ventricular dysrhythmias in reported cases, thus potentially serving as a marker of severe fluoride toxicity. It should be noted that in some cases of HF poisoning, hypokalemia is reported and for unclear reasons, are specifically related to sodium fluoride toxicity.

**MANAGEMENT**

**General**

For patients with more than localized exposure to low concentration (<20%) HF or any exposures to high concentration (>50%) HF, the mainstay of management is to prevent or limit systemic absorption, assess for systemic toxicity, and rapidly correct any electrolyte imbalances. Intravenous access should be obtained. An
ECG should be obtained and examined for dysrhythmias and signs of hypocalcemia, hypomagnesemia, and hyperkalemia. The patient should be attached to continuous cardiac monitoring and have a rapid assessment of serum electrolyte concentrations.

Rapid airway assessment and protection should occur early in patients with inhalation or ingestion, respiratory distress, ingestion with vomiting, or burns significant enough to cause a change in mental status or phonation. If an unstable patient requires intubation, the depolarizing neuromuscular blocking agent, succinylcholine, should not be used because of potential hyperkalemia.

For patients with less significant dermal exposures, studies have focused on alternatives to irrigation with water or saline as decontamination techniques. The compound “hexafluorine” is promoted for dermal and ophthalmic decontamination of HF splashes. Hexafluorine is a proprietary name whose chemical formula is not disclosed and papers that report success have strong ties to the manufacturer. In a controlled and blinded experimental study, Hexafluorine treatment was less effective than irrigation with water followed by the application of topical calcium. In a follow-up animal study, water irrigation was as effective as Hexafluorine in preventing systemic toxicity from HF. At this time, until further objective data are available, we do not recommend the use Hexafluorine for initial decontamination of patients with HF exposures.

An iodine-containing preparation was evaluated in a guinea pig model of HF-induced burns and found to be associated with significant reductions in ulceration area. Iodine is hypothesized to inhibit apoptosis and has protective effects against burns from various alkylating agents, including mustard gas. Because experience with iodine treatment of human HF burns is lacking, it cannot be recommended at this time.

The most important therapy for skin exposures is the rapid removal of clothing and irrigation of the affected area with copious amounts of water or saline, whichever is more readily available.

One report describes a woman who was dying from severe HF toxicity who was treated by amputation of the affected limb, and survived. Although this may be an alternative measure for patients who are critically ill and demonstrate an inadequate response to all other therapeutic modalities, we do not recommend such aggressive measures.

Dermal Toxicity

Several therapeutic options have been studied in animal models for treatment of topical HF burns. Unfortunately, many study designs use histologic or subjective wound inspection as outcome parameters, some with unblinded inspection. These animal models do not address the clinically important parameters of pain reduction, cosmesis, and functionality (Antidotes in Depth: A32).

We recommend that a topical calcium gel be applied to the affected area. A commercial gel is available in the United States but an acceptable substitute is reasonable and easily prepared. This is accomplished by mixing
3.5 g of calcium gluconate powder in 150 mL of sterile water-soluble lubricant, or 25 mL of 10% calcium gluconate in 75 mL of sterile water-soluble lubricant. If calcium gluconate is unavailable, it is reasonable to use calcium chloride or calcium carbonate in a similar formulation. This topical therapy for severe and non–life-threatening toxicity scavenges fluoride ions. After irrigation, we recommend a gel solution of calcium carbonate or gluconate be applied directly to the affected area or mixed directly into a sterile surgical glove and then placed on the patient’s burned hand for 30 minutes. Two case series report limited success with this therapy. Some patients describe prompt and dramatic relief of pain. Alternatively or simultaneously, analgesics are recommended orally or parenterally as needed, but preferably not to the point of sedation, because local pain response is used to guide therapy. Digital nerve blocks with subcutaneous lidocaine or bupivacaine is also reasonable for patients with significant pain presenting 12 to 24 hours after the injury from a low concentration of HF and with no systemic signs of toxicity since that time topical calcium salts are unlikely to be effective. An animal study examining the efficacy and mechanism of topical calcium gel therapy found that the fluoride ion concentration in the calcium gel was significantly higher than non–calcium-containing gel controls. Although this was a limited study, these animals also had a decrease in urinary fluoride ion concentration as compared to controls, suggesting less overall tissue absorption of the HF. Delivery of calcium transcutaneously is enhanced by various means. In a rodent study of HF burns, iontophoretic (facilitated transport using an electromotive force) delivery of calcium ions appeared to increase calcium concentrations in vitro and improve pathologic changes in vivo. Significant limitations to this study are time to administration of therapy and feasibility in patients with complex burns. Human data are lacking. Dimethyl sulfoxide (DMSO) mixed with topical calcium salts facilitates the transport of calcium ions through the skin to penetrate deeply into the tissues. Dimethyl sulfoxide also is able to act as a scavenger of free radicals, thus limiting inflammation and ongoing injury. Although one group of authors advocates for the combined use of DMSO and calcium, concerns remain over reported adverse effects of DMSO. There are currently inadequate data to support the routine use of DMSO in the treatment of HF burns.

Three other therapies have had variable success in human exposures: the application of calcium via intradermal, intravenous, and intraarterial routes. If topical gel therapy fails within the first few minutes of application, intradermal therapy with dilute calcium gluconate is a reasonable next step. Unfortunately, this treatment has limited usefulness and is not recommend in nondistensible spaces such as fingertips. Histologic studies in animal models demonstrate that 10% calcium chloride solution is damaging to the tissues and is not recommended. The preferred method is to approach the wound from a distal point of injury and inject intradermally no more than 0.5 mL/cm² of 5% calcium gluconate. Although one author recommends a palmar fasciotomy whenever this method of treatment is used in the hand, this practice is not recommended unless a compartment syndrome is present. The potential for iatrogenic injury exceeds the potential benefit of injections in the hand. The limits of intradermal injection include the potential to increase soft-tissue damage without adequate relief, infection, and inadequate space to safely inject without causing a compartment syndrome.
Effective pain relief is especially problematic for nailbed involvement, leading some authors to suggest removal of the nail. This approach has some advantages in accessing the affected area; however, it is a painful procedure that is often cosmetically undesirable and the outcome is not always significantly improved. We therefore do not routinely recommend this procedure.

If the wound is large or on a section of the fingerpad or an area that is not amenable to intradermal injections, intraarterial calcium gluconate is the next most reasonable step. This procedure delivers calcium directly to the affected tissue from a proximal artery. Placement should be ipsilateral and proximal to the affected area, usually in the radial or brachial artery. The method of obtaining access is debated. Because of the potential to damage the endothelial lining of the artery, and because extravasation can have potentially devastating consequences, angiographic confirmation or direct visualization of the vessel was formerly recommended. This practice is still prudent if cannulation of the artery is expected to be difficult because of prior surgery or if an anatomic deformity is suspected. If the arterial line is carefully placed in a single attempt, and a good confirmatory arterial tracing is obtained, the infusion can be started. We recommend adding 10 mL of 10% calcium gluconate to either 40 mL of D₅W (dextrose 5% in water) or 0.9% sodium chloride solution infused continuously over 4 hours. This results in a 2% calcium gluconate solution. An animal model examined the effect of undiluted 10% calcium gluconate intraaortically. Although the model did not involve exposure to HF, there was significant tissue injury in the vessel wall as compared to a 2% calcium gluconate solution. Calcium chloride has also been used successfully, although the potential for vessel injury and extravasation are significant and there is no defined benefit over calcium gluconate. The complications associated with the use of intraarterial calcium infusion in several case series were relatively benign, and include transient radial artery spasm, hematoma, inflammation at the puncture site, and a fall in serum magnesium concentration. After the infusion is initiated, patients typically experience significant pain relief. Patients requiring an arterial line for treatment should be admitted to the hospital, as the majority will require more than one treatment, and some patients require as many as 5 separate infusions of calcium gluconate. Although wounds may require débridement, some authors suggest that following intraarterial calcium infusion, tissue can be salvaged that initially would not have been considered viable. There are no reported cases of clinically significant hypercalcemia following infusion as the total dose infused is quite low, although serum calcium concentrations were not routinely recorded in some cases.

Magnesium salts are an alternative or adjunctive therapy to the administration of calcium salts for patients with dermal HF burns. Application of magnesium hydroxide and magnesium gluconate gel show histologic evidence of efficacy in rabbit models of dermal HF burns. Two other animal models of intravenous magnesium for dermal HF burns also suggest efficacy in terms of wound healing. Magnesium was suggested as an antidote for fluoride poisoning because magnesium fluoride is more water soluble than calcium fluoride and magnesium is readily excreted by the kidneys. However, these magnesium models inadequately address the disadvantage of magnesium salt solubility, and both topical and intravenous magnesium therapy remain incompletely evaluated in humans and therefore is not routinely recommended.
Another reported therapy for localized HF poisoning is an intravenous Bier block technique that uses 25 mL of 2.5% calcium gluconate. In one case, the effects lasted 5 hours and there were no adverse events. In 2 other cases of patients exposed to HF, a 6% calcium gluconate solution administered using this procedure resulted in rapid and complete analgesia with minimal tissue necrosis. Although the intravenous Bier block technique is not reported as being used in a substantial number of patients, it is reasonable, particularly when intraarterial infusion is problematic. Further data are required before this therapy is routinely recommended.

We routinely observe all patients with digital exposures to HF over 4 to 6 hours, as the pain often recurs and reapplication of the gel or an alternative therapy will be necessary. Even if successful pain control is achieved, the patient will require specialized follow-up and wound care.

**Inhalational Toxicity**

Patients exposed to a low concentration of HF and treated with 4 mL of a 2.5% nebulized calcium gluconate solution demonstrated a subjective decrease in irritation with no adverse effects. Another report demonstrated a good outcome following nebulization of a 5% calcium gluconate solution in a patient with an inhalational exposure. Because nebulized calcium gluconate is a relatively benign therapy, we recommend that all patients with symptomatic inhalational exposures to any concentration of HF be administered a dilute solution of calcium gluconate.

**Ingestions**

In patients with intentional ingestions of HF, gastrointestinal decontamination poses a dilemma. Induction of emesis is potentially harmful and therefore contraindicated. Because aqueous HF is a weak acid, the risk of perforation by passage of a small nasogastric tube may be lower than the risk of death from systemic absorption. In the acidic environment of the stomach, more of the weak acid solution remains nonionized, thus penetrating the gastric mucosa and causing rapid systemic poisoning. Moreover, activated charcoal is unlikely to adsorb the relatively small fluoride ions. Although placement of a nasogastric tube to perform gastric lavage is clearly associated with risks to the patient, insertion of a nasogastric tube is beneficial under specific circumstances if done safely and in a timely manner. Consequently, gastric emptying via a nasogastric tube is reasonable in the absence of significant spontaneous emesis because these exposures are almost universally fatal. Health care providers should exercise extreme caution during this procedure because secondary dermal or inhalational exposures to the provider is possible in the absence of appropriate personal protective equipment. If there is a possibility of inhalation by the provider, the area should be well ventilated. Acceptable forms of hand protection include gloves made of nitrile, butyl rubber, polyvinyl chloride, or Neoprene. Latex gloves should not be used.

Following ingestion, we recommend a solution of a calcium or magnesium salt be administered orally as soon as possible to prevent HF penetration into the stomach and to provide an alternative source of cations for the damaging electronegative fluoride ions.
When comparing the efficacy of calcium to magnesium salts, calcium is better than magnesium in reducing the bioavailability of fluoride as described in a murine model. Magnesium citrate in a standard cathartic dose, magnesium sulfate, or any of the calcium solutions can be administered orally to prevent absorption (Antidotes in Depth: A16). Although intuitive, evidence for the benefit of oral calcium or magnesium salts is limited. In a mouse model of oral HF toxicity, administration of calcium- or magnesium-containing solutions did not change average survival time. The study results, however, were limited because the calcium and magnesium salts were premixed together with the HF during administration, thus being an inadequate model for the study of HF ingestion. In another study, the survival rate of mice poisoned with NaF was significantly greater when treated with either high doses of oral CaCl₂ or MgSO₄. Given the current information, we recommend oral calcium salts for oral ingestion; however, if calcium salts are unavailable, magnesium salts are reasonable should be given.

**Ophthalmic Toxicity**

Patients with ophthalmic exposures should have each eye irrigated with 1 L of 0.9% sodium chloride solution, lactated Ringer solution, or water. Although there are limited data, repetitive or prolonged irrigation appears to worsen outcome. A complete ophthalmic examination should be performed after the patient is deemed stable, and an ophthalmology consultation should be obtained (Chap. 24). One case report demonstrated a good outcome following ocular HF exposure with the use of 1% calcium gluconate eye drops. Although 2 reviews also recommend the use of 1% calcium gluconate for this purpose, calcium salts tend to be irritating to the eye and this therapy is not adequately studied; consequently, use is not recommended at this time. There is no role for gel therapy or ophthalmic injection for these patients, because most calcium and magnesium salts are potentially toxic to ophthalmic tissues and may actually worsen outcome.

**Systemic Toxicity**

If there is a clinical suspicion of severe toxicity, the immediate intravenous administration of both calcium and magnesium salts is recommended. Calcium gluconate is preferred over calcium chloride because of the risks associated with extravasation (Antidotes in Depth: A32). Patients often require several grams of calcium to treat severe HF toxicity. We recommend that intravenous magnesium be administered to adults as 20 mL of a 20% magnesium sulfate solution (4 g) over 20 to 30 minutes. An approach that uses intravenous calcium or magnesium, and local calcium or magnesium gels to limit absorption protects against life-threatening hypocalcemia and hyperkalemia. Because of the numerous adverse effects of systemic fluoride poisoning, administration of calcium and magnesium salts alone is often insufficient in improving survival from systemic fluoride poisoning. Furthermore, an animal model of hydrogen fluoride toxicity found that maintaining a normal acid–base balance was protective against HF toxicity. Moreover, in a study of patients receiving enflurane, an inhalational anesthetic metabolized by the liver to fluoride ions, urine alkalinization improved the excretion of fluoride. Thus, it is beneficial to correct any significant acidemia with hydration.
and IV sodium bicarbonate (calcium salts and sodium bicarbonate cannot be mixed). Because standard treatment for systemic fluoride toxicity includes administration of calcium salts and sodium bicarbonate, hyperkalemia is simultaneously addressed.

Treatment with large quantities of calcium and magnesium do not generally result in significant hypercalcemia or hypermagnesemia. Several explanations are proposed. First, in systemically HF-poisoned patients, total body calcium and magnesium stores are severely decreased so that large doses are required for adequate repletion. In addition, most patients who are exposed to HF are young and healthy, with intact kidney function. Administration of calcium also results in antidiuretic hormone antagonism on renal tubular reabsorption resulting in polyuria which facilitates the urinary excretion of calcium and magnesium.

Because most of the fluoride ions are eliminated renally, hemodialysis is reasonable in patients with severe HF poisoning and acute kidney injury. There are several reported cases of successful clearance of fluoride ions via hemodialysis, with one case also using continuous venovenous hemodialysis. Because the reported clearance rate did not differ significantly from normally functioning kidneys, it is unclear whether hemodialysis alters outcome in patients with normal kidney function. Furthermore, prolonged hemodialysis, beyond the standard 4-hour course, is unnecessary for most patients unless they have kidney failure.

Although the use of quinidine, a potassium channel blocker, is protective in dogs, it has not been studied or used in humans, and at this time cannot be recommended, but in the presence of life-threatening ventricular dysrhythmias, quinidine (or any other class III antidysrhythmic) is reasonable.

**SUMMARY**

Although HF has a pKa of 3.17 and is considered a weak acid, it causes local and systemic toxicity because of fluoride binding to cations.

Dermal exposure to HF causes severe pain, often before any physical manifestations are evident.

In patients with greater than 2.5% BSA HF burns we recommend periodic assessment of serum calcium, magnesium, and potassium concentrations. Admission is required for prolonged electrolyte and cardiac monitoring.

Therapy for local toxicity includes topical calcium and magnesium salts and systemic analgesia. In some cases, intradermal or intraarterial administration of calcium is required.

Therapy for systemic toxicity includes all treatments for local toxicity plus intravenous calcium and magnesium salts, sodium bicarbonate, and potentially hemodialysis.
REFERENCES


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