A Fatality Due to Ingestion of Hydrofluoric Acid*†

S.C. Cordero¹, W.W. Goodhue², E.M. Splichal¹,³, and V.F. Kalasinsky¹,‡

1 Armed Forces Institute of Pathology, Division of Environmental Toxicology, Washington, D.C. and 2 Department of Pathology, Tripler Army Medical Center, Honolulu, Hawaii

Abstract

We report a fatal case of hydrofluoric acid (HF) ingestion with suicidal intent. Quantitation using an ion-selective electrode for fluoride in fresh bile, gastric contents, kidney, liver, skeletal muscle, urine, and vitreous humor yielded 6.5, 39.0, 10.0, 6.0, 4.5, 5.0, and 4.5 ppm, respectively. In addition to the unfixed specimens, fluoride ion was measured in the following fixed tissue: brain, heart, kidney, liver, pancreas, stomach, and heart. Tissues were measured directly and/or by using the technique of standard addition. Fluoride concentrations using either method were found to be comparable. Fluoride concentration in fresh tissue was consistent with toxicity, although the urine fluoride concentration was in the range observed for asymptomatic workers exposed to fluoride in air. Fixed tissue preparations revealed fluoride concentrations consistent with nonexposure, whereas examination of the formalin fixative revealed fluoride concentrations only slightly higher than negative control formalin. We conclude that fixed tissues are inappropriate for fluoride determination. This is the first case we are aware of that provides fluoride concentrations in skeletal muscle in a fatality involving HF ingestion.

Introduction

The industrial uses of hydrofluoric acid (HF) include the etching of glass, silicon-chip manufacturing, metal processing, and uranium enrichment. HF is commonly used in household products such as wheel cleaners and rust removers. More recently, ammonium fluoride and ammonium bifluoride have appeared in wheel cleaners, where contact with body fluids has resulted in cases of fluoride toxicity (1). Fluoride salts are used in dental-care products (sodium fluoride, sodium fluorosilicate) and were commonly used in household settings as rodenticides and insecticides (sodium fluoride, sodium fluoroacetate).

Toxic episodes and death can occur with the ingestion of hydrofluoric acid or fluoride salts (1–3). Cases of inhalation exposure have been recorded involving ammonium bifluoride (1) and hydrogen fluoride gas (4,5). Hydrofluoric acid causes painful tissue inflammation and necrosis on contact. The pKₐ of HF is 3.2, allowing it to readily cross cell membrane barriers, especially in the acidic conditions of the stomach. At physiologic pH, HF dissociates to fluoride and hydrogen ions, leading to acidosis. Fluoride ion binds to free calcium and magnesium cations, leading to hypocalcemia and hypomagnesemia. Fluoride interferes with enzymes of the Krebs cycle, adenyi cyclase, acetylcholinesterase, and the Na⁺K⁺ ATPase, leading to extracellular release of potassium and hyperkalemia. The resulting imbalance in serum electrolytes can lead to ventricular fibrillations and eventual cardiovascular collapse.

Case History

A 43-year-old male was despondent over personal matters. He obtained and consumed a 10-fl oz bottle of “Whink Rust and Stain Remover” mixed with a carbonated beverage. Shortly afterward, he experienced excruciating abdominal pain, for which he attempted to slash his wrist to expedite the suicide. This was unsuccessful, and he appeared at a nearby police station where he told officers that he “drank poison”. At the time, he was holding the empty bottle and a receipt for its purchase. Almost immediately thereafter, he developed convulsions and projectile vomiting.

The victim was transported to a local hospital emergency room by ambulance at 01:45 h. On arrival, the patient exhibited hyperventilation, incontinence, paresthesias, nausea, and continued vomiting. He had clear lungs, normal sinus heart rhythm, and presented the following vital signs: blood pressure, 96/58 mm Hg; pulse, 83 beats/min; respirations, 28 breaths/min; temperature, 97.3°F. Conversations with emergency room personnel indicated that the HF solution was consumed at approximately 21:00 h the previous evening. He had no history of alcohol, tobacco, or illicit drug use and was taking prescribed medication for hypercholesterolemia. Standard laboratory tests were negative for ethanol (10 mg/dL cutoff) and common drugs of abuse.

The patient's condition progressed to hypocalcemia, hypomagnesemia, and hyperkalemia reported at 02:36 (Table I), accompanied by characteristic electrocardiographic QT interval.

* Previously presented as a lecture at the 2002 Pittsburgh Conference, New Orleans, LA.
† DISCLAIMER: The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the U.S. Department of the Army or the Department of Defense.
* Author to whom correspondence should be addressed: Dr. Victor Kalasinsky, Armed Forces Institute of Pathology, 6825 16th Street, NW, Bldg. 54, Washington, D.C. 20306-6000. E-mail: kalasinv@afip.osd.mil.
prolongation. Subsequent electrolyte levels reflected administration of calcium and magnesium boluses and insulin in 50% dextrose solution with a cation exchange resin. Hyperglycemia, as observed in this case, has been noted in other cases of fluoride intoxication (1,5). The QT prolongation further progressed to ventricular tachycardia and ventricular fibrillation unresponsive to prolonged resuscitative efforts. The first defibrillation occurred 5 h 20 min after ingestion. Over the course of hospitalization, a total of 23 defibrillation attempts were necessary before the patient expired at 05:10 h, 8 h post ingestion.

At autopsy, severe erosive cheilitis, glossitis, esophagitis, and gastritis were noted, in addition to bilateral pulmonary congestion and edema. There was no evidence of aspiration, acute hemorrhagic pancreatitis, acute tubular necrosis, or subarachnoid hemorrhage. The skin showed marked retention of tenting on pinching and markedly puckered skin on finger pads and toe pads suggesting dehydration. Other findings included centrilobular macrovesicular steatosis of the liver and moderate occlusive atherosclerosis of the coronary arteries. The cause of death was ruled toxicity due to hydrofluoric acid ingestion with suicide as the manner of death.

### Methods

Fluoride concentration was determined using a fluoride ion-selective electrode connected to a Thermo Orion model 290A pH/mV meter (Beverly, MA) that could be calibrated to provide direct concentration readings. Standards were prepared in-house with sodium fluoride and Type I water at a stock concentration of 100 ppm fluoride or were obtained from Thermo Orion at concentrations of 100, 10, 2, and 1 ppm. Total ionic strength adjustment buffer (TISAB) was obtained from Thermo Orion. The purpose of TISAB is to buffer the samples at pH 5–5.5 to prevent formation of HF, as the electrode is sensitive only to free fluoride ion. TISAB also prevents fluoride complexation by aluminum and iron and brings the samples and standards to a similar level of ionic strength for meaningful comparison.

An equal volume of TISAB was added to all standards and samples, except standards obtained from Thermo Orion. The commercial standards are preformulated to have an appropriate amount of TISAB and were used as received. The electrode slope and calibration were performed according to the manufacturer's instructions and produced a slope of ~58 mV/decade, in accordance with the Nernst equation (lab temperature 20°C). The electrode was calibrated at 1, 5, and 10 ppm and was verified using the 10-ppm standard hourly. Standards prepared in-house produced the same concentration results as those obtained commercially.

Bile, gastric contents, urine, and vitreous humor were measured directly by immersing the electrode in the sample after an equal volume of TISAB had been added. The electrode was tapped gently to ensure that no air bubbles adhered to the sensing element. Samples were measured in polystyrene vials, and all samples and standards were constantly stirred using a Teflon-coated magnetic stir bar. The addition of a Teflon-coated magnetic stir bar. The addition of TISAB did not produce the same concentration results as those obtained commercially.

### Table I. Serum Electrolytes during Hospitalization

<table>
<thead>
<tr>
<th>Test</th>
<th>Time</th>
<th>Sodium</th>
<th>Potassium</th>
<th>Chloride</th>
<th>Carbon dioxide</th>
<th>Glucose</th>
<th>Urea nitrogen</th>
<th>Creatinine</th>
<th>Calcium</th>
<th>Magnesium</th>
</tr>
</thead>
<tbody>
<tr>
<td>02:36</td>
<td>143</td>
<td>5.5</td>
<td>105</td>
<td>182</td>
<td>22</td>
<td>1.9</td>
<td>4.1</td>
<td>0.5</td>
<td>4.1</td>
<td>0.5</td>
</tr>
<tr>
<td>04:11</td>
<td>144</td>
<td>3.8</td>
<td>112</td>
<td>253</td>
<td>19</td>
<td>1.5</td>
<td>5.0</td>
<td>3.1</td>
<td>5.0</td>
<td>3.1</td>
</tr>
<tr>
<td>05:10</td>
<td>144</td>
<td>3.4</td>
<td>114</td>
<td>234</td>
<td>20</td>
<td>1.7</td>
<td>23.6</td>
<td>2.8</td>
<td>23.6</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Reference Range
- Sodium: 137–145 mmol/L
- Potassium: 3.6–5.0 mmol/L
- Chloride: 98–107 mmol/L
- Carbon dioxide: 65–110 mg/dL
- Glucose: 7–20 mg/dL
- Creatinine: 0.7–1.5 mg/dL
- Calcium: 8.4–10.2 mg/dL
- Magnesium: 1.6–2.3 mg/dL

### Table II. Fluoride Concentrations in Fixed and Not-Fixed Tissues (ppm)

<table>
<thead>
<tr>
<th>Material</th>
<th>Frozen Specimen</th>
<th>Fixed Specimen</th>
<th>Formalin</th>
<th>Normal Range</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bile</td>
<td>6.5</td>
<td>unavailable</td>
<td>unavailable</td>
<td>0.4–0.7*</td>
<td>3.4*</td>
</tr>
<tr>
<td>Brain</td>
<td>unavailable</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4–0.68*</td>
<td>1.6–3.4*</td>
</tr>
<tr>
<td>Gastric</td>
<td>39.0</td>
<td>unavailable</td>
<td>unknown</td>
<td>5.6*</td>
<td>4.4–225*</td>
</tr>
<tr>
<td>Liver</td>
<td>6.0</td>
<td>0.4</td>
<td>0.5</td>
<td>0.2–0.8*</td>
<td>1.7–81*</td>
</tr>
<tr>
<td>Lung</td>
<td>unavailable</td>
<td>0.4</td>
<td>0.9</td>
<td>0.16–0.42*</td>
<td>12.4–15.6*</td>
</tr>
<tr>
<td>Heart</td>
<td>unavailable</td>
<td>0.3</td>
<td>0.2</td>
<td>0.44–0.60*</td>
<td>10.6*</td>
</tr>
<tr>
<td>Kidney</td>
<td>10.0</td>
<td>0.7</td>
<td>0.4</td>
<td>0.2–0.8*</td>
<td>2.1–66*</td>
</tr>
<tr>
<td>Muscle</td>
<td>4.5</td>
<td>unavailable</td>
<td>unavailable</td>
<td>1.6*</td>
<td>4.5</td>
</tr>
<tr>
<td>Pancreas</td>
<td>unavailable</td>
<td>0.7</td>
<td>0.4</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Stomach</td>
<td>unavailable</td>
<td>0.4</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Urine</td>
<td>5.0</td>
<td>unavailable</td>
<td>0.2–3.2*</td>
<td>17–320*</td>
<td>unknown</td>
</tr>
<tr>
<td>Vitreous</td>
<td>4.5</td>
<td>unavailable</td>
<td>unknown</td>
<td>12**</td>
<td></td>
</tr>
</tbody>
</table>

*Reference 9, Reference 3, Reference 5, Reference 4, Reference 8, Reference 12.
Urine and vitreous humor concentrations were determined directly from the electrode meter. Concentrations for tissue homogenates, bile, and gastric contents were calculated using the slope of the standard addition measurements and dilution factors for the tissue homogenates. The gastric contents were diluted to bring its concentration within the calibration range.

Results and Discussion

Fluoride concentrations measured for the submitted specimens are listed in Table II. The highest concentrations are observed in the gastric contents and kidney tissue. Interestingly, urine fluoride is only slightly higher than normal and, in fact, is lower than what has been observed in asymptomatic individuals occupationally exposed to fluoride in air (range, 2.1–14.7 ppm; average, 4.5 ppm) (7). The low urine fluoride concentration may be due to urine loss during the victim’s emergency treatment. Emergency room personnel reported the patient lost bladder control, and some urine may have been lost through a urinary catheter. Only about 5 mL urine was available in the bladder at autopsy. Previous authors have speculated that low urine fluoride concentrations may be observed in fatalities due to early renal shutdown (8). In their case, a fluoride fatality from ingestion of 3–4 oz of a rust remover product [10% HF, 25% ammonium bifluoride, 1% 2-(2-butoxy)ethanol] produced a urine fluoride concentration of 17.0 mg/L (ppm).

Human heart muscle has been found to normally contain 440–600 ppb fluoride and 10.6 ppm in a fatality due to sodium fluoride, whereas “muscles” are reported to have a fluoride concentration of 1.6 ppm (9). These same authors have speculated that the variety of techniques employed prior to their study overestimated the normal tissue concentration of fluorine, and, therefore, the 1.6 ppm fluoride observation in muscle may also be an underestimate. Acute death caused by fluoride salts in dogs produced tissue fluoride levels comparable to those observed in acute human fatalities (1.4–16 ppm) (9). Fluoride content in the muscles of dogs poisoned with sodium fluoride varied from 2–4 ppm. This is similar to the 4.5 ppm observed in skeletal muscle in this case. Blood fluoride levels in fatalities caused by fluoride salts are comparable to those observed when death was caused by percutaneous hydrofluoric acid exposure (10). A blood specimen was unavailable in this case.

Although one could reasonably predict that fluoride would distribute out of tissue into an aqueous fixative, we measured its concentration in fixed tissue on the chance that enough might remain in a tissue-bound form to indicate a concentration greater than in nonexposed individuals. If it worked, this would allow the retrospective analysis of fixed tissue specimens in cases where fluoride was implicated and unfixed tissue was no longer available.

The fluoride concentration in the formalin from these tissues is only slightly higher than in a formalin control. Formalin was not available from the stomach tissue. Only liver and kidney were available in both fixed and unfixed forms for comparison. There is no similarity in fluoride concentration between fixed and unfixed liver and kidney. The other fixed specimens are consistent with reported normal fluoride concentrations and by themselves do not suggest fluoride exposure.

From the victim’s statements to police and emergency room personnel, we are reasonably confident that the entire 10 fl oz of the 2–3% HF product was consumed. This corresponds to an ingested dose of 6–9 g HF causing a fatality approximately 8 h after ingestion. However, as little as 1.5 g HF ingested has resulted with fatal outcome, with an interval between ingestion and death of 6.5 h (11).

Conclusions

The specimen fluoride concentrations in this case, with the exception of urine, are consistent with fatal exposure. Skeletal muscle concentrations in a fatal HF ingestion are presented for the first time. As was expected, we have demonstrated that fluoride ion will distribute out of fixed tissue into 10% formalin fixative. Fixed tissue is not an appropriate sample for fluoride determination.

References


Manuscript received December 30, 2002; revision received June 10, 2003.