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Darcy J. Cope,[1] B.A. and Tosha L. Dupras,[1] Ph.D.

The Effects of Household Corrosive Chemicals on Human Dentition*

ABSTRACT: There is a gap in the literature concerning the chemical effects that household products may produce on human remains. The present study examines the effects of household chemical products on teeth. A total of eight chemicals were utilized for this experiment. The corrosive chemical categories include: hydrochloric acid, sulfuric acid, phosphoric acid, and sodium hydroxide. Two products with each chemical were used, each representing varying concentrations of the corrosive product. Two human teeth were allocated for emergence in the chemical throughout a 24-h period of exposure. Results demonstrate hydrochloric acid as the most detrimental chemical to the dental samples. Sulfuric acid enacted minimal alterations to the teeth, although some etching and discoloration were noticeable. Phosphoric acid resulted in variable changes of the organic and inorganic contents of teeth. Lastly, exposure of sodium hydroxide resulted in little to no change. As hypothesized, distinct effects are observable of each chemical.

KEYWORDS: forensic science, forensic anthropology, caustics, acids, masking identity, dentition, teeth

Household corrosive chemicals can be used as a deadly accomplice when a murderer's goal is to mask the identity of their victim (1). Such chemicals include everyday consumer products such as drain cleaners, toilet bowl cleaners, muriatic acid, and rust dissolvers, all of which are easily attainable by the general public. Although these chemicals may not be used in every household, their easy accessibility in local home hardware stores certainly allows for a range of applications within the household and various other settings. Analysis from a forensic case involving the skeletal remains of a woman revealed peculiar alterations to the teeth and erosion of the maxillary and mandibular bone, resulting in exposure of tooth roots (Fig. 1). Both the bone and teeth also exhibited staining. One of the perpetrators confessed to using an acid on the victim with the intent of eradicating the facial features and deterring forensic efforts in establishing a positive identification of the victim. Regardless of this confession, it was necessary to corroborate the assailant's statement, preferably by identifying the type of acid used on the victim. Due to the lack of publications pertaining to a methodological approach for analyzing skeletal remains exposed to corrosive chemicals, initial forensic analysis did not reveal an identification of the chemical used on the victim's corpse, nor was it possible to corroborate the assailant's statement. Unfortunately, published forensics cases only hint at the utilization of chemicals for intentional destruction of an individual and the chemical effects on the human skeleton. These sources include the use of sulfuric acid in concealing the identity of the Romanovs (2), a case reported by Ubelaker and Sperber (3) that presents evidence of chemicals causing corrosion on tooth fragments, and finally a case involving the murderer John George Haigh, sometimes termed "The Acid Bath" case for Haigh's method of disposing the bodies of his victims in a vat of sulfuric acid (4).

A variety of techniques are used to ascertain a positive identification of human skeletal remains (e.g., radiographic comparisons or DNA matching); however, one of the most common methods is the comparison of antemortem and postmortem dental records (5). The remains of dental fragments are important parts of archaeological and forensic human remain analysis because of their longstanding presence even after deterioration of all other soft tissue and bone. Dental enamel tissue of teeth is the strongest component of the human skeleton, and this strength and resilience is because of the formation of crystals, the main composition of the enamel tissue, into parallel bundles, which allow the tooth to withstand traumatic forces, such as chemicals (6,7). The specialization of forensic odontology relies on the durability of teeth to analyze antemortem dental records and compare that data to the postmortem analysis of the deceased person. If conclusive analogous traits are evident between the two sets of data, a positive identification of the deceased individual is likely. The corroboration of the antemortem and postmortem records depends on identifying characteristics, such as any type of dental work or specific structures of the teeth (5). In some cases, antemortem information cannot be appropriated because of inadequate information or a lack of dental examinations throughout the person's lifetime. In such an occurrence, a forensic odontologist may request information from family and friends regarding the deceased person's participation in any distinct occupation or habit (i.e., smoking) that could result in deformation of the tooth structure and consequently be used as a matching variable for postmortem dental records (8). Although this route may not always yield a positive identification, there is potential that such information could reduce the possible matches of the remains. Recognizing the importance of forensic odontology provides substantiating confirmation that any trauma (in this case, chemical use) that teeth are subjected to could potentially destroy vital evidence for identification purposes (5).

The research presented here is a continuation of the work by Lang (9) and Dupras and colleagues (10) exploring the effects of household corrosive chemicals on human teeth and bone. Lang (9)

[1]University of Central Florida, Department of Anthropology, 25000 University Blvd., Orlando, FL.

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FIG. 1—*Mandible and maxilla displaying dental erosion caused by intentional exposure to a corrosive chemical.*

documents the effects of muriatic acid, sulfuric acid, potassium hydroxide, and sodium hydroxide on teeth and bone exposed for 8 h to each chemical, through changes in mass, crown width, and tooth length. This research includes qualitative descriptions of how each tooth sample was affected by the corrosive chemical. Based on the results, Lang (9) concludes that muriatic acid was the most damaging of the chemicals while the other chemicals had a very minor effect on bone and teeth.

A major addition to this research is the inclusion of extensive qualitative documentation and analysis in an effort to identify features that are unique for the effects of each chemical on human dentition. It is hypothesized that each corrosive chemical will produce unique dental morphological changes analogous to each individual chemical. Human teeth were monitored for causative defects resulting from exposure of household chemicals containing corrosive elements.

The Exposure of Human Dentition to Chemicals

There are several potential contexts in which human teeth may be exposed to corrosive chemicals: forensic cases involving the use of corrosive chemicals on a victim, the act of vomiting in bulimic individuals, industrial chemical hazards in the workplace, and methods in dentistry which regularly expose teeth to acidic chemicals for etching purposes. Dental fragments from the legendary Romanov case displayed convincing evidence that suggested for the exposure to a corrosive chemical. Soil samples revealed high acidity and skeletal analysis noted corrosion and etching on the bones which supported claims that some sort of acidic property was poured over the remains (2,11). Examination of dental material revealed noticeable etching on the enamel surface of the teeth. Identification of the corrosive chemical was not made through analysis of the teeth, but rather through interview reports of the offenders and a receipt found for 400 pounds of sulfuric acid (2). Because this recounting comes from popular literature that is not scientifically based, the description and analysis of the dental remains are lacking.

Another forensic case documenting the use of a corrosive chemical concerns the killings and disposing of the victims of John George Haigh (12). Haigh utilized sulfuric acid to dispose of the bodies. The body of one victim was found after being submerged in a vat with 40 gallons of sulfuric acid for 4 days. Reports indicate that teeth fragments, along with bone fragments and various synthetic materials, were collected during the investigation. A description of the teeth fragments was not given, but it was hypothesized that if the body of the victim were to have remained in the vat for an entire month, no identifiable evidence of the victim would be found (4,12).

A case examined by Ubelaker and Sperber (3) found the use of another chemical tentatively identified as sodium hydroxide. Dental fragments were described as having a loss of sheen and polish from the enamel surface, corrosion, and a chalky white color. Despite this damage, the chemical did not significantly affect the restorative dental work of the victim, thus potentially allowing for identification.

Individuals diagnosed with bulimia nervosa may display a variety of oral complications in response to their practice of self-induced vomiting. Several studies have focused on the oral side-effects of bulimic individuals whose compulsive vomiting results in dental erosion (13). Interestingly, the acidic properties present in vomit are also found in a variety of highly corrosive household products. Self-induced vomiting is accompanied with the release of hydrochloric acid, commonly referred to as stomach or gastric acid (14). The labial (tongue) surface of the incisors and canines and the occlusal (biting) surface of the molars and premolars are frequently affected by stomach acid during vomiting. Incessant vomiting over an extended period of time (likely to be months) can ultimately lead to severe erosion of the enamel because of the persistent presence of stomach acids in the mouth. Studies have reported enamel loss, shorter teeth, jagged edges, and detachment of fillings from their original position (15–17). These morphological changes are a direct result of the gastric acid causing a demineralization of the enamel and thinning of the incisal edge of the maxillary incisors (15). The inclusion of data relating to bulimic individuals is helpful in establishing identifiable features, particularly the pattern of erosion, which may also be consistent with the household products containing hydrochloric acid.

Chemical hazards are evident in a variety of worksites, such as chemical plants and factories. Workers in contact with these chemicals are susceptible to health dangers on a daily basis (18). Characteristic malformations on dental surfaces are the result of constant exposure to acid fumes (19). Physical effects caused by chemicals at worksites are useful in deriving possible parallels between the effects of chemical exposure at worksites and the use of chemicals on a victim's body. A murderer will presumably use an aqueous form of a chemical to achieve destruction of a victim's identity. In contrast, chemicals at workplaces are dispersed in a variety of modes such as gas, vapor, aerosol, dust, fume, smoke, mist, and fog (20). The variability of exposure, or any extrinsic factors such as dietary consumption, can account for the diverse effects that the tooth structure exhibits. Reports state the symptoms of long-term exposure to hydrochloric acid as producing erosion on dental surfaces (20,21). Similarly, exposure to sulfuric acid has been directly linked to enamel erosion in addition to a brownish stain covering the tooth surface (19,21,22). Sulfuric acid has a Threshold Limit Value-Time Weighted Average (TLV-TWA) of 1 mg/m^3. The TLV-TWA is the average concentration for an 8- and 40-h workweek, that workers can be continually exposed to a chemical, day after day, without adverse effects. In a case of exposure (through inhalation) of sulfuric acid over a 4-month period, a concentration of 0.23 mg/m^3 had the ability to cause erosion of the teeth (20). Petersen and Gormsen's (22) report on dental examinations of

TABLE 1—*Household corrosive products used in experiment. Each is listed with dominant corrosive chemical and concentration is reported from manufacturer information.*

	Household Product	Acid/Base	Acid/Base Concentration (%)	Tooth Samples (2 For Each Group)
1	Smart Products® pH Decreaser	Hydrochloric acid	31.45	Group A1
2	Sno Bol® Liquid Disinfectant	Hydrochloric acid	14.50	Group A2
3	Floweasy® Drain Opener	Sulfuric acid	94.19	Group B1
4	Rooto® Professional Drain Opener	Sulfuric acid	93.20	Group B2
5	PH-OSPHO-RIC Plus	Phosphoric acid	85.00	Group C1
6	Naval Jelly® Brand Rust Dissolver	Phosphoric acid	25–30	Group C2
7	Roebic® Professional Strength Liquid Drain Opener	Sodium hydroxide	28.00	Group D1
8	Dissolved sodium hydroxide pellets	Sodium hydroxide	0.1 M	Group D2

workers at a German battery factory, with a TLV-TWA of airborne sulfuric acid ranging from 0.4 to 4.1 mg/m^3, revealed substantial dental erosion that eventually led to short, sharp. and thin teeth, a symptom linked to the acid mist contaminated atmosphere (22). Another study observed the erosion of the teeth caused by sulfuric acid concentration in the air ranging from 0.1 to 2.00 mg/m^3. A number of workers displayed a smooth, glaze effect on the teeth surface, without damage of the dentine tissue, while other workers reportedly had severe deteriorations involving the dentine tissue for more than one-third of the tooth (19). Unfortunately, the current literature pertaining to workplace chemical exposure does not include the effects of phosphoric acid and sodium hydroxide on dental structures. Toxicology reports describe phosphoric acid and sodium hydroxide as an irritant to the eyes, skin, and respiratory tract, as well as a highly corrosive chemical with the ability to cause severe burns (21).

In restorative dentistry, phosphoric acid is frequently used to prepare the surface of the tooth for the adhesion of orthodontic attachments or resins (23,24). The acid etches the surface of the tooth by demineralizing the inorganic components of the enamel and dentine, namely calcium phosphates. This results in microporosity of the surface for penetration of the resin through the now demineralized zone and bonding of the hydrophilic resin with the collagen properties of the solid surface (25). As indicated, phosphoric acid attacks the mineralized portion of the teeth. Some studies have reported a continued decalcification of the enamel area that is treated with phosphoric acid, leading to the development of caries (24,26). Studies have also focused on the effects of phosphoric acid in comparison with other acid-etching chemicals. Generally, these studies have concluded that phosphoric acid is a strong chemical that is reliable in eliminating mineralized portions at greater depths (24,27–29). It was noted in one study that a concentration of just 5% phosphoric acid adequately remove inorganic material from dentine, at a progressive rate (29). A 10% concentration of phosphoric acid has been reported to partially remove the mineral portions of the root dentine, while a 32% concentration resulted in complete removal (27). In these studies, the teeth were exposed to phosphoric acid for a minimum of 10 sec to a maximum of 15 min; however, an actual orthodontic etching procedures using phosphoric acid is typically a 45-sec process, in which the tooth is exposed to the acid for 15 sec, followed by 15 sec of spraying water, and finally 15 sec for air drying (24).

Materials and Methods

Adult human teeth were collected from a dentist in Orlando, Florida that totaled 41 and of these 16 teeth were chosen because of their overall completeness and lack of pathology. Many of these teeth had calculus buildup and cavities, representing real-world dental conditions. Any changes caused by these deformities during experimentation are noted in the results.

A total of eight chemicals were utilized for this experiment. Of these chemicals, seven products were purchased at general stores and one chemical was prepared by dissolving sodium hydroxide pellets (in the absence of easily finding a second product containing sodium hydroxide at general consumer stores). Each chemical/product is categorized according to the amount of corrosive chemical found within the product (Table 1). The corrosive chemical categories include: hydrochloric acid, sulfuric acid, phosphoric acid, and sodium hydroxide. Two products were assigned to each chemical category, with one product demonstrating a higher concentration of the caustic chemical and the second product demonstrating a lower concentration.

An incisor and molar were selected for each chemical group, for a total of 16 teeth (Table 1). To simulate the position of the tooth in the mandible/maxilla, a hole was drilled through the root of each tooth where a wire was fed through (9). A wooden dowel permitted the tooth to suspend over a beaker, allowing 40 mL of the chemical to make contact with only the enamel surface of the tooth. Each sample was submerged in the chemical for 24 h with changes being documented after 1, 2, 3, 4, 5, 6, 12, and 24 h. There was no replenishment of the chemical throughout the experimentation process. Documentation consisted of quantitative and qualitative data. Quantitative data of the teeth included measurement of the crown width and tooth length, and weight. A microscope with a digital camera was used for capturing images.

Results

The mass for each group is reported on a graph (Fig. 2). The mass consisted of the wet weight and thus differences in the density and consistencies of the chemicals can affect what is reported as a change in weight as a sole response to any chemical actions against the teeth. Despite this, results show a correlation with the physical changes of the teeth and the recorded weight. The average was taken for each measurement interval for the two sets of teeth in each group. The changes in crown width and tooth length are reported on Table 2. The effects of hydrochloric acid were by far the most destructive on dentition. The products Smart Products® pH Decreaser (Sunbelt Chemicals, Palm Coast, FL) and Sno Bol® Liquid Disinfectant (Church & Dwight Co., Inc., Princeton, NJ), both completely destroyed the enamel tissue of the teeth within an hour (Table 3). The remaining dentine of the incisor exhibited a progressive thinning and translucent effect. By the end of the 24-h experimentation period, the incisor and molar showed a radical change in morphology with only the roots of the teeth remaining (Fig. 3*b,d*). The molar sample from Group A1 (31.45% hydrochloric concentration) was completely destroyed. Tooth samples

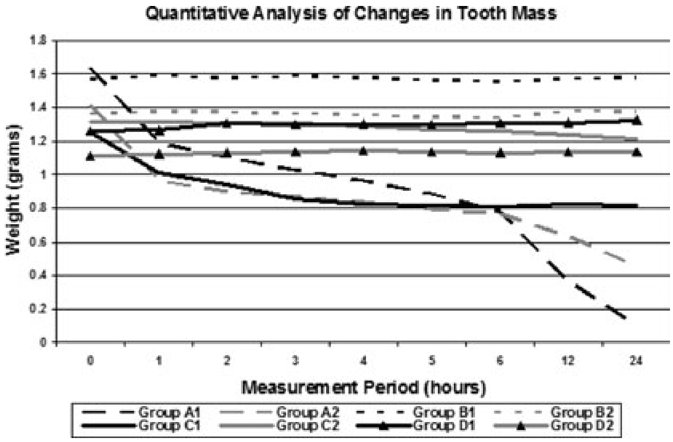

FIG. 2—*Changes in tooth mass. As is clearly expected, those teeth belonging to Group A1 and A2 defined the greatest decrease in mass caused by the destructive effects of hydrochloric acid.*

subjected to both products also displayed a jelly-like consistency (Table 3, Fig. 3). Exposure to Sno Bol® caused a unique effect on both the molar and incisor from Group A2 (14.5% hydrochloric concentration), as contact with the chemical caused blue coloration of the enamel on both the molar and incisor. The incisor also showed a fragmented crystal-like crown (Fig. 3*e*). Within 3 h the crystal-like crown quickly transformed to a jelly-like substance and degraded continually afterwards. At the end of the 24-h testing period only the roots of the teeth remained, lacking crystal-like formations or blue coloration as seen at the start of the experiment. As would be expected from the physical destruction of the teeth, exposure of hydrochloric acid caused a decrease in the mass of the teeth (Fig. 2: Group A1 and A2), complete dissolution of the crown (Table 2) and almost complete destruction in the tooth, except for tooth A2 which resulted in complete loss of the tooth (Table 2)

Sulfuric acid was not as efficient in the breakdown of the dentition in comparison to products containing hydrochloric and phosphoric acid (Table 4). Group B1 teeth exposed to Rooto® Professional Drain Opener (The Rooto Corperation, Howell, MI) (94.19% sulfuric acid) displayed a brown discoloration within the first hour of contact and removal of calculus buildup on the incisor (Fig. 4*b*). Group B1 and B2 (93.2% sulfuric acid) teeth exhibited erosion of the enamel with slight exposure of the dentine tissue. Within 24 h of exposure the sulfuric acid altered the surface of the teeth into a pasty consistency (Fig. 4*b,d*). Slight increases in mass also occurred, most probably in response to the retention of the chemical in the tooth structures (Fig. 2: Group B1 and B2). There were minor changes in the crown width and tooth length (Table 2).

TABLE 3—*Qualitative description of the effects of hydrochloric acid on dentition.*

Duration (hour)	Group A1—Smart Products® pH Decreaser (31.45% Concentration)	Group A2—Sno Bol® Liquid Disinfectant (14.50% Concentration)
1	Both teeth: Complete enamel loss on both teeth; Severe etching lending to jagged edges	Both teeth: Enamel not present; blue coloration
	Incisor: Increase in size of primary cracks	Incisor: Crystal-like appearance
3	Both teeth: Very fragile, etching evident	Incisor: Very fragile, crystal-like crown still present, blue coloration visible
	Incisor: Thin and transparent appearance	Molar: Continued etching, jelly-like consistency at occlusal surface
4–6	Both teeth: Spongy consistency;	Incisor: Crystal-like remains are now gelatinous
	Overall destruction of teeth has stabilized	Molar: occlusal surface is gelatinous
12	Both teeth: Spongy consistency	Incisor: Dramatic decrease in size, no longer in contact with the chemical, incisal surface still has blue coloration
	Incisor: Only root portion remaining	Molar: Increase in corroding, molar pale in color
	Molar: Severe deterioration of the molar did not allow suspension causing the remaining tooth material to submerge in the acid	
24	Incisor: Root portion has decreased in size; jelly-like consistency on surface of incisor root	Incisor: Very dry, no decrease in size
	Molar: Completely destroyed	Molar: Dramatic decrease in size with a gelatinous consistency

Despite the effects of the sulfuric acid, each tooth retained its overall initial morphology (Table 4, Fig. 4).

Products containing phosphoric acid created dramatic changes in tooth structure throughout the 24-h experimentation period (Table 5). Contact with PHO-OSPHO-RIC Plus and Navel Jelly® Brand Rust Dissolver (Henkel Consumer Adhesives, Avon, OH) for 1 h caused progressive thinning of the enamel tissue, exposure of dentine, dryness of the entire tooth, and a chalky texture, all of which were consistent throughout a majority of the experimentation period (Fig. 5*b,d*). After 24 h of exposure, the enamel ceased to exhibit a chalky texture, instead showing a sticky and pasty consistency. This change was largely distinguished on tooth samples

TABLE 2—*Change in crown width and length of human dentition exposed to chemicals.*

Household Product	Initial Crown Width (cm)		Total Loss in Crown Width (cm)		Initial Tooth Length (cm)		Total Loss in Tooth Length (cm)	
	Incisor	Molar	Incisor	Molar	Incisor	Molar	Incisor	Molar
Group A1: Smart Products® pH Decreaser	0.9	1.11	0.9	1.11	2.15	1.95	1.35	1.95
Group A2: Sno Bol® Liquid Disinfectant	0.7	1.11	0.7	1.11	2.2	1.5	1.1	1
Group B1: Floweasy® Drain Opener	0.85	1.25	0	0.15	2.1	1.9	0	0
Group B2: Rooto® Professional Drain Opener	1.05	1.15	0.25	0.05	1.9	1.8	0.3	0.1
Group C1: PH-OSPHO-RIC Plus	0.6	1.1	0.3	1.1	2.15	1.6	0.45	2
Group C2: Naval Jelly® Brand Rust Dissolve	0.55	1.05	0.15	0.25	1.95	1.9	0.05	0.3
Group D1: Roebic® Professional Strength Liquid Drain Opener	0.55	1.1	0	0.1	2.2	2.1	0.1	0
Group D2: Dissolved sodium hydroxide pellets	0.5	1.1	0.05	0.1	2.1	1.95	0	0.1

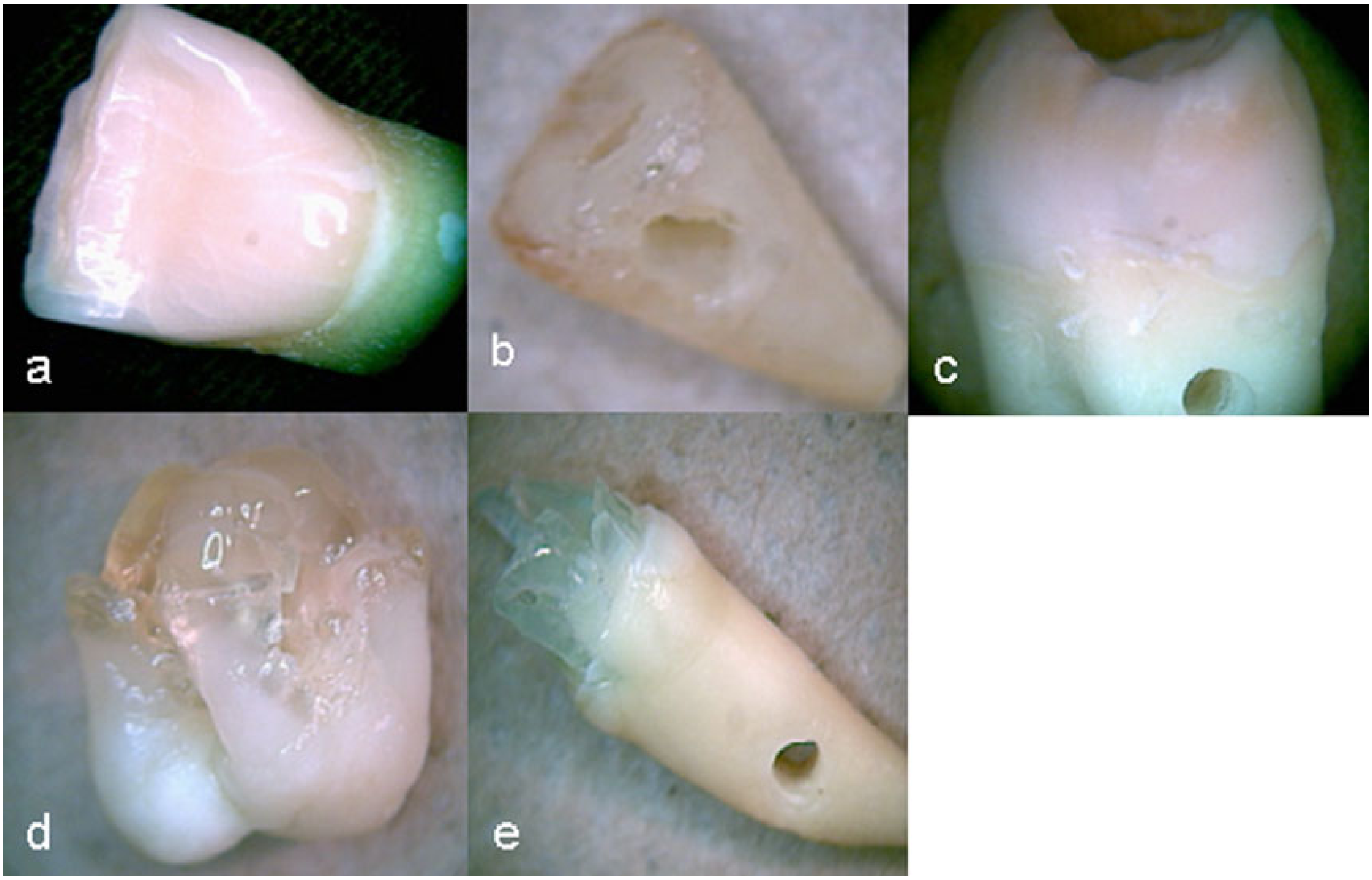

FIG. 3—*Hydrochloric acid effects on human teeth. Pictures (a) and (b) represent the same incisor tooth. Pictures (c) and (d) represent the same molar tooth. (a) Incisor tooth prior to contact with 31.45% concentration of hydrochloric acid. (b) Incisor tooth at 24 h of contact with 31.45% concentration of hydrochloric acid displaying a jelly-like consistency on the roots, the only remaining structure of the tooth. (c) Molar tooth prior to contact with 14.50% concentration of hydrochloric acid. (d) Molar tooth at 24 h of contact with 14.50% concentration of hydrochloric acid also displaying a jelly-like consistency and dramatic modification in shape. (e) Incisor tooth at 2 h of contact with Sno Bol® Liquid Disinfectant displaying the blue crystal-like crown.*

affected by the PHO-OSPHO-RIC Plus product. The enamel's metamorphosis into a flexible substance allowed easy bending and shaping of the enamel without any resulting breakage (Fig. 5*b*). The varying concentrations of phosphoric acid in both products had similar effects on the teeth but to different extents depending on the concentration of the acid. The higher concentration of phosphoric acid found in PH-OSPHO-RIC Plus increased dissolution of the teeth in comparison to the lower concentration found in Naval Jelly® Brand Rust Dissolver. In contrast to the Group C1 samples, Group C2 retained semblance to the initial morphology due to the ability of the teeth withstanding major degradation. Mass reduction correlated with the structural changes (Fig. 2: Group C1 and C2, Table 2).

Sodium hydroxide proved to be the least effective in degrading the teeth, but significant changes were observed on the surface (Table 6). Initial cracks in the teeth of Group D1 (28% sulfuric concentration) expanded with continual exposure to Roebic® Professional Strength Liquid Drain Opener (Roebic Laboratories, Inc., Orange, CT) (Fig. 6*b*). Calculus on the incisor was completely eliminated within 1 h of the experiment. The enamel was slightly affected by the chemical, first with the appearance of a sheen affect and afterwards with minor enamel flaking. Teeth of Group D2 (0.1 M sodium hydroxide concentration) showed little effect from the sodium hydroxide. The only distinguishable changes were minor removal of enamel and calculus (Fig. 6). No other changes were evident. A slight increase of mass occurred 1 h into experimentation, followed by a relatively stable mass throughout the remaining experimentation period (Fig. 2: Group D1 and D2).

Discussion

Understanding the anatomy of teeth is essential in relating the chemical effects resulting from the experiments. Each tooth is comprised of three tissues—enamel, dentin, and cementum. The crown is composed of enamel, underneath lays the dentin tissue, which forms most of the tooth and surrounds the pulp cavity. The roots are surrounded by the cementum, and at the apex of the tooth is the apical foramen, a small hole that allows entry of blood vessels and nerves into the pulp cavity (30). Mature enamel is highly mineralized with 95% of the weight being hydroxyapatite (mineralized portion) and the remaining 5% made up of water, protein, and organic (collagen fiber) material (31). In dentine, about 48% of the volume is formed by mineral content (hydroxyapatite), while the remaining volume is composed of organic material, mostly collagen fibers.

The results of this experiment have shown that products containing hydrochloric acid can produce severe dissolution of dentition and are thus able to eradicate crucial evidence on dentition, such as trauma or unique features that are important in attaining a positive identification of a victim. Exposure to hydrochloric acid results in

TABLE 4—*Qualitative description of the effects of sulfuric acid on dentition.*

Duration (hour)	Group B1—Floweasy® Drain Opener (94.19% Sulfuric Acid)	Group B2—Rooto® Professional Drain Opener (93.2% Sulfuric Acid)
1	Both teeth: Brown coloration, increase in mass which is most likely due to intake of acid	Both teeth: Teeth are heavier, likely due to retention of chemical in initial cracks of teeth.
	Incisor: Enamel is smooth with no presence of previous calculus, labial surface looks corroded	No other significant changes
3	Both teeth: Deterioration of enamel tissue and brown coloration	Both teeth: Slow deterioration of enamel
4–6	Both teeth: No significant changes	Both teeth: No significant changes
12	Both teeth: Teeth demonstrate a greater mass that may be due to retention of chemical; no other significant changes	Both teeth: Showing more dentine Incisor: Minor flaking of enamel
24	Both teeth: Enamel has become a pasty consistency; slight flaking of enamel	Both teeth: Enamel has become a pasty consistency

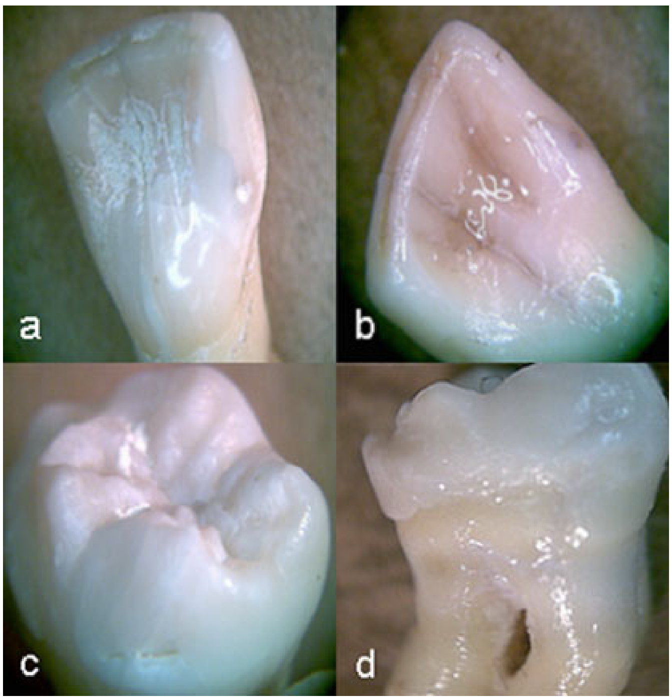

FIG. 4—*Sulfuric acid effects on human teeth. Pictures (a) and (b) represent the same incisor tooth. Pictures (c) and (d) represent the same molar tooth. (a) Incisor tooth prior to contact with 94.19% concentration of sulfuric acid. (b) Same incisor tooth at 24 h of contact with 94.19% concentration of sulfuric acid. A slight brown coloration is evident and a pasty consistency of the enamel. The tooth structure itself did not drastically change. (c) Molar tooth prior to contact with 93.20% concentration of sulfuric acid. (d) Same molar tooth at 24 h of contact with 93.20% concentration of sulfuric acid, displaying enamel with a pasty texture. The overall morphology of the tooth did not show a drastic change.*

two particular characteristics, rapid removal of the enamel and the resulting jelly-like consistency. The chemical basis behind these effects occurs as a result of hydrochloric acid attacking the mineralized portion (hydroxyapatite crystals) of the enamel, thus resulting in a quick eradication of most of the enamel. The remaining

TABLE 5—*Qualitative description of the effects of phosphoric acid on dentition.*

Duration (hour)	Group B1—PH-OSPHO-RIC Plus (94.19% Phosphoric Acid)	Group B2—Naval Jelly® Brand Rust Dissolver (93.2% Phosphoric Acid)
1	Both teeth: Enamel became dry and chalky; decrease in mass	Both teeth: Enamel became dry and chalky; enamel still intact
	Incisor: Crown thickness has significantly reduced Molar: Cusp is no longer evident creating a flat occlusal surface	Incisor: Removal of initial calculus on incisor teeth
3	Both teeth: Progression towards complete enamel removal; enamel has a flaky appearance	Molar: Cusp becoming less defined
4–6	Both teeth: Mostly dentine remaining; portions of remaining enamel are not in contact with the acid Incisor: Incisal surface is very thin and transparent with jagged edges	Both teeth: Increased exposure of dentine with slow removal of enamel
12	Both teeth: Remaining enamel has become pasty; enamel is no longer dry and chalky Incisor: Dentine is very fragmented and fragile	Both teeth: Continued dry and chalky appearance of enamel
24	Both teeth: Pasty consistency of remaining enamel; experienced complete erosion of enamel	Both teeth: Enamel has a pasty consistency
	Incisor: Dentine is very thin and transparent	Incisor: Shape of incisor is intact Molar: Occlusal surface is flat and enamel peeling away

gelatinous consistency is a direct result of the remaining collagen fibers and proteins, now absent of any minerals.

Presently, there is a lack of literature that directly examines the detrimental effects of household corrosive chemicals on teeth and how such damage can compromise a forensic analysis of human remains. A search on this topic resulted in one study by Mazza et al. (32) who acknowledge their failure to retrieve published material that approaches the subject of intentional dissolution of human remains by the utilization of acidic products. Their study documents the intentional use of acidic chemicals on human teeth, most notably hydrochloric and sulfuric acid. Mazza et al. (32) conclude that to partially or entirely destroy a human body, a perpetrator is likely to choose hydrochloric or sulfuric acid, because of ease in attaining these chemicals in large quantities, and their overall destructive effects on dentition (32). Unlike Mazza et al. (32), our experiments also tested phosphoric acid and sodium hydroxide. Also, while their experiment involved the immersion of the teeth within an acidic solution, our experiment was set up to simulate the teeth within the mouth (only crown exposed to chemical).

Our conclusions have indicated hydrochloric as the most detrimental acid in the dissolution of dentition. Despite differences in experimental setup, results from Mazza et al. (32) yielded consistencies with our present study. Their description of a "translucent appearance" of the tooth samples submerged in hydrochloric acid is identical to the progressive thinning and transparent look of both sets of teeth from Group A1 and A2 subjected to 31.45% and 14.5% hydrochloric acid concentrations, respectively (32). As is also clearly expected with hydrochloric acid, the previous study also reports complete dissolution of the tooth (32). In regards to

FIG. 5—*Phosphoric acid effects on human teeth. Pictures (a) and (b) represent the same incisor tooth. Pictures (c) and (d) represent the same incisor tooth. (a) Incisor tooth prior to contact with 85% concentration of phosphoric acid. (b) Same incisor tooth after 24 h of contact with 85% phosphoric acid. The white material is the remaining enamel, which became easily pliable. (c) Incisor tooth prior to contact with 25–30% concentration of phosphoric acid. (d) Same incisor tooth at 24 h of contact with 25–30% concentration of phosphoric acid. The enamel portion was no longer a solid material; rather it became pasty and easily removable.*

sulfuric acid their study indicates the acid was unable to completely breakdown or destroy the tooth, as is also evidenced in our results (32), although in their study, there is much more severity in the dissolution of the dentition exposed to the acid.

Other resulting effects, such as the erosion and etching of the enamel and thinning of the tooth, is conclusive with the aftereffects often witnessed with patients of bulimia nervosa (15–17). These are also reported effects of individual's teeth who work in close proximity with chemicals on a daily basis (20,21). However, the clear difference in these cases is the pattern and location of occurrence therefore confusion should not occur during forensic analysis. The blue coloration of the incisor and molar from Group A2 is a direct result of the blue dye contained and expressed in Sno Bol® Liquid Disinfectant. This effect is an important factor that may be utilized as an identifier of the product, or at least aid in the isolation of possible products.

Sulfuric acid caused minor changes to tooth structure. The acid caused etching of the enamel, similar to that reported in the Romanov case (2). The teeth in this experiment also displayed the characteristic brown staining observed by Plunkett (21) and a glazed effect on the teeth of individuals in contact with sulfuric acid at workplaces (19). The current experiments did not manifest the distinguishably short, thin, and fragile teeth reported by Petersen and Gormsen (22). Variations in sulfuric acid concentration and the longer exposure time experienced by workers in close proximity to the acid can account for the lack of discernible changes in the

TABLE 6—*Qualitative description of effects of sodium hydroxide on dentition.*

Duration (hour)	Group D1—Roebic® Professional Strength Liquid Drain Opener (28% Sodium Hydroxide)	Group B2—Dissolved Sodium Hydroxide Pellets (0.1 M Sodium Hydroxide)
1	Both teeth: Initial cracks have widened Incisor: slight removal of the initial calculus	No significant changes
2	Both teeth: Further widening of cracks	Both teeth: Slight decrease of enamel and increase in dentine exposure
3	Both teeth: Enamel has flaky appearance; sheen or polish affect on the enamel	No significant changes
4–6	No significant changes	No significant changes
12	Both teeth: Cracks are more pronounced, minor flaking of enamel	No significant changes
24	Both teeth: Cracks expanded; enamel still present with sheen affect; slight increase in mass may be due to intake of chemical	Incisor: In comparison with an hour in solution—very minimal decrease of the initial calculus Molar: Very minimal destruction of the enamel

FIG. 6—*Sodium hydroxide effects on human teeth. Pictures (a) and (b) represent the same incisor tooth. Pictures (c) and (d) represent the same incisor tooth in 0.1 M of sodium hydroxide. (a) Incisor tooth prior to contact with 28% sodium hydroxide concentration. (b) Same incisor tooth at 24 h of contact with 28% sodium hydroxide concentration. The chemical caused an initial crack on the tooth to expand. (c) Incisor tooth prior to contact with 0.1 M of sodium hydroxide. (d) Incisor tooth at 24 h of contact with 0.1 M of sodium hydroxide displayed no identifiable changes in tooth structure.*

current experiments. The brown discoloration expressed on Group B1 teeth that were exposed to Floweasy® Drain Opener (Jones Stephens Corp., Moody, AL), was most likely caused by the dye in the product, like that by Sno Bol®. Additional effects caused by sulfuric acid, such as the pasty consistency of the enamel are likely because of the loss of inorganic (mineral) material of the tooth. Similarities were observed with the phosphoric acid which also produced a pasty effect on the enamel, but at a much higher degree in comparison with sulfuric acid.

Phosphoric acid had variable harmful effects on dentition. During the first 6 h of experimentation, the teeth remained in a dry and chalky state with evident etching of the enamel. During this stage it appears that phosphoric acid attacks the collagen fibers and proteins, resulting in the remaining mineral portion that resembles a dry and chalky consistency. After 6 additional hours of exposure to the acid the consistency changes to a more pasty state that may be attributed to the breakdown of the hydroxyapatite minerals of the enamel. This mineral loss lends to the resulting fragility of the remaining enamel and a failure to conserve the shape of the tooth. Because of these drastic changes to the enamel, the possibility of distinguishing initial features of the teeth that may have existed prior to contact with the acid are very slim. The morphological effects of hydrochloric acid and phosphoric acid on dentition are similar in the eradication of enamel, but there are clear distinctions on how each alters the enamel portion (Table 7). Hydrochloric acid begins with a breakdown of the mineral portion of the enamel, the hydroxypatite, and some gelatinous collagen portion may remain. Phosphoric acid, on the other hand, first attacks the organic composition of the tooth, resulting in only the hydroxyapatite remaining in a chalky and dried state. Longer exposure to phosphoric acid begins a very slow eradication of inorganic material and changes the enamel to soft, flexible state, but never manages (after 24 h) to completely destroy all the properties of enamel. The effects of the phosphoric acid on the teeth in this study have variable results in comparison to what is reported in the literature pertaining to acid-etching for restorative dentistry. As discussed earlier, in dental treatment phosphoric acid serves to demineralize the mineral content of the tooth surface for adhesion of resins or other attachments (23,24). At the beginning of the present study, it appeared that the phosphoric acid had more of an effect on the organic portion of the teeth, resulting in the chalky and dry consistency. It was not until a longer exposure that the phosphoric acid had a major impact on the inorganic content. Reasons for this inconsistency are likely because of the phosphoric acid solution selected for these experiments, which contain other chemicals and components, unlike the concentrated phosphoric acid used for restorative dentistry.

Sodium hydroxide provided no distinguishable reactions with the organic or inorganic properties of enamel as previously observed with the acids. Interestingly, Ubelaker and Sperber (3) identify sodium hydroxide, in a tentative manner, as the responsible chemical in a case involving human remains. They describe the teeth as exhibiting a loss of sheen and polish, with some corrosion, and chalky white color. The effects observed on the teeth in this study are contrary to the descriptions given by Ubelaker and Sperber (3). Experiments with sodium hydroxide only showed a sheen and polish of the teeth, with no corrosion or chalky consistency. Ubelaker and Sperber (3) may have suggested the wrong chemical as the culprit in the case. Their descriptions are more fitting with the morphological changes caused by phosphoric acid, which illustrates a loss of sheen and polish and a white chalkiness. Understandably, the case of Ubelaker and Sperber (3) involves a different situational context (e.g., environmental effects, the manner and amount of the chemical used), and as such the teeth may have also been affected by these factors.

Conclusions

Results from this experiment have directed special attention to the underlying effects that household corrosive chemicals can have on human teeth. Variations in the morphological effects support the initial hypothesis that each chemical creates morphological changes on teeth that are uniquely characteristic for each individual chemical (Table 7). This comparable data can be potentially useful if dealing with forensic cases that show evidence of chemical corrosion on the dentition. For example, a characteristic of phosphoric acid exposure are teeth that show a chalky consistency within the first hour followed by a gradual progression to a pasty texture, and eventually drastic changes to the morphology of the tooth. Conversely, sodium hydroxide produces a sheen and polish on the tooth surface without any noted difference in the overall tooth structure. An understanding of the unique effects caused by household chemicals on human teeth may lead to the identification of corrosive chemicals utilized on a victim. Such an understanding can only be of value to the forensic field, not only in establishing the identity

TABLE 7—*Summarization of chemical effects on human dentition.*

Duration (hour)	Hydrochloric Acid	Sulfuric Acid	Phosphoric Acid	Sodium Hydroxide
1	Complete/partial removal of enamel, severe etching. If product has a distinct color (i.e., blue coloration) the tooth may display this color	Brown coloration; increase in mass; deterioration of calculus; very minor corroding	Enamel becomes dry and chalky; deterioration of enamel	If tooth displays cracks, those cracks may be widened
2–3	Thinning of crown; transparent appearance; etching	Deterioration of enamel; continuation of brown coloration	Continuation of enamel removal; enamel may have a flaky appearance	Slight decrease in enamel; further widening of cracks
4–6	Spongy/gelatinous consistency	No significant changes	Continued enamel removal; incisal surface of incisor will display thinning and transparent effect	Sheen or polish affect on enamel; flaky appearance of enamel
12	Spongy consistency; corroding; significant destruction of enamel	Increase in mass, which may be due to retention of chemical	Enamel may become pasty, if not the enamel will continue a dry and chalky state	Widening of cracks; minor flaking of enamel
24	Gelatinous consistency may continue or a complete destruction of tooth; if tooth is not in contact with chemical, tooth will assume a dry state	Enamel becomes a pasty consistency, slight flaking of the enamel	Enamel has a pasty consistency, incisor still displaying a thin and transparent crown	Enamel still has sheen affect; cracks expanded, increase in mass may be due to retention of chemical

of a corrosive chemical but also in providing leads as to criminal intent, differentiating taphonomic processes, and providing substantiation of a criminal's confession. Additionally, dental pathology, such as cavities, can be separated from chemical trauma, allowing a forensic odontologist the necessary means of substantiating antemortem records of the victim's dental morphology with that of postmortem evidence.

The absence of literature pertaining to the use and effects of chemicals on human dentition is evident. Future research in this area should include the employment of histological or microscopic examination to reveal further information regarding the microstructural changes of chemicals on the dental tissues. Radiographic studies, which are widely used in odontology, should also be employed in further studies and could reveal further changes that are not observable on the surface. In addition, the implementations of experiments relating to DNA extraction from chemically affected teeth could delineate how corrosive chemicals impede forensic efforts in DNA extraction procedures. Other experimental changes, such as extending the experimentation period, may encompass variability not captured during the initial 24-period experimentation. Another situational factor is the locality of the experiments. Modifying the experiment context to a more environmentally affected area (e.g., outside, burial setting) versus laboratory surroundings (e.g., steady temperature, lack of natural environmental stresses) may reveal variations in how chemical substances affect dentition. Despite the alternate avenues in exploring the effects of chemicals on human teeth, the current experiments in this research provide useful guidelines for distinguishing the effects of chemicals on human dentition in forensic contexts.

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Additional information and reprint requests:
Tosha L. Dupras, Ph.D.
Department of Anthropology
University of Central Florida
4000 Central Florida Blvd.
Orlando, FL 32816
E-mail: tdupras@mail.ucf.edu