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TECHNICAL NOTE

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Observations on Dental Structures when Placed in Contact with Acids: Experimental Studies to Aid Identification Processes*

ABSTRACT: In a "mafia" crime case, a magistrate asked us whether it is possible to destroy a cadaver by immersing it in acids, and would it be possible to identify any residues. The aim of this study was to observe the behavior of teeth exposed to four kinds of acid solutions. The teeth were placed in plastic containers with 25 mL of acid and observed. The experiences showed that teeth are completely dissolved after 14 h of immersion in 37% solution of hydrochloric acid, while at 90 h in 96% sulfuric acid, the destruction of the samples is still incomplete. In nitric acid the teeth undergo a complete dissolution in 12 h, and in 17 h in aqua regia (chloroazotic acid—hydrochloric/nitric acid 1:3). It was possible to recognize the characteristic morphological features of dental tissues and structures up until the advanced stages of degradation.

KEYWORDS: forensic science, forensic odontology, identification, dental materials, acid solution, dissolution, oral biology

In 1998, the authors were contacted by a court judge in order to have an expert opinion about a "mafia" crime case. The request was to research whether it is possible to partially or totally destroy a human body by immersing it in acids, and to quantify how much time this would take. In addition, is it hypothetically possible to identify the residual remains?

This theme is of great forensic interest in Italy because organized crime will often use acids or caustic substances to destroy bodies or part of bodies in order to avoid a personal identification process.

Following a literature review we found no studies or notices regarding destruction of human remains by chemical substances. No positive identifications related to events of acid dissolution were reported. The only communication on this topic is a brief mention in the Italian journal "Archivio di Medicina Legale" concerning an experimental animal destruction in an acid environment (1).

We started our investigation by adopting the hypothesis that it is possible to achieve a positive identification from the study of the final residual solution and the eventual organic human remains. It is known that the Forensic Odontology techniques are suitable to aid the identification process, because the natural teeth are the most durable organs: they can persist long after other skeletal structures decay or are destroyed by physical agents (2–8). Furthermore, it is possible to extract fragments of DNA from teeth even decades after death (9,10). It is also well known that the histological analysis of tooth structures is possible up until complete destruction of the sample (11). Consequently it should be possible to employ identification techniques to dental structures until their total destruction.

The aim of this pilot study was to observe the morphological behavior of natural human teeth in an acid environment obtaining reference data in order to aid the identification processes.

Materials and Methods

Human teeth without caries were used for the studies. The teeth were upper anteriors that had been extracted because of periodontal disease. The teeth were stored in a dry environment at room temperature before the experimental procedures.

The following acids/aqueous solutions were used in the studies: hydrochloric acid in a 37% solution, sulfuric acid 96%, nitric acid 65%, and aqua regia (chloroazotic acid—hydrochloric/nitric acid 1:3).

Hydrochloric acid at 37% is the highest concentration of the acid in a liquid state (it is called "fuming") and is easily available on the market at low cost. Sulfuric acid at 96% is the highest common concentration; it appears fairly viscous and is also easily available at low cost. Nitric acid at 65% is the more current concentration on the market, and it is easier to handle than the dangerous "fuming" nitric acid (concentration at 100%). Nitric acid is available for purchase, but it is expensive. Aqua regia consists of a mixture of nitric acid and hydrochloric acid at a volumetric ratio of 3:1.

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The samples were immersed in an amount of acid solution suitable to achieve a correct volume ratio between the sample and the liquid phase (about 25 mL). The specimens were observed continually until they were completely destroyed. At various intervals, the teeth were taken from the container, washed in distilled water, dried, photographed, and then placed in the acid again.

Results

The samples were immersed in hydrochloric acid for 14 h and checked continually. The teeth initially showed a chromatic change of the surface followed by a progressive reduction in their volume. Complete dissolution was characterized by a translucent appearance (Table 1, Figs. 1 and 2).

The samples placed in sulfuric acid were checked at intervals through 90 h and showed a gradual breakdown in structure with the formation of nodular topography; in particular, we noticed a surface appearance similar to a corrosion process. A progressive reduction in volume was observed with considerable fragility and tendency to spontaneous break-up starting from hour 65, but never leading to the complete dissolution (Table 2, Figs. 3 and 4).

TABLE 1—*Teeth changes following different immersion times in 37% hydrochloric acid aqueous solution.*

Time	Changes Observed
5 min 15 min 30 min 60 min	No visible effect of deterioration of the teeth. Evident pink color was present on the roots, which disappeared when the teeth were washed in distilled water (Fig. 1).
2 h	Persistence of the above chromatic effect on the roots. The teeth exhibited a translucent appearance in the root tip and in part of the enamel.
4 h	The chromatic effect was still present but confined to a superficial portion of the roots. An increase in the dissolution of the teeth was noticed as a transparent-like appearance of their surfaces.
8 h 9 h 10 h	Progressive reduction of the size of the teeth with an increase in transparency. (Fig. 2)
12 h	Increase in dissolution and transparency of the whole specimens.
14 h	The teeth were completely dissolved.

FIG. 1—*Macro-image of an upper canine tooth after immersion in 37% hydrochloric acid aqueous solution for 1 h. Evident pink color is present on the root, which disappears when the tooth is washed in distilled water.*

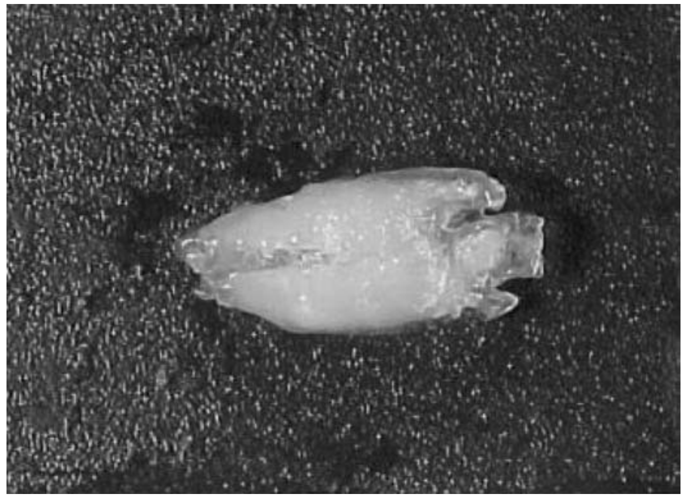

FIG. 2—*Macro-image of the canine tooth shown in Fig. 1 after immersion in 37% hydrochloric acid aqueous solution for 10 h. Progressive reduction of the size of the tooth.*

TABLE 2—*Teeth changes following different immersion times in 96% sulfuric acid aqueous solution.*

Time	Changes Observed
10 min 30 min 2 h 4 h 5 h	No visible effect of degradation or dissolution.
8 h	Initial "corrosion" of the enamel with partial detachment of fragments (Fig. 3).
12 h 22 h	Considerable fragmentation and superficial breakdown. Increase of the teeth's "fragility" with fissures. The presence of a corpusculate deposit was observed in the containers.
25 h	Increase in the breakdown of the structures.
30 h 40 h	Further breakdown of the structures with corpusculate deposit.
50 h	Increase in breakdown, but the structure of the teeth is still recognizable.
65 h	Increase in the "fragility" of the teeth with spontaneous rupture into two or three longitudinal fragments.
70 h 80 h 90 h	Increase in the breakdown of the teeth and reduction of their size. Complete breakdown or destruction was not observed (Fig. 4).

The samples immersed in nitric acid showed gradual deterioration, taking a translucent appearance with a progressive reduction in volume until complete dissolution within 12 h (Table 3, Figs. 5 and 6).

The samples immersed in aqua regia showed a progressive reduction in volume until the complete dissolution at 17 h. As an experiment note, we point out that one sample showed a residual central structure not destroyed by the acid; this finding was identified as a gutta-percha bulk, a result of endodontic therapy. This residue was then sectioned into two fragments. One fragment was submerged in pure hydrochloric acid, the other in nitric acid. Neither fragment exhibited any dissolution at 50 h (Table 4, Figs. 7 and 8).

Discussion

The use of teeth without caries is justified by the assumption that any caries could modify the behavior of the teeth when placed

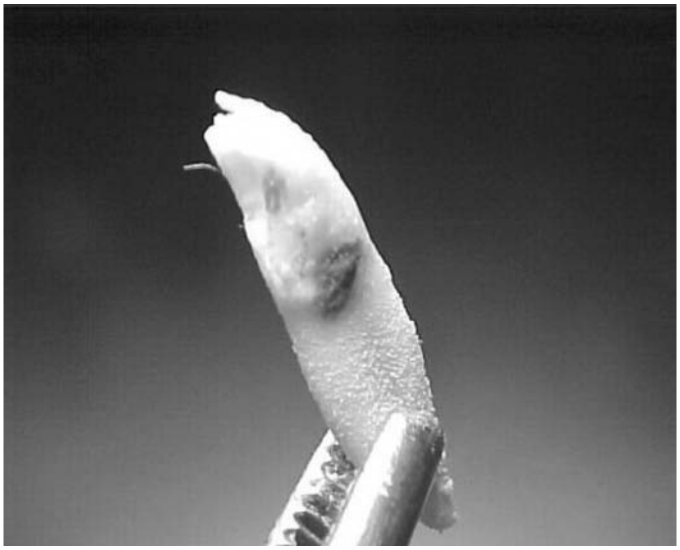

FIG. 3—*Macro-image of an upper incisor tooth after immersion in 96% sulfuric acid aqueous solution for 8 h. Progressive reduction of the size of the tooth with an initial "corrosion" of the enamel and partial detachment of fragments.*

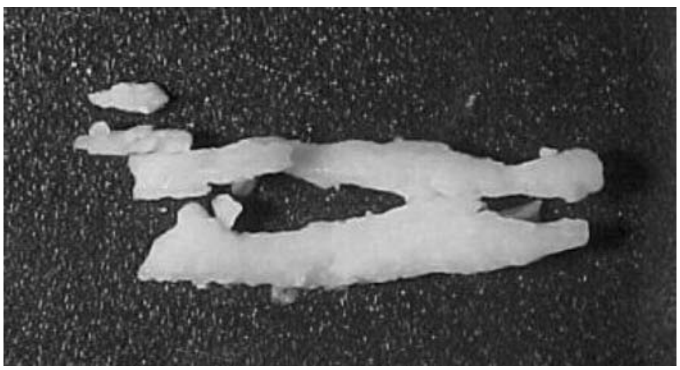

FIG. 4—*Macro-image of the upper incisor tooth shown in Fig. 3 after immersion in 96% sulfuric acid aqueous solution for 90 h. Increase in the breakdown of the tooth and reduction of its size but no complete destruction was observed. Presence of a corpusculate deposit in the container.*

TABLE 3—*Teeth changes following different immersion times in 65% nitric acid aqueous solution.*

Time	Changes Observed
15 min 30 min	No macroscopic effect observable.
1 h	Presence of the translucent appearance due to initial dissolution.
2 h	Increase in the dissolution of the teeth (Fig. 5).
4 h 9 h	Progressive homogenous dissolution of the teeth (Fig. 6).
12 h	Complete dissolution.

in contact with acids, for example, by accelerating the destructive processes.

The experiments showed that the teeth placed in a 37% solution of hydrochloric acid are completely dissolved in 14 h. The chemical process which occurs between the acid and the calcium in the teeth probably led to the formation of salt (calcium chloride), which is

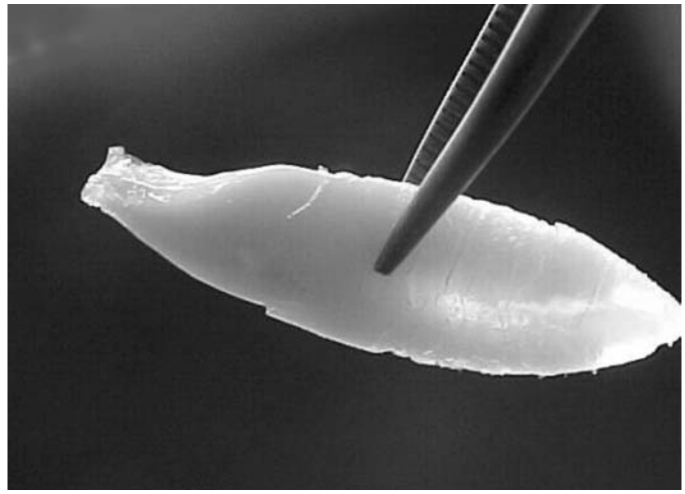

FIG. 5—*Macro-image of an inferior canine tooth after immersion in 65% nitric acid aqueous solution for 2 h. Progressive reduction of the size of the tooth as happened in the 37% hydrochloric acid aqueous solution at 1 h.*

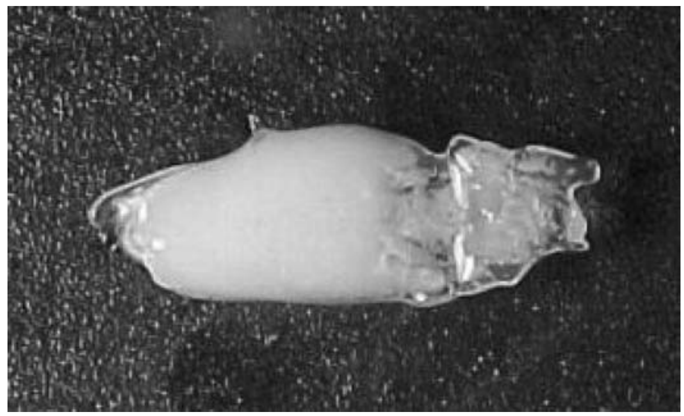

FIG. 6—*Macro-image of the inferior canine tooth shown in Fig. 5 after immersion in 65% nitric acid aqueous solution for 9 h. Progressive homogenous dissolution of the sample.*

TABLE 4—*Teeth changes following different immersion times in aqua regia (chloroazotic acid—hydrochloric/nitric acid 1:3).*

Time	Changes Observed
10 min	Production of bubbles, as a result of chemical reactions associated with the development of gas.
25 min 45 min 60 min 2 h 4 h 9 h	Progressive reduction in thickness with dissolution of the enamel and continuing production of gas (Fig. 7). One sample showed an integrity of the central radicular nucleus.
13 h 17 h 20 h 25 h 30 h	Complete dissolution of the teeth. Production of gas ceased when the teeth were completely dissolved. Persistence of a "central nucleus" in one sample (Fig. 8).
50 h	The central part of the root of one sample (a gutta-percha bulk) was unaltered.

completely soluble in water. We also observed a chromatic color change in the roots, which disappears after washing in distilled water. This could be due to the presence of chemical compounds

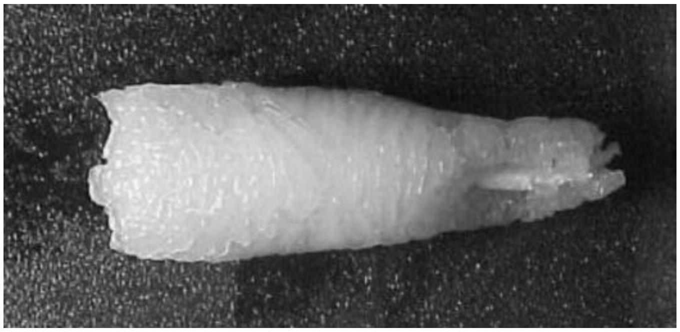

FIG. 7—*Macro-image of an upper incisor tooth after immersion in aqua regia (chloroazotic acid—hydrochloric/nitric acid 1:3) for 9 h. Progressive reduction in thickness of the tooth with dissolution of the enamel and production of gas. It is possible to observe an unusual finding at the center of the radicular portion of the tooth.*

FIG. 8—*Macro-image of the upper incisor tooth shown in Fig. 7 after immersion in aqua regia (chloroazotic acid—hydrochloric/nitric acid 1:3) for 17 h. Total dissolution of the tooth with an integrity of the central radicular nucleus. This unusual finding was identified as a gutta-percha bulk, a common part of a dental treatment.*

on the surface that acted like pH indicators (pink at an acid pH and colorless at a neutral pH) and that are soluble in water.

Immersion of teeth in a 96% solution of sulfuric acid demonstrated breakdown and disintegration, without leading to their complete destruction even after 90 h of observation. This behavior is probably due to the reaction between the acid and the calcium, which led to the formation of a non-soluble salt (calcium sulfate) in the medium.

Treatment with a 65% solution of nitric acid over 12 h caused the complete dissolution of the teeth. As described for hydrochloric acid, a chemical reaction probably occurs with the formation of a salt (calcium nitrate), which is completely soluble in water.

Immersion in aqua regia for 17 h led to a complete dissolution of the teeth. Soluble salts are probably formed in the water medium as happened with the single pure acids.

On the basis of the results, it is possible to observe differences in the destructive capacity of the acids used. The complete destruction of the teeth, without leaving residues, was obtained as a progressive phenomenon with hydrochloric acid in 14 h, with nitric acid in 12 h, and with aqua regia in 17 h. On the other hand, sulfuric acid did not have the same efficacy: in over 90 h of immersion, it led only to the partial destruction of the teeth, leaving corpuscles of residues at the end of the observation period. In sulfuric acid, a progressive fragmentation of the specimens was found instead of the dissolution showed by the other acids. This is probably due to a chemical reaction not acting as a homogeneous process, but in the formation of fissures in a similar way to what happens in the crevice corrosion process typically found in metals.

If we relate these results to the initial problem regarding the feasibility of dissolving a body completely or partially, we can formulate some considerations. The amount of acid needed to completely destroy a body is about 80–100 L (1). Such a volume brings inevitable difficulties in managing the process. Personal experience and investigations showed that all the acids are easily available on the market. However, the low cost of hydrochloric and sulfuric acid compared with nitric acid allow us to believe that the first two would be preferred, given the great quantity of acid required. In choosing between hydrochloric and sulfuric acid, when the aim is to dissolve a body in the shortest time, the former would guarantee the best results also because it can yield the complete dissolution of the biological specimen without leaving any residues. Nevertheless, the use of acids to dissolve a body is unquestionably difficult because of problems on managing such an unwieldy process. In fact, large volumes of acid, particularly if placed in contact with organic materials, give rise to the development of toxic vapors, noxious fumes, and thermal reactions.

The progressive demineralization of the teeth appears to be the same decalcification process well known in the histological procedures utilized in dental morphological researches, but with an increased effect due to the nature and the force of the strong acids used.

On the basis of these experiments, it has been possible for us to recognize the dental structures from the start of exposure until the advanced stages of degradation. The morphological appearance of the teeth persist until the 10th hour in the hydrochloric acid, the 50th hour in the sulfuric acid, the 9th hour in the nitric acid, and the 10th hour in the aqua regia.

Such morphological aspects allow us to identify the tooth as human or animal, single or multi-rooted, deciduous or permanent, and restored or un-restored. This may be of great help for the Forensic Odontology Science as an aid to dental human identification. It seems possible to reach a good approximation in the correlation between the time of exposure to the different acid solutions and the degradation rate of dental structures and also in the comparison of the residuals of dissolution with the ante-mortem records.

When it is no longer possible to identify dental structures that have been dissolved in acid, other types of investigations are available: a chemical or histological analysis of the residues, the possibility of an eventual DNA analysis, and the chemical analysis of final solutions and residues.

The unusual finding reported of the gutta-percha bulk, a common part of endodontic therapy, could represent an important aspect in the identification process because it showed to be an unchangeable and firm element that can assure a positive report (12).

We would like to emphasize that further investigations about the effects of acids on restored teeth could develop useful data. Additional studies that look into the combined effects of acid induced and thermal changes to teeth and dental materials need to be completed (8).

Our experiments did not take into account possible factors present in real-life conditions: the protection provided by soft and hard tissues surrounding the dental components or devices and the effect of dentures and other prostheses on acid dissolution. These tissues and materials prevent direct exposure to acids. As an example, the root part of the tooth may be much more resistant to acid insults when it is incorporated in bone.

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