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# Identification Through X-Ray Fluorescence Analysis of Dental Restorative Resin Materials: A Comprehensive Study of Noncremated, Cremated, and Processed-Cremated Individuals*

**ABSTRACT:** Tooth-colored restorative materials are increasingly being placed in the practice of modern dentistry, replacing traditional materials such as amalgam. Many restorative resins have distinct elemental compositions that allow identification of brand. Not only are resins classifiable by elemental content, but they also survive extreme conditions such as cremation. This is of significance to the forensic odontologist because resin uniqueness adds another level of certainty in victim identification, especially when traditional means are exhausted. In this three-part study, unique combinations of resins were placed in six human cadavers (total 70 restorations). Simulated ante-mortem dental records were created. In a blind experiment, a portable X-ray fluorescence (XRF) unit was used to locate and identify the resin brands placed in the dentition. The technique was successful in location and brand identification of 53 of the restorations, which was sufficient to enable positive victim identification among the study group. This part of the experiment demonstrated the utility of portable XRF in detection and analysis of restorative materials for victim identification in field or morgue settings. Identification of individuals after cremation is a more difficult task, as the dentition is altered by shrinkage and fragmentation, and may not be comparable with a dental chart. Identification of processed cremains is a much greater challenge, as comminution obliterates all structural relationships. Under both circumstances, it is the nonbiological artifacts that aid in identification. Restorative resin fillings can survive these conditions, and can still be named by brand utilizing elemental analysis. In a continuation of the study, the cadavers were cremated in a cremation retort under standard mortuary conditions. XRF was again used to analyze retrieved resins and to identify the individuals based on restorative materials known to exist from dental records. The cremains were then processed and the analysis was repeated to determine whether restorative resins could be found under this extreme condition. Under both circumstances, sufficient surviving resin material was found to distinguish positively each individual in the study group. This study showed the utility of XRF as an analytical tool for forensic odontology and also the significance of the role of restorative resins in victim identification, even after cremation.

**KEYWORDS:** forensic science, forensic odontology, victim identification, restorative composite resins, XRF, cremains

Victim identification through dental records is well established and may be the preferred method for determining identity when a victim is decomposed, disarticulated, or incinerated. The dentition represents one of the most resilient structures in the human body and can survive extreme conditions (1–4). It is also an excellent source of distinction among individuals. The combinations of restored, nonrestored, missing, and decayed teeth can be as unique as a fingerprint as the probability of two dentitions being the same is very low. It is this uniqueness that allows for dental comparison to be a legally acceptable means of identification, even if one tooth remains. Under this condition, it is only acceptable if the examiner is certain of the analysis and can provide reasonable proof as to his/her findings. If one more variable other than the descriptors restored, nonrestored, missing, and decayed were available to the examiner, for example, restorative resin brand, then the examiner would have one more degree of certainty on which to base his or her conclusion. Thus, the knowledge of restorative material brand can be a great asset in aiding identification.

In modern dentistry, the placement of amalgam restorations is dwindling. In the last 10 years, there has been a 30% decrease in the use of amalgam (5). This direction will inevitably continue as patients become increasingly esthetic conscious, and as dentists respond to the trend by offering more natural-appearing restorations. Tooth-colored resins are used under most circumstances, even for posterior placement. However, one drawback is that these materials may be difficult to detect both visually and radiographically (6,7). As they necessarily form part of the uniqueness of an individual's dental record, methods to detect their presence and classify their brand accurately, easily, and rapidly are important for forensic identification purposes.

When an individual has been incinerated to the point of cremation, identification of the victim can be far more challenging. Subjection to the extreme conditions associated with cremation will cause the structural features of the dentition to become dramatically altered or lost entirely. All that typically remains are fragile tooth and bone fragments. The enamel will fracture, leaving the dentin free of its clinical crown. Restorative materials tend

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to dislodge as the tooth structure shrinks. The shrinkage rate for both tooth and bone is about 20–25% (8). This shrinkage, coupled with the loss of the enamel and restorations, makes traditional radiographic comparison difficult at best (Fig. 1).

Under these circumstances, any other information that can be obtained can be of great importance. In cremation, everything organic is destroyed. When all that is left is calcined bone and teeth, very little is present for identification. It is the nonbiological artifacts that survive the high temperatures and that are used to aid in the identification process. Victims are usually identified by the presence of medical and metal/porcelain dental artifacts, which are well known to be recoverable following cremation (9–11). Several studies have been conducted examining the effect of heat on dental materials, and it is known that prostheses can withstand high temperatures (12–15). Analysis of such materials has resulted in the resolution of a number of murder cases involving incineration (16,17). In one particular case, resolution was aided by the detection and analysis of a cement liner (18). In this case, the victim was almost completely incinerated with only one tooth remaining. Elemental analysis of the cement liner showed a unique composition that matched the brand used and recorded in the dental chart.

It has been reported, however, that amalgam fillings or dental restorations do not withstand the heat of the fire, and cannot be recovered (17). One of the purposes of this study was to demonstrate the existence and persistence of these materials, even after cremation.

Commercial cremation is a two-step procedure. After the body has been incinerated, the cremains must be ground to reduce the larger bony fragments to a granular ash for inurnment. This is accomplished with a machine that has a large rotary blade that rotates over a steel mesh. Processed cremains are the final and comminuted presentation of human life and represent the ultimate challenge for identification as little evidence of diagnostic value may be found. Establishment of human identification after the cremains have been processed has been important in cases where there may be wrongful cremation or the identity of the individual is in question, and also as to whether the material in the urn is of human origin (10,19–21).

Many of the nonbiological artifacts that can be used for identification are removed before processing. They are removed by means of gross inspection and with the aid of a magnet. If left among the cremains, they would cause significant damage to the processing equipment. Thus, it is normal mortuary practice to remove the larger prostheses such as hip replacements, bone screws, or partial denture frameworks, and depending on size, they may not be placed back with the individual at the time of inurnment. Incinerated restorative resins, however, can resemble particles of incinerated bone and tooth structure, are nonmagnetic, and thus would not be removed before processing. There is a strong likelihood of their presence in the urn. There are so few clues regarding identity present in processed cremains that it was thought that an attempt should be made to determine whether restorative materials were persistent and recognizable under this extreme condition.

There are well over 50 restorative resins currently on the market, supplied by over 12 manufacturers (22). These manufacturers each have distinct formulations for their products. Restorative resins consist of an organic resin matrix containing inorganic filler particles. The filler compositions are formulated for reasons such as handling, polishing, compressive strength, and radiopacity. In a previous study, we reported on the surprising differences in microstructure and elemental composition of the inorganic fillers used by different manufacturers (23). The 10 resins analyzed in that study had remarkably different microstructures, and elemental analysis enabled them to be divided into six elementally distinct groups. We also showed that restorative resins not only survive cremation conditions but are still identifiable by brand. It is the inorganic filler particles of the resin that are resistant to high temperatures. This allows for the distinction between brands, or classes of brands, even after exposure to extreme conditions such as cremation.

The analytical method used in our previous study was Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDS). This method typically requires that the specimen to be analyzed be small, such as a single extracted tooth, and the equipment is large and laboratory-based. In addition, our previous study was performed using extracted teeth. In the current study, we sought to find an analytical method that could be used in the field or in morgue laboratories, and also to create conditions that would more closely simulate victim identification of human remains. Thus, this study consisted of placing resins in human cadavers. After placement of the resins, a portable X-ray fluorescence spectrometer (XRF) was utilized to determine (1) the location of resins within the dentition as well as the brand of the resin based on elemental composition in noncremated individuals, (2) confirm existence and identify resin by brand name in cremated individuals, and (3) confirm existence and identify resin by brand name in processed cremains. Our hypothesis was that given detailed written dental records, identification of individuals could be accomplished based on restorative resins alone in these 3 situations.

Recent technological advances in XRF have resulted in the development of miniaturized excitation sources that do not use radioactive material, thus avoiding issues associated with radioactivity such as transportation and disposal of materials (24,25).

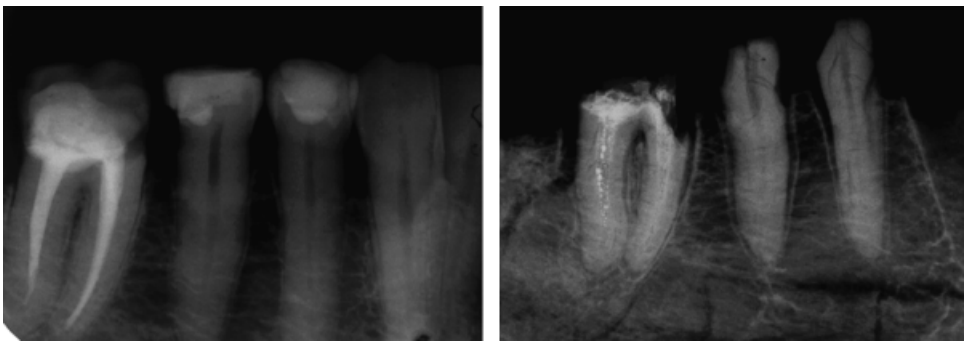

FIG. 1—*Pre- and postcremation X-radiographs of mandible. Note the shrinkage of tooth structure, loss of enamel, and restorations.*

Together with the development of small controlling computers, this has allowed design of lightweight handheld devices that can carry out elemental analysis of materials in the field in seconds.

In both SEM/EDS and XRF, characteristic X-ray emissions are excited by an energetic source. The main difference between the techniques is the type of radiation used to excite the emissions. In SEM/EDS, it is an electron beam, whereas in XRF an X-ray beam excites the characteristic X-rays. Spectroscopy in both cases consists of measuring the energy of the emitted X-ray peaks, forming a spectrum that represents an elemental fingerprint of the sample. In XRF, because an X-ray source is used, the spectral background is lower, allowing small peaks to be recognized. This results in the ability to detect very low concentrations of an element.

One technical limitation of a portable XRF is that light elements (in this case P and below in the periodic table) are not detectable due to absorption of low-energy X-rays by air and the detector window. Thus, some elements making up the tooth and bone structure (P, O) are not detectable. This also applies to the principal components of the resin fillers in which the elements Si and O are not detectable. The elements added to fillers for radiopacity, however, are readily detectable (Ba, Sr, Zr, and Yb), and the presence and combinations of these elements enable identification of resin brand. As $SiO_2$ is common to all resin brands, its absence from the spectrum in this technique had no effect on the outcome.

In the first section of this study, the cadavers were used to simulate circumstances of decomposition or disarticulation when no other means of identification is possible. The portable XRF was used for two purposes. One, to locate resins that may not be readily detectable by visual or radiological inspection, and two, to distinguish correctly resins by brand name. Analysis could be performed in the field or morgue and could be concurrent with the process of charting the dentition of the victim. In the second section, identification of the individuals was tested under circumstances of severe incineration as represented by cremation and the XRF was used to identify particles from the incineration scene. Finally, particles of the cremains were again analyzed after processing (grinding), which represents the ultimate challenge for the forensic odontologist. All three three study parts demonstrated the versatility of the XRF. Nondestructive analysis of fragments could be performed by either SEM/EDS or XRF, but the XRF had the significant advantage of rapid analysis (6–10 sec) without introduction of the sample into a vacuum chamber as is necessary in SEM/EDS, thus saving considerable time. Owing to its portability, speed, and accuracy, the portable XRF proved to be invaluable under both field and laboratory conditions.

## Materials and Methods

### *Noncremated Remains*

Six human cadavers were utilized in this study. The cadavers had been donated to the University for educational and research purposes. The cadavers were made available for this experiment after their use for dissection instruction and before cremation. Cremation is the normal method used for remains disposition at the University, and a modern crematorium is maintained on campus. After standard review procedures, the University at Buffalo Human Subject Review Board granted approval for this project.

Five restorative resin brands were selected. The resins were prepared in 1 cm disks and cured according to the manufacturer's instructions. Each disk was analyzed by XRF and a reference spectrum was generated. These reference spectra were utilized as control spectra for all subsequent analyses.

TABLE 1—*Resins used in this study, and the elements as detected by the EDS and XRF techniques.*

| Resin brand | EDS | XRF |
|---|---|---|
| Filtek Supreme (3M, St Paul, MN) | Si, Zr | Zr |
| Heliomolar (Ivoclar, Amherst, NY) | Si, Yb | Yb |
| Quixx (Dentsply, Milford, DE) | Si, Al, Sr | Sr |
| Tetric Ceram (Ivoclar, Amherst, NY) | Si, Al, Ba, Yb, Zr | Ba, Yb, Zr |
| TPH3 (Dentsply) | Si, Al, Ba | Ba, Sr |

EDS, energy dispersive X-ray spectroscopy; XRF, X-ray fluorescence.

A complete examination including a full-mouth series of radiographs was performed on each of the cadavers. All restorations were documented. All existing resins were then removed with a high-speed handpiece. Most amalgam fillings were left in place, along with metal and porcelain crowns. A minimum of 10 (range 10–13) new resin restorations were placed in each individual following standard procedures of etching with phosphoric acid and bonding with a light-cured bonding agent. All restorative procedures were performed according to the manufacturer's instructions. A total of 70 new resin restorations were completed.

A unique selection of the five resin brands was used in each dentition. The resins were placed in random locations according to the available tooth surfaces. Table 1 lists the resins chosen and the elemental combination that is unique to each, comparing SEM/EDS results with XRF. The detection limit in EDS is around 1% concentration, whereas in XRF it is much lower: 10–100 p.p.m. for the elements of interest (0.00001–0.0001% concentration).

This detection limit difference resulted in some differences in the analyses reported by the 2 techniques. In the case of TPH3, for example, the element Sr is detected by XRF and not SEM/EDS. This is due to the low concentration of Sr in TPH3. Figure 2 shows an example of comparative analysis by the two techniques for the resin TPH3. In the EDS spectrum, the Si peak is dominant and Al and Ba are detected, while in the XRF spectrum, Ba and Sr are detected. Al will not be detected by XRF analysis as it is below P in the periodic table.

Table 2 lists the brands used and the tooth number in which the resins were placed for each cadaver. The dentitions were charted again with a second full series of X-rays. This second set simulated ante-mortem dental records. All of the dental procedures were performed by authors R. M. and M. B. (clinical dentists), and the dental records and resin information were not revealed to the other author until the analysis was complete. As this was a blind study, each individual was then inspected using the portable XRF analyzer by author P. B. (analytical scientist). Figure 3 shows the XRF unit and the analysis in progress.

The portable XRF unit used in this study was the Innov-X Systems Alpha-2 (Woburn, MA), provided under a collaborative agreement for this study. The Alpha-2 when used as a handheld instrument is controlled by a palm-type computer that is equipped with wireless data transfer capability (Bluetooth). For field or morgue operation, this mode of operation would be ideal for paperless transmission of data to a central computer. This model also has the capability of being operated in a vertical position in a laboratory test stand, during which it can be controlled by a laptop computer. It was in this mode that the instrument was operated for analysis in the latter parts of this study.

The XRF instrument was scanned over all accessible tooth surfaces, occlusal, buccal, lingual, mesial, and distal, to detect the presence of restorative resins. Several other restorations including porcelain fused to metal crowns and amalgams were noted during the inspection. Although readily recognizable visually, these were

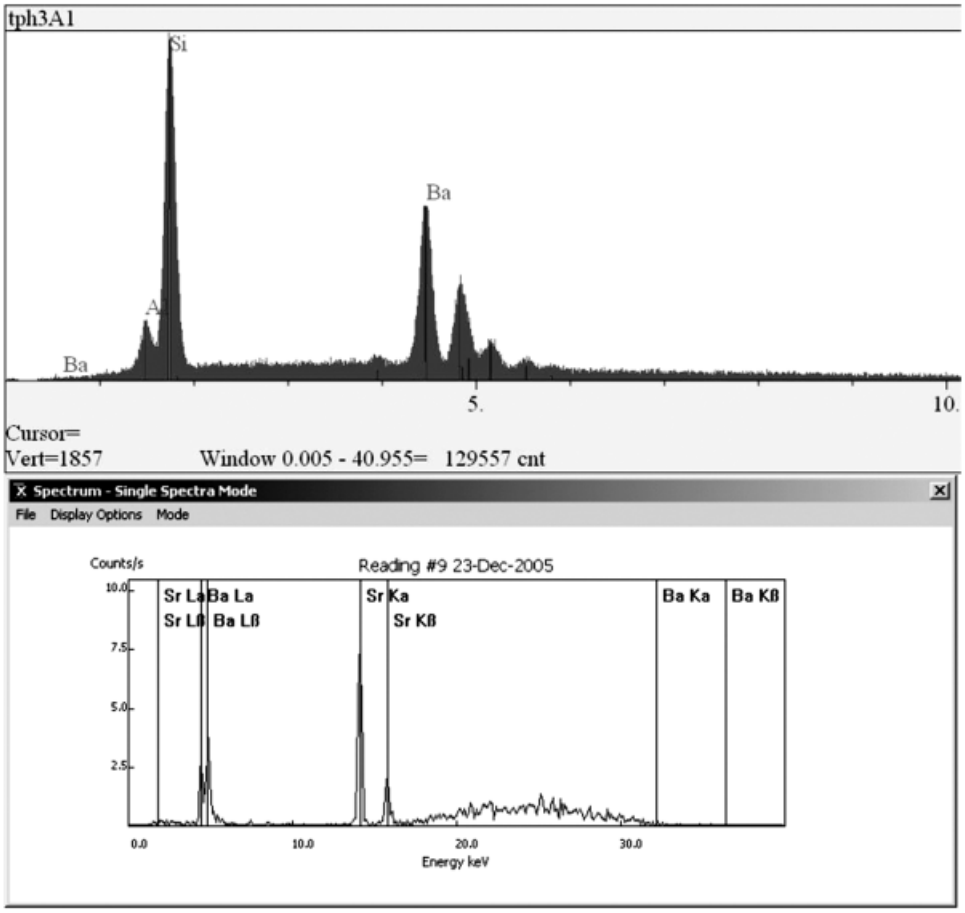


FIG. 2—*Energy dispersive X-ray spectroscopy (EDS) spectrum (top) and X-ray fluorescence (XRF) spectrum (lower) of TPH3 resin. The silicon peak seen in the EDS spectrum does not appear in the XRF spectrum, but Sr is seen in the XRF spectrum due to the greater sensitivity of the XRF.*

also characterized and distinguished by the elements present in the XRF spectra (Sn, Ag, Zn, Hg, Cu, Co, Cr).

Spectra were typically obtained within 6–10 sec. The spectra were compared with reference spectra collected from cured disks of resin from each brand. Each brand used in this study had a characteristic spectrum that allowed unequivocal identification of brand, and the in-the-field spectra corresponded exactly with the reference spectra.

The analysis area of the XRF is *c*. 8 mm in diameter; thus, in certain areas of the dentition the analysis encompassed two teeth together. In these cases, elements associated with two different resins appeared in a single spectrum. Careful inspection and repeat analysis allowed distinction of spectra and identification of resin brand and their location in the dentition. Two specific combinations of resins did not allow separation when analyzed together; these were TPH3 with Quixx and Tetric with Filtek.

The tooth surface and brand of each resin detected were recorded. This stage of the experiment was performed to determine the success rate of resin detection using XRF and was intended to simulate situations in which an identification must be made of a decomposed or disarticulated victim (not incinerated), with the assumption that comparison could be made with dental records.

### *Individual Cremains*

Each cadaver was separately cremated under standard cremation conditions of 1010°C for 2.5 h. A B&L Cremation Systems Model N20AA Cremation Retort was utilized (B&L, Largo, FL). After cremation, the anatomical outline of the body was recognizable.

Cremation conditions alone do not reduce the bones to ash. The cremains still resemble a human skeleton with some bones fully intact and others fragmented. The cremains from the head area were separately removed and swept onto a tray. Care was exercised to collect all material from the retort floor.

The skull and tooth fragments were divided into large and small fractions (Fig. 4). These portions ranged in size from partially intact crania, mandibles, and maxillas to unrecognizable sub-millimeter particles. Most of the teeth had dislodged from the alveolar bone. None of the teeth recovered, whether loose or still in the jaws, had enamel remaining. The enamel was found in shattered pieces within the small fraction material. A few teeth had suspected resin-filling material adhering to the dentin, and others had amalgam still adherent.

The material in the small particle fraction was inspected visually and by stereomicroscopy to retrieve suspected resin fragments. Also, suspected amalgam and any other restorative materials were removed for analysis. Any material in question was then analyzed individually with the XRF. Samples were placed in a small paper cup on top of the analysis window for analysis. The paper cup was transparent to the X-rays. This allowed rapid sequential analysis of individual fragments as small as 1 mm. Diagnostic spectra were obtained from each fragment in $<10$ sec. The spectra from these unknown samples were compared with known control spectra of the resins. As with the SEM/EDS analyses previously published, the elemental content of

TABLE 2—*Resin type placed by tooth number in each cadaver.*

| Tooth # | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| 2 | | | | Q | F | |
| 3 | | | | | | H |
| 4 | | TP | Q | TE | F | |
| 5 | | | Q | | H | |
| 6 | F | F | | Q | H | TP |
| 7 | | | | | H | TP |
| 8 | | F | | | | |
| 9 | H | TP | | | | TE |
| 11 | H | TP | TE | | | |
| 12 | H | | TE | Q | | H |
| 13 | | TP | | TP | | |
| 14 | | | | | | Q |
| 15 | | F | | TP | | |
| 16 | | F | | | | |
| 17 | | | Q | | F | |
| 18 | | | | Q | | |
| 19 | Q | | | | | |
| 20 | | | | Q | F | |
| 21 | Q | | | TE | H | H |
| 22 | Q | F | TE | | | TE |
| 23 | | F | TE | | | |
| 24 | | F | Q | | | F |
| 25 | | | Q | | | |
| 26 | | | Q | | | Q |
| 27 | | TP | TE | | H | Q |
| 28 | H | | TE | TE | H | |
| 29 | F | | | TE | | |
| 30 | F | TP | | TP | | |
| 32 | | | | TP | | F |

F, Filtek supreme; H, heliomolar; Q, Quixx; TE, tetric ceram; TP, TPH3.

resins as measured with XRF did not change after cremation. The resin brands thus retrieved were compared with the cadaver's dental record.

### *Processed Cremains*

Following the above analysis, the head area cremains and restorative materials were reunited with the skeletal cremains to be processed using a B&L Cremation Systems Model BL-499 mortuary processor. The processor was equipped with a stainless-steel blade rotating above a steel mesh screen with openings 4 mm in size. In 30–60 sec, the processor was capable of reducing the calcined skeleton to a material with the consistency of "shelly sand" with a particle size ranging from 3 to 4 mm to less than 125 μm.

FIG. 4—*Retrieval of resin fragments from the fine fraction of cremains.*

The processed cremains were collected below the screen. The steel mesh screen was inspected afterwards for remaining material. This was collected and added back to the ashes. It is typical mortuary practice to add the contents of the screen back to the cremains for inurnment.

The processed cremains were then passed through an ASTM-certified test sieve with a mesh size of 2 mm. Our rationale for this step was that the restorative materials existed as discrete particles separated from the tooth structure and that these particles may pass rapidly through the 4 mm processor sieve openings and thus avoid crushing by repeated collision with the larger bone pieces. The resins might therefore remain intact in the larger size fractions.

Inspection and retrieval of fragments from the smaller size fraction would be a challenging task. Our study did not incorporate the use of radiographs to locate resins in fields of smaller debris, although test radiographs were taken to verify the method. The entire fine fraction could have been X-rayed utilizing a grid-separated container. Any material that was radiopaque would indicate the possible presence of restorative material, as the radiopacity of the inorganic fillers in the resins was retained. In this study, it was possible to collect sufficient material from the large size fraction to accomplish identification. However, radiography would be a valuable tool if it were necessary to examine the cremains exhaustively.

FIG. 3—*Portable X-ray fluorescence in use to locate and identify resins* in situ.

It was also noted that under illumination with long-wave ultraviolet light, most of the bone and tooth fragments fluoresced. The incinerated resins, however, had lost any fluorescence that they originally possessed. The resins, therefore, appeared as darker particles in a field of bright particles. This inspection method was not ideal, however, because there were also other particles present that did not fluoresce. Visual inspection was deemed the better method.

All material greater than 2 mm was inspected manually with a stereomicroscope to select pieces of suspected restorative material, including amalgam. Retrieved particles were analyzed again individually by XRF as described above, and the materials were sorted according to elemental composition.

After completion of this analysis, all components of the individual's cremains were replaced in the urn. The University donation program provides for the ashes either to be returned to the family, or for interment in the University Memorial Grove with an appropriate service.

### *Strontium-Level Analysis in Bone and Teeth*

Two of the resins used in this study contained Sr. In Quixx, the Sr concentration in the filler particles was high: 30% as measured by EDS. In TPH3, the Sr level was below the detection limit in EDS, but gave a significant peak in the XRF spectrum, due to the p.p.m. level sensitivity of that technique.

It is well known that Sr is found in trace levels in bone and teeth (26–30). Sr substitutes for Ca in the hydroxyapatite molecule, which makes up the mineral building block of bone and teeth. Sr concentrations in bone reflect the dietary intake of the trace element as an average of the last 6–10 years before death (31), as bone remodels continually during life. Sr levels in the tooth structure remain fixed for life and reflect the dietary Sr intake at the time of tooth development. Sr levels in bone reflect the local geological level of Sr if local water and food sources are ingested.

In order to be able to distinguish tooth and bone structure from suspected resin that contains Sr, a separate series of analyses was conducted to assess the Sr levels in the hard tissue of the study individuals.

Fragments from six anatomical bone sites were collected from each individual after cremation and before processing. These were combined and ground together in a laboratory rotary blade processor in order to create a homogenized mixture. The resulting powder was considered to represent an average bone sample for each individual. Samples of this powder were analyzed by XRF in a software mode designed for analysis of trace elements in environmental samples. The results were reported in p.p.m. concentrations. Measurements were also made on enamel samples. The range of concentrations was found to be similar to that of bone for the individuals in this study. The study individuals had Sr levels close to one another, in the range of 60–100 p.p.m.

While Sr did appear in each spectrum when a sample of bone or tooth was analyzed in the search for resin fragments, knowledge of the Sr concentration and expected peak intensities as compared with those of resin allowed clear distinction of resin from an individual's hard tissue, as the Sr level in the restorative material was orders of magnitude higher.

## Results

### *Noncremated Remains*

Out of 70 resins placed, 13 could not detected due to the physical limitation of placing the XRF detector in close proximity to the tooth surface. The analyzer head must be placed no further than 2 mm from the object in question in order to obtain a reading. The accessibility issues principally occurred in situations such as mal-aligned teeth or tight curvature of the arch, where certain tooth surfaces could not be placed close to the analyzer head. This was in the case of small lower anterior teeth where the XRF head was too large to fit in the lingual curvature of the mandible. This also occurred on a few of the posterior occlusal surfaces when the opening of the jaw did not permit access. Extraction of the tooth in question or resection of the jaw would have easily solved this problem, but sufficient evidence was established to identify the individuals without these procedures.

Fifty-three resins were successfully located. All 53 corresponded exactly to the dental chart for tooth number and resin placed in that tooth. Four resins that were accessible were missed. These four resins were in situations in which the XRF analyzer detected combinations of TPH3/Quixx and Tetric/Filtek in the same analysis volume.

Under these two separate circumstances, where one resin contained a high concentration of an element that was also in another resin at a low concentration, the peak for the high-concentration element dominated the spectrum and the other peaks were indistinguishable from the background. Thus, in the case of TPH3 and Quixx in which Sr is present in both resins, the high concentration of Sr in Quixx dominates, and the Ba in TPH3 will not be displayed. Although TPH3 is present in the analysis volume, it will not be recognized as distinct from Quixx. Also in the case of Filtek and Tetric, in which both have Zr, the high concentration of Zr in Filtek dominates and the Yb in Tetric may not be recognized. Again, this situation could have been resolved by extraction.

Where it was possible to attain close physical proximity to the restoration with no overlap, the technique was 100% successful in locating resins according to tooth number and 100% successful in identifying resin brands. All six individuals were positively identified based on restorative resins alone, without reference to the other restorative materials present in the dentition.

This experiment represented a group of six individuals whose dental records were known, but whose identity was unknown to the analyst. The ability to correspond tooth number and filling material to the individuals chart provided a unique and powerful discriminator. In this closed experimental population, each successive combination of tooth number and material discovered lent significant weight to the identification.

### *Individual Cremains*

The larger resin fragments were easy to recognize visually as particles having different appearance from tooth and bone structure. In our previous paper on extracted teeth, we reported on the difficulty of distinguishing charred resin from tooth structure. With experience, however, the examiners were able to develop the skills necessary to detect the resin visually. Smaller particles not immediately evident were recognizable using a magnifying glass or a stereomicroscope.

Once resin particles were located, identification of brand was immediately achievable by XRF analysis. In those cases where distinction was difficult due to similar appearance to incinerated tooth structure, rapid XRF analysis resolved the issue. For each individual, it was possible to recover almost all of the resin that was placed, and the amalgam that was original to the dentition. The different resins reacted in different ways to the heat. Some tended to fragment, while others fused into a ball. Heliomolar, for example, fractured easily, while TPH3 melted into a hard glass-

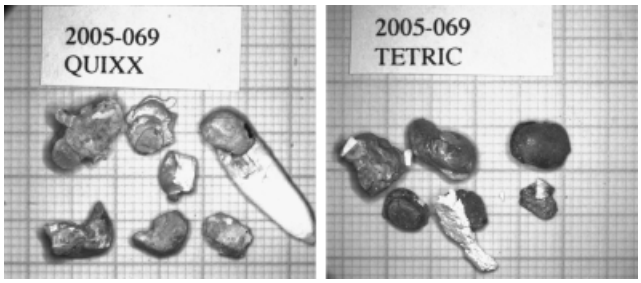


FIG. 5—*Resins retrieved after cremation. These were from one individual who had received six Quixx and six Tetric resins. Almost all resin material was recovered. The upper left Quixx filling has retained its original shape. There are some fragments of adhering tooth structure.*

like pellet. In some cases, the original restoration shape was closely retained. Fractures did occur in the resin at the marginal ridges for class II preparations. Occlusal and buccal restorations typically remained intact. The five different resins also showed characteristic color changes and relative hardness differences due to elemental composition and microstructure. Amalgams appeared to have partially melted, but remained as an identifiable mass. The Hg content was found to have disappeared.

For each individual, sufficient quantities of each of the unique combinations of resins placed provided positive discrimination and identification. In each cadaver, almost all the material placed was recovered. Figure 5 shows the material recovered for an individual in which six Quixx resins and six Tetric resins were placed. The restorations are recognizable and are almost whole with some fragmentation. Positive individual identification was possible even without referral to the other unique aspects of each dentition that survived cremation (amalgams, porcelain and gold crowns, root canals, posts, and silver points).

### *Processed Cremains*

In the processed cremains, it was more difficult to recognize the resin fragments. There remained some very fine dust that coated the particles, making color determination and visual inspection more challenging. Also, although the finer fractions that passed the sieves made up the bulk of the ashes, a considerable amount of material remained to be inspected. Table 3 shows the weights of the fraction greater than 2 mm, and their percentage of the total ash weight. The $>2$ mm fraction consistently formed 5–6% of the total weight.

The $>2$ mm fragments were inspected manually using a magnifying glass and stereomicroscope, and the same process of XRF analysis was used to distinguish the materials found. Table 4 lists the total weights of resins and amalgams found before and postprocessing. Figure 6 shows the resins retrieved after processing for the same individual whose resins are shown in Fig. 5. The amounts of resin fragments found after processing were considerably less than were found before processing, ranging from 2% to 8% of original mass. This suggests that the resins were in fact distributed evenly throughout the size fractions, contrary to our expectation that they would be preferentially retained in the large fraction. The amalgam, however, was more resistant to the crushing action and a much larger percentage of amalgam than resin was recovered from the $>2$ mm fraction after processing.

TABLE 3—*Total cremains weights and weight and percentage of particle size fraction greater than 2 mm.*

| Individual # | Total (g) | $>2$ mm (g) | % of total |
|---|---|---|---|
| 1 | 2330 | 138 | 5.9 |
| 2 | 2885 | 160 | 5.5 |
| 3 | 2996 | 182 | 6.1 |
| 4 | 1491 | 101 | 6.7 |
| 5 | 2432 | 138 | 5.6 |
| 6 | 1201 | 70 | 5.8 |

TABLE 4—*Total weights of restorative materials found after cremation and after processing in grams, and the percentage of material found post- versus preprocessing.*

| | Preprocessing | | Postprocessing | | % Post versus Pre | |
|---|---|---|---|---|---|---|
| Individual # | Resin | Amalgam | Resin | Amalgam | Resin | Amalgam |
| 1 | 4.86 | 3.06 | 0.41 | 1.64 | 8.4 | 53.5 |
| 2 | 5.08 | 2.07 | 0.23 | 0.93 | 4.5 | 44.9 |
| 3 | 4.86 | 3.06 | 0.11 | 0.3 | 2.2 | 9.8 |
| 4 | 6.0 | 4.15 | 0.24 | 2.38 | 4.0 | 57.3 |
| 5 | 4.5 | 2.51 | 0.09 | 0.83 | 2.0 | 33.0 |
| 6 | 10.3 | 4.30 | 0.32 | 2.41 | 3.1 | 56.0 |

In particular, for those cadavers that had received Heliomolar resins, the amount recovered from the processed cremains was reduced. In two individuals, none was recovered in the $>2$ mm fraction. This was due to the fragile nature of Heliomolar after exposure to heat. It is thought that the fragments of this resin principally resided in the small particle fraction. Table 5 summarizes the brands found at each stage of the study.

In this experiment, sufficient quantities of the expected resins were again recovered from each individual to distinguish between individuals in the study group.

## Discussion

This study demonstrated that when accurate written dental records exist, identification of individuals can be achieved by recognition of restorative resin brand through XRF analysis. This underlines the importance of descriptive text in the chart-specifying materials used in procedures. Record keeping of this nature enhances the value of dental radiographs as identifiers.

The application of portable XRF was successfully tested under conditions representing morgue or field conditions when unidentifiable human remains are presented. Owing to its speed and ease, the type of analysis described could be performed concurrently with dental postmortem charting. The wireless communication capabilities of the unit used in this study could be of great advantage to transfer spectral data directly to applications such as

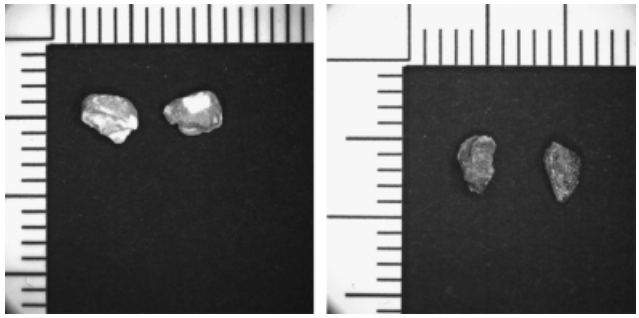

FIG. 6—*Resins retrieved after the cremains were processed. This is the same individual who received the resins shown in Fig. 2. The resin Quixx is shown on the left, and Tetric on the right.*

TABLE 5—*Summary table showing resins placed, found after cremation, and found after processing the cremains (abbreviations as in Table 2).*

| Individual # | Resins placed | Cremated | Processed |
|---|---|---|---|
| 1 | F, H, Q | F, H, Q | F, H, Q |
| 2 | TP, F | TP, F | TP, F |
| 3 | Q, TE | Q, TE | Q, TE |
| 4 | Q, TE, TP | Q, TE, TP | Q, TE, TP |
| 5 | F, H | F, H | F |
| 6 | H, TP, TE, Q, F | H, TP, TE, Q, F | TP, TE, Q, F |

In only two cases, 5 and 6, was a brand not located in the processed cremains (Heliomolar).

F, Filtek supreme; H, heliomolar; Q, Quixx; TE, tetric ceram; TP, TPH3.

WIN-ID. Elemental analysis could also be extended to personal effects found with the victim such as rings and other jewelry as a further aid for identification purposes. Analysis could rapidly distinguish materials of similar appearance such as silver, platinum, white gold or diamond, and cubic zirconia.

The development of new technology affords an opportunity to gain additional information, and when combined with knowledge of composition of dental materials, the forensic odontologist has a powerful new tool for identification.

It is the understanding of the authors that quality *ante-* and *post*mortem radiographs and detailed record keeping may preclude the need for such an analysis. It is important, however, to recognize the potential additional information that identification of restorative brand provides. The analysis confers another degree of certainty for individual identification, further rendering scientific proof of identification.

This study involved a small population of six individuals who had both heavily restored teeth and excellent dental records. It is recognized that this is a controlled and limited experiment. The study is confined to five resins currently on the market, and does not address historical resins, some of which contain only silica as a filler and that would therefore be undetectable by this method. Nonetheless, it was the goal to test the hypothesis that identification of restorative resins can provide victim identification under certain conditions. The study was conducted blind and the successful result indicated that the hypothesis is true and that confidence can be placed in this type of analysis. The technique described can provide additional information to confirm identification when traditional procedures are exhausted.

In this study, the cremation retort was used in order to simulate situations such as intense fires, accidents involving accelerants, or mass disasters. The standard conditions of cremation represent an extreme, for in many disasters sustained high temperatures may not be encountered and damage may be minimal as the tissues of the oral cavity locally protect the dentition. Nonetheless, under these extreme conditions, the existence and persistence of resins and amalgams was demonstrated. In addition, it was found to be feasible to recover fragments from an incineration scene, sufficient for identification. Indeed, almost all the resin material was found, allowing positive identification of the six individuals based on known combinations of resin brand in their dentitions.

In this case, it was possible to retrieve the restorative fragments along with the disarticulated elements of the skull under near-ideal conditions. Retrieval at an actual incineration scene, however, may present a much greater challenge. Careful scene investigation utilizing protocols of archeological recovery techniques, including sieving (screening) of material, would be necessary to recover small particles.

Although this study focused on identification through analysis of restorative resins, the importance of the presence of the other types of restorative materials should be noted. Crowns, posts, and all the amalgam restorations survived the high temperatures. The presence of these, together with the resin analysis, would provide a higher degree of certainty in identification.

The third part of the study simulated situations in which there may be questions concerning cremains identity, wrongful cremation, or commingling of ashes. Processing the cremains added another level of difficulty to the task of individual identification. It was still possible, however, to find resins in the processed cremains. Sufficient amounts of resin were again found to distinguish between the individuals in this study, and no foreign materials were discovered. Amalgam was also found, which would add further substance to the determination.

Processed cremains present an analytical challenge to the investigator. For detection of resins, the difficulty lies in demonstrating the presence of a small number of particles of unique composition in a large amount of material with potentially similar particle sizes. This may truly be considered trace evidence analysis. One approach attempted here was to take subsamples of the ash in the 5–10 g range and analyze each using XRF. The entire cremains sample is inhomogeneous because of the distribution of the resin particles, and as expected, the results were variable. The sampling problem inherent in this approach also applies to other potential bulk analytical methods such as Inductively Coupled Plasma emission spectroscopy (ICP) or Atomic Absorption spectroscopy (AA). Although both methods have sensitivity better than XRF, they also require dissolution and therefore destruction of the sample.

It was concluded that the optimum methods for inspection of the cremains was a visual and microscopic inspection of the larger size fraction after sieving, using XRF as a confirmatory analytical technique. X-radiography would be an essential supplement if an exhaustive examination were necessary, and further confirmation of elemental composition of particles could be performed by SEM/EDS.

The retrieval of small amounts of resin as described here would not carry as much weight for identification as a dental chart comparison, but the evidence found was indisputable and unequivocal. In the case of processed cremains, this evidence serves as an aid in identification when very little evidence otherwise exists or when added scientific corroboration is needed.

We have described in this paper the use of new analytical methods in identification of individuals based on knowledge of composition of modern restorative materials. The outcome of this study again highlights the importance of maintaining precise dental records. The advent of complex and varied restorative materials places a greater onus on the practitioner to document in the dental chart both the procedures performed and the materials used.

The authors recognize the responsibility that accompanies custody of human remains and are grateful for the opportunity to complete research of this nature. Through the selflessness of the individuals who donated their bodies for science, we can advance our endeavors to provide resolution under difficult circumstances.

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