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TECHNICAL NOTE

ANTHROPOLOGY

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Differentiation of Traumatic and Heat-Induced Dental Tissue Fractures via SEM Analysis*

ABSTRACT: Previous studies have examined the effects of heating on teeth; however, none have identified characteristics that allow analysts to differentiate traumatic from heat-induced fractures. This study examined our ability to discern notable differences in preincineration traumatic fractures and heat-induced fractures in postincineration dentition. Twelve anterior dental specimens were subjected to blunt force trauma while a second set were not. All 24 samples were then incinerated in a muffle furnace at a peak temperature (900°C) consistent with house fires. The specimens were subsequently examined with a scanning electron microscope to identify and compare heat-induced and traumatic fractures. The results obtained during examination yielded no differences between the features displayed by specimens that had been inflicted with preincineration trauma and those that did not. Unlike bone, distinguishing features for the differentiation of traumatic and heat-induced fractures could not be compiled.

KEYWORDS: forensic science, forensic odontology, dental tissue, heat-induced fractures, traumatic fractures, scanning electron microscope

A branch of forensic odontology has focused on incinerated dentition (1–9). Of this research, most of the attention has been directed to the effects of heat on restorative materials as well as the benefits of using this material and other dental work to obtain positive identifications in burned remains (1,3–6,8). A few studies have developed, and assessed, the methods used for the analysis of dentition exposed to extreme temperatures and in doing so have noted the effects of heat on dental histologic structures (2,7,9). Despite this, a few have examined the effects of heat on teeth for the identification and classification of certain pathologies, such as fractures. Fereira et al. (2) examined the internal and external effects of extreme heat, both direct and gradual, on juvenile (<18 years of age) and older adult (>60 years of age) teeth. They noted differences in the types of fracturing that occurred after direct and gradual heating as well as the types of fractures found in juvenile teeth when compared to elderly teeth. They also indicate that dental morphology, including restorations, anomalies, and pathologies, make teeth unique identifiers (2). Hence, further research is necessary to define features of incinerated dentition that may be used for identification and provide more information as to perimortem circumstances.

Although the literature does not appear to address the classification or differentiation of traumatic and heat-induced fractures in teeth, bone has been examined. Herrmann and Bennett (10) macroscopically and microscopically examined preincineration trauma caused by sharp, blunt, and gunshot forces, as well as heat-induced fractures in domestic pig (*Sus scrofa*) femora. Sharp force trauma was still recognizable after incineration whereas the gunshot trauma produced extreme fragmentation which prevented an interpretation. Blunt force trauma was correctly identified 77% of the time after partial reconstruction of the femoral bone. Similarities in the chemical composition of bones and teeth suggest that this type of research may be applied to the analysis of fractures in dental tissue.

To date, forensic odontology literature has focused on analyzing traumatic and heat-induced fractures in dentition separately, with little focus on the characteristics of these fractures. The purpose of our study was to determine whether diagnostic differences exist between preincineration traumatic fractures and heat-induced fractures in postincineration dentition. By compiling a set of criteria for the differentiation of these types of fractures, it was hoped to eliminate as much of the subjectivity as possible when performing an analysis to determine if trauma preceded the incineration of these teeth. The definition of such analytical criteria would fulfill *Daubert* guidelines (11).

Materials and Methods

Twenty-four human dental samples were chosen from the Laurentian University Documented Human Dental Collection. The 24 teeth utilized consisted of central incisors and canines taken from each of the four quadrants of human dentition (upper right, upper left, lower right, lower left) (Table 1). The anterior dentition's position makes these teeth more likely to be traumatically fractured, and thus, they are ideal specimens for this study. From the Collection, specimens were chosen based on their condition and lack of amalgam or restorations. Dental samples that had been well preserved with minimal damage were selected. Minimal damage was defined as a lack of indentations, chipping or large fractures in the specimen's crown. Because of the Collection's small reserve of

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anterior dentition, three samples did contain porcelain fillings. Although these specimens did contain restorative material, they were selected because the porcelain did not occupy more than 50% of the tooth's crown.

The above sample was separated into two groups: the control group and the experimental group. The control specimens were not to be inflicted with trauma while the experimental group were inflicted with blunt force trauma prior to heating both sample groups.

All dental samples were weighed, measured, and photographed prior to trauma and/or heating. Standard odontometric measurements including the mesiodistal crown diameter, buccodistal crown diameter, labial-lingual, mesiodistal diameter, and root length, all from the cementoenamel junction, were recorded for each tooth. The control specimens were set aside, as they were not inflicted with trauma while the experimental samples were individually taken and placed between folds of a medical tensor bandage to mimic the flesh covering the oral cavity of a human face. A standard crowbar was used to inflict trauma to the experimental dental specimens. The rounded, blunt end of the crowbar was utilized to strike the dental specimens. Each specimen was hit only once with medium force. All fractured pieces of the specimen were collected from between the folds of bandage. Subsequently, the next specimen was wrapped and the trauma infliction process was performed again in the same manner.

All 24 dental specimens were then incinerated using a Sybron Thermolyne Furnatrol II muffle furnace. Because of the number of specimens, the heating process was performed in two sets: first, the control specimens, then the experimental specimens. Each dental specimen was placed in a ceramic crucible fitted with a lid. Lids were used to prevent pieces of the specimen from being ejected from the crucible as they were fractured by the heat. The muffle furnace was set to 900°C. Once heated to 300°C, the furnace was opened and the first set of crucibles were placed into the heating chamber. The samples were then left inside the muffle furnace until the temperature reached 900°C. When the furnace reached the peak temperature of 900°C, this temperature was held for 2 min. After 2 min at peak temperature, the temperature decline phase began. When the muffle furnace reached 400°C, the door was opened and the samples were removed from the heating chamber. The samples were then left in their crucibles overnight, with the crucible lids left on, to complete the cooling process. This same process was repeated with the second set of dental specimens.

A randomly chosen sample from each dental specimen was coated in 10 nm of gold with a Cressington Sputter Coater 108 (Ted Pella, Inc., Redding, CA) and then analyzed with a Cambridge Stereoscan 120 scanning electron microscope (SEM).

Scanning Electron Microscope Analysis

The entire fragment was first surveyed at low magnification (*c.* 20–30×). Areas containing specific features and different tissue were then observed while gradually increasing the magnification. Images were captured at *c.* 75, 150, 300, 600, and 1000× magnification. These magnifications were kept consistent for all specimens to assist in the comparison of features.

As the SEM analysis proceeded, images acquired with the instrument were saved as tagged image files (tif). Subsequently, these files were enhanced for contrast and brightness using Adobe Photoshop® CS2 (Adobe Systems Incorporated, San Jose, CA). After enhancement, all the images captured for each specimen were examined for features and general structures.

After the basic analysis, images were grouped to compare the observed features. These groupings were based on their mechanism of fracture, tissue type, and magnification.

TABLE 1—*Numbers of dental specimens used in the heat-induced versus traumatic fracture study according to type and quadrant.*

Quadrant	Central incisors	Canines	Total
Upper left	2	3	5
Upper right	4	2	6
Lower left	5	2	7
Lower right	4	2	6
Total	15	9	24

Results

Numerous comparisons of the control and experimental group images were performed in an attempt to compile diagnostic criteria that would allow for the differentiation of dental specimens that were, or were not, inflicted with preincineration trauma.

The major feature observed in cementum was a series of reticular patina fractures, both superficial and deep. Analysis of both sample groups, control and experimental, demonstrated that this characteristic was found in all dental specimens (Fig. 1). A tally was taken to emphasize the commonality of this feature in the different samples types, which was formatted as a 2×2 contingency table. Of the specimens that contained cementum, three untraumatized specimens and five traumatized specimens, all displayed deep reticular patina fractures with some superficial ones present as well. A chi-squared test was performed and the results were undefined. Hence, patina fractures are present in cementum of both the control and experimental samples.

Enamel was found to lack numerous unique features. The two features that were identified included superficial patina fractures on the outer enamel surface and the fracture surface roughness. The

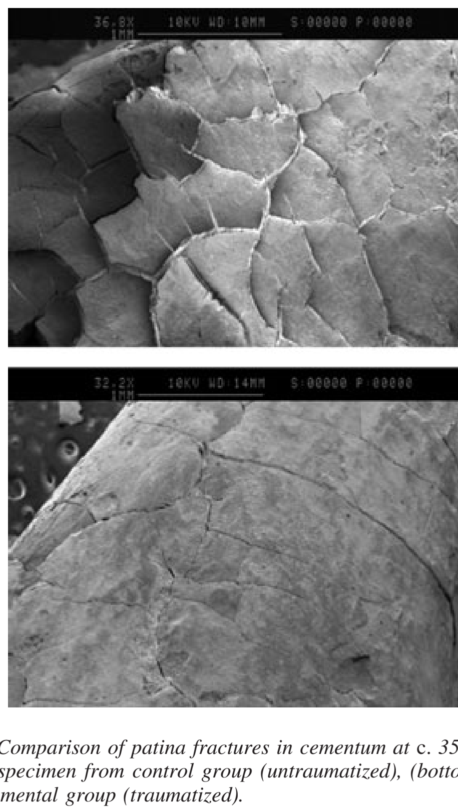

FIG. 1—*Comparison of patina fractures in cementum at* c. *35× magnification; (top) specimen from control group (untraumatized), (bottom) specimen from experimental group (traumatized).*

superficial patina fractures were seen on both traumatized and untraumatized dental specimens, demonstrating similar results to those exhibited by cementum. As the dental specimens were examined, it was noted that a similar fracture surface roughness was detected in enamel. This roughness was compared between dental specimens from the different sample groups, and the presence of this fracture surface was recorded (Fig. 2). Once again, a contingency table was created to analyze the relationship of this fracture surface with the two types of sample groups, and a chi-squared test was performed to reinforce the conclusion from these data. Again, the null hypothesis could not be rejected and hence, this rough fracture surface is present in the enamel of traumatized and untraumatized specimens.

The next area of the dental specimen that was analyzed for unique features was the enamodentin junction (EDJ). This feature of the tooth was analyzed for separation in specimens with and without preincineration trauma. The examination revealed that separation at the EDJ occurred in samples from both the control and the experimental groups. To further underscore these findings, the number of traumatized and untraumatized specimens that demonstrated separation of the EDJ were recorded and subjected to chi-squared analysis. Once again, there is no significant difference, and hence, the separation of the EDJ is equally consistent in traumatized and untraumatized dental specimens. During the analysis of the EDJ, fractures were also found to propagate into the dentin from this tissue border. These fractures were first analyzed for their presence in specimens from both sample groups. It was soon discovered that these fractures were present in the control and experimental samples. The fractures were then analyzed to determine whether they had a different appearance or different characteristics in traumatized specimens than the fractures in untraumatized specimens. After analysis it was evident that there was no difference between these dentin fractures in traumatized and untraumatized specimens.

Dentin, in both control and experimental samples, was analyzed for the presence of fractures and their frequency, as well as the texture of fracture surfaces in this dental tissue. Any appearance of flaking and stepping on the fracture surface was determined to be evidence of the manner in which the fracture propagated through the tissue. The frequency and characteristics of fractures throughout the dentin were very similar, and any differences present were not indicative of whether the specimen had been previously traumatized or not. Reticular fracturing was encountered in some of the untraumatized specimens. The presence of these multiple, smooth intersection fractures was not common enough to be labeled as a significant feature. This manner of fracturing was also present in some experimental specimens, indicating that this feature is not specific to one type of sample group. Therefore, this feature could not be used as an identifying feature. Smooth fracture surfaces were also found near the neck of the tooth bisecting the dentin. These smooth fractures were found in specimens from both sample groups and were therefore not identifiable features.

During the preliminary analysis of the dentin fracture surfaces, there appeared to be a slight difference in the texture of the surface. At a magnification of *c.* 150×, the dentin of specimens that were previously inflicted with trauma were smoother in appearance than those that were not traumatized preincineration (Fig. 3). From this analysis, the fracture surface texture was labeled as a possible differentiating criterion. After further analysis at higher magnifications, 300–600×, it was found that the texture of the fracture surfaces was indistinguishable (Figs 4 and 5).

The results from this study led to the conclusion that dental specimens that were traumatized preincineration, as performed here, did not possess any distinguishing features that allow for their identification when compared to dental specimens that have not undergone preincineration trauma.

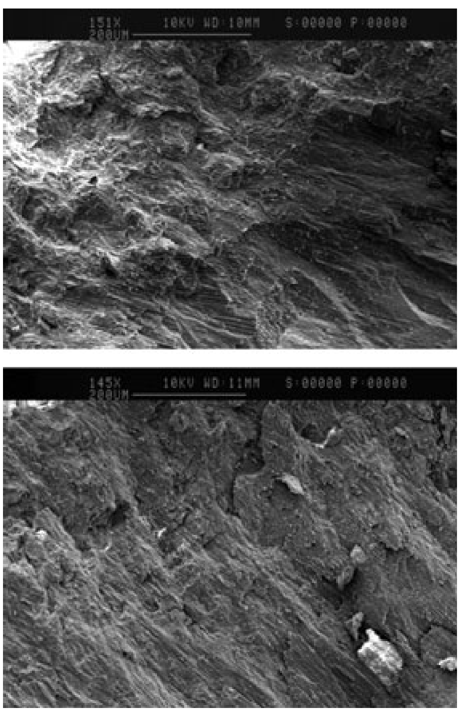

FIG. 2—*Comparison of enamel fracture surface at* c. *150× magnification; (top) specimen from control group (untraumatized), (bottom) specimen from experimental group (traumatized).*

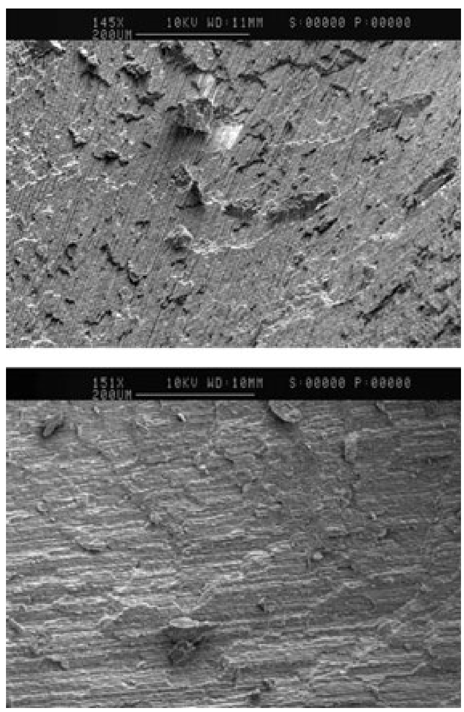

FIG. 3—*Comparison of dentin fracture surfaces at* c. *150× magnification; (top) specimen from control group (untraumatized), (bottom) specimen from experimental group (traumatized).*

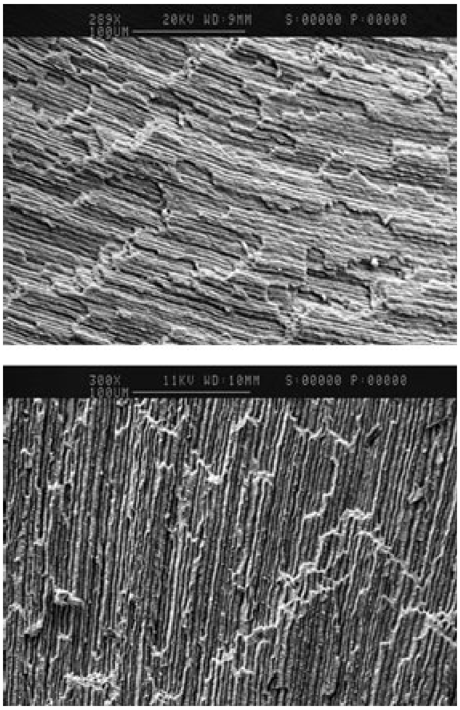

FIG. 4—*Comparison of dentin fracture surfaces at* c. *300× magnification; (top) specimen from control group (untraumatized), (bottom) specimen from experimental group (traumatized).*

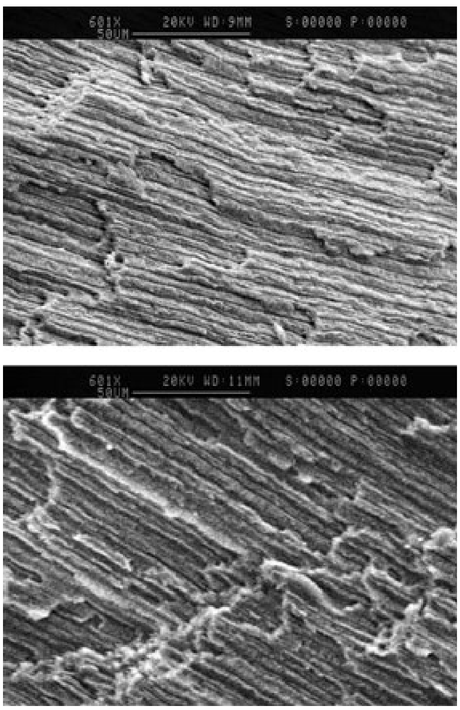

FIG. 5—*Comparison of dentin fracture surfaces at 601× magnification; (top) specimen from control group (untraumatized), (bottom) specimen from experimental group (traumatized).*

Discussion

The microscopic analysis in Herrmann and Bennett's study (10) corresponds closely with the objectives of our study. During analysis of their bone samples with a SEM, they noted a melted appearance of the burned traumatic fracture surfaces. They also inferred that heat fracture surfaces appeared smooth, and were deemed very smooth in comparison with both burned and fresh traumatic fracture surfaces. However, could similar results be expected using teeth rather than bone? If this was the case, then the surface morphology of traumatic fracture surfaces should demonstrate slight melting or fusion making their surface appearance different than that of the heat-induced fractures because of varying exposure times. A more pronounced melted appearance was anticipated in the traumatized dentition than in the untraumatized dentition because the dentin and pulp chamber would be exposed and in turn be more susceptible to the heat. No dental specimens from either the control or the experimental groups exhibited the aforementioned characteristics. The surface morphology for both sample groups appeared the same. Traumatized specimens did not display any fracture surfaces with a melted appearance. Neither group of specimens demonstrated a frequent occurrence of a particular fracture surface texture; specimens from both groups displayed rough and smooth fracture surfaces. A lack in the frequency of features was also displayed in both groups of specimens, with neither group exhibiting a characteristic feature.

It was found that the dental specimens in this study closely resembled the results from those analyzed in Fereira et al. (7). One of their sample groups contained specimens from individuals who were aged 60 years and older, that underwent an incremental heating process, increasing the temperature from 18°C by 18.8°C every minute, until the furnace reached 1150°C (7). The external surface exhibited penetrating cracks that originated on the external surface and followed the orientation of the enamel prisms. Separation of the enamodentinal junction was also observed along with deep cracks in the cementum, some of which extended from the external surface to the cementum–dentinal junction (CDJ) and others which propagated past the CDJ and into the dentin. These same features were observed in specimens from the control and experimental groups in our study, not just those that were heat-induced as reported by Fereira et al. (7).

The specimens used in the current study may have resembled the older, gradually heated specimens from the Fereira et al. study for a number of reasons. The muffle furnace required *c.* 2 h to reach a peak temperature of 900°C. With the muffle furnace's gradual increase in temperature, the specimens in this study were gradually heated as opposed to direct heating in a house fire. The rate for the muffle furnace to heat to the peak temperature closely resembled that used in the Fereira et al. study and differ from Herrmann and Bennett's study which used direct heating (10). Therefore, it would appear that the rate of heating needs to be explored. These similarities in heating profiles would explain the concordance of both studies.

The preservation of the samples used for this study may have also influenced the trauma and heat infliction processes. The samples in this study were not stored in air-tight containers or a liquid preservative. They were stored in open containers that allowed for the samples to dry over time. Fereira et al. (7) believed that the postincineration difference in features was attributed to the varying composition of teeth in individuals under 18 years and those over 60 years. In older individuals, the percentage of water, or humidity grade, is lower than that in younger individuals. The age of individuals whose dental specimens were utilized for the current study is unknown. The natural drying of these specimens may have resulted in a loss of water that equates their water composition to that of the dentition of individuals over 60 years of age.

It is also possible that drying fractures were present in our samples. While the samples that were chosen were examined and selected based on minimal damage, minute drying fractures were not noted in some cases. The formation of drying fractures creates areas of weakness in the specimens. When confronted with either heat or mechanical trauma, the force will dissipate along the already formed fracture and in so doing will further fracture the tooth. If all specimens that were traumatized continued to break along preexisting natural drying fractures, then the fractures were not actually caused by the trauma.

Our results indicate that specimens subjected to preincineration trauma do not display any features that are distinguishable from the features displayed by specimens that were not subjected to trauma. Hence, no objective diagnostic criteria could be formatted. Various limitations did arise throughout the undertaking of this study, which may have influenced the results obtained. Although the specimens did not demonstrate any clinical symptoms, the lack of patient documentation does prevent the correlation of this study's results with the presence or absence of any pathology.

Although the fracture characteristics would have been indicative of natural drying, it would have been consistent among all traumatically fractured specimens. This should not have negatively influenced the results of this study because these fractured surfaces were still the primary surfaces exposed to heat upon incineration. Therefore, they should have still demonstrated a difference from those dental specimens that contained only heat-induced fractures. Similarly, some traumatic fractures may have been attenuated by the preexisting drying fractures.

The heating of these teeth was a gradual process attributable to the nature of the muffle furnace used in this study. This gradual heating may factor into why our results differ from Herrmann and Bennett's study (10). Herrmann and Bennett incinerated the majority of their samples in a single story frame house, and the remaining samples were incinerated in a firebox. The gradual heating of the specimens used in the current study may also explain the similarity to results ascertained by Fereira et al. (7).

Teeth subjected directly to the fire of a Bunsen burner will often crack like glass because of the evaporation of the moisture content, whereas teeth heated gradually to the same temperature will survive despite charring and becoming very brittle (2). If the specimens were heated directly, or within a 3.5 min time frame, the types of fractures and patterns observed would have differed. When the samples were removed from the furnace, those that did not have previous trauma remained intact until they were disturbed. This demonstrates that the evaporation of moisture from the samples was not rapid enough to shatter the tooth. Although the gradual heating did produce fracturing in the specimens, the fractures that propagated through the specimen had a lower energy than others produced by heat. With direct heating, the moisture evaporation is rapid, forming fractures that propagate quickly and with high energy. Hence, the heating protocol will affect the nature of the fractures.

The flesh and bones surrounding the teeth provide protection from direct flame and heat until the flesh is eliminated. The crucibles we used did not afford similar protection provided by the oral cavity. The roots of the dental specimens were exposed during heating. This area is usually housed in the maxillary or mandibular alveolus and therefore has even greater protection from trauma and heat than the crowns of the teeth. The absence of protection for specimens in this study allowed for direct heating to the roots and covering cementum. Therefore, the testing of samples in an alveolus with associated soft tissue would be ideal.

Conclusions

Although distinguishable features for traumatic and heat-induced fractures were not observed in this study, this area of research should continue to be pursued. The methods and materials of the current study resulted in a lack of distinguishable features between traumatic and heat-induced fractures through the use of scanning electron microscopy. It is suggested that heating teeth in a fire, similar to that done to bone by Herrmann and Bennett, be the next step in this research. At this stage, the criteria examined in this study should not be applied to dental remains in a forensic context until further research is conducted.

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