The effects of temperature on extracted teeth of different age groups: A pilot study

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Abstract

Context: Type of dentition and age related changes may affect the behavior of dental hard tissues under thermal stress. Aim: This study was conducted to analyze the effects of varying temperatures on extracted teeth of different age groups in a simulated laboratory set up. Settings and Design: Experimental pilot study. Methods and Material: Extracted teeth from three age groups (deciduous, young permanent and adult permanent) were collected and were exposed to three different temperatures (400°C, 700°C and 1000°C) in a laboratory set up. Post-test changes were analyzed visually and radiographically. Results: (1) The colour changes of the teeth may serve as an indicator for the temperature to which they were exposed. (2) Deciduous teeth tolerated thermal stress with lesser morphological changes compared to young and adult permanent teeth. (3) Coronal dentin of elderly permanent teeth appeared to be more resistant to thermal stress compared to that of young permanent teeth. (4) The root portion of the teeth showed better tolerance to temperature while crown was fragmented easily under thermal stress. Conclusion: The age factor and type of the dentition may influence the heat induced changes in teeth. These variables should be taken into consideration while applying comparative dental identification methods where dental hard tissues are exposed to extreme temperatures.

Key words: Age, effect of temperature, forensic, odontology, radiological, teeth

Introduction

Forensic dentistry has an important role in personal identification in crime investigations and disaster victim identification. Comparative methods are used where the degree of match between antemortem and postmortem data decides positive or negative identification. Teeth are more resistant to decomposition and biological degradation due to its highly mineralized structure compared to soft tissues. Enamel, the hardest substance in the human body, protects the underlying tissues and this can be attributed to the thermal resistance of tooth. Even though teeth are resistant to high temperatures when compared to other tissues, extreme temperatures can induce structural and chemical changes which will make them unsuitable for any comparative identification method.

As age progress, the dental hard tissues undergo changes to their chemical composition. In addition, there are differences between the microstructure of deciduous and permanent teeth. These variations can in turn affect the behavior of the tissues to thermal stress.
This experimental pilot study was conducted to analyze the effects of varying temperatures on extracted teeth of different age groups in a laboratory set-up.

Materials and Methods

Extracted teeth were collected and were divided into three groups based on age. Group A consisted of deciduous teeth, Group B with samples from 20 to 40 years of age, and Group C with samples from subjects above 40 years. Each group consisted of 15 teeth and was tagged with a unique identification number which denotes the age group and temperature to which they were exposed. The first five specimens of each group were (A1–A5, B1–B5, and C1–C5) exposed to a temperature of 400°C, second set (A6–A10, B6–B10, and C6–C10) to 700°C, and the third set (A11–A15, B11–B15, and C11–C15) to 1000°C. Trials with different types of teeth (maxillary and mandibular incisors, premolars and molars) exposed to varying thermal stress were conducted. The changes due to thermal stress were comparable in specimens regardless the type of teeth. Purposive sampling was done and the sample size was dictated by the number of available samples meeting the inclusion criteria. Teeth samples with caries, abrasion, attrition, erosion, hypoplasia, fracture, and restorations were excluded from the study.

The extracted teeth were washed under running tap water, and any soft tissue residue was removed using a hand scaler. The teeth were then disinfected and stored in labeled containers (according to age groups) with 0.9% normal saline solution at room temperature. Deposits of the tooth surface were removed using an ultrasonic scaler before the experiment.

All the teeth were photographed and were then placed on a digital occlusal film (Durr-Dental®) and radiographed (VistaScan®) under fixed parameters.

Five teeth from each group were then loaded onto a tray made of high-strength dental stone. The teeth were placed inside a blast furnace (Zhermack DM40®) which was preheated to the target temperatures of 450°C, 750°C, and 1050°C. The furnace was heated to 50°C above the required temperature to compensate the temperature drop while opening of chamber door to insert the loaded tray. The temperature drop was calculated based on trial and error. The samples were exposed to predetermined temperatures for 15 min. The teeth were exposed to experimental temperatures to simulate a sudden and rapid temperature rise, similar to that seen in gasoline accidents, aviation disasters, or explosions. The teeth were taken out after the exposure and allowed to cool at room temperature. Postexposure photographs and radiographs of the teeth were taken as described previously.

The specimens from each age group which were exposed to different temperatures (400°C, 700°C, and 1000°C) were assessed visually for changes in color, translucency, surface texture, and morphology. Changes such as separation of enamel from dentin, fracture lines, and dimensional changes were radiographically assessed. Quantitative measurements were done using Planmeca Romexis® image viewer software. The software was calibrated based on inter-observer agreement, and the measurements were standardized with fixed landmarks to avoid inter-observer variations. The average value of measurements from two observers was taken as final for every quantitative parameter. All the measurements were done in millimeters.

Results

Visual analysis

Changes in crown of teeth

The details of visual analysis for all the three groups are given in Tables 1-3. The color changes after thermal exposure were similar for a particular temperature regardless of age group. The color of the enamel changed to yellowish-gray with dark brown patches at 400°C [Figures 1-3], dark gray with patches of bluish-gray at 700°C [Figures 4-6], and gray with patches of light bluish-gray at 1000°C [Figures 6-8]. The loss of glossiness on the enamel surface after 400°C was noticed in all the groups. The loss of enamel translucency was not observed in any of the groups at 400°C, while all the groups showed complete loss of translucency at 700°C and 1000°C. Fracture lines appeared to occur on the enamel surface at 400°C in all three groups [Figures 4-6].

At 700°C, the enamel showed some amount of fragmentation and was separated from underlying coronal dentin in specimens from Groups B and C [Figures 5 and 6]. The enamel layer remained adhered to dentin in Group A [Figure 4]. At 1000°C, four specimens from Group A showed partial fragmentation of enamel exposing the underlying dentin [Figure 7]. Fracture lines were also present on the underlying coronal dentin. Some samples showed partial fragmentation of both enamel and dentin exposing pulp chamber. Four specimens from Group B showed...
complete fragmentation of enamel and coronal dentin [Figures 8 and 9]. Teeth from Group C showed complete loss of enamel layer. Fracture lines and some degree of fragmentation were observed in the coronal dentin.

Changes in root of teeth
At 400°C, the root color changed to amber brown with black patches in Groups A and B, while it was brownish black in Group C [Figures 1-3]. At 700°C, Group A showed root color ranging from white to light bluish-gray, with pale yellow tinge [Figure 4]. Groups B and C showed bluish-gray root color [Figures 5 and 6]. At 1000°C, specimens from all the groups showed more grayish-blue color in general. Few of the specimens from Groups A and C showed a pinkish discoloration of root at 1000°C. Areas where root dentin was exposed especially in specimens from Group A showed pale yellowish discoloration. The surface showed changes from
Fracture lines were observed on the root surface of teeth from Groups B and C at 700°C and were increased at 1000°C. Specimens from Group A did not show any fracture line on the root surface at 700°C.

**Radiographic analysis**

Teeth from Groups B and C showed few fracture lines at 400°C and were confined to coronal and root dentin [Figures 2 and 3]. However, the fracture lines were not present in specimens from Group A [Figure 1]. At 700 and 1000°C, the fracture lines increased in number and width in teeth from all the age groups [Figures 4-6]. The fracture lines involved both dentin and enamel in specimens from Groups B and C only at 700°C and above [Figures 5, 6, 8, and 9].
There was no separation of enamel from the coronal dentin in radiographs of specimens from Groups A and B at 400°C [Figures 1 and 2]. However, few of the specimens from Group C showed a radiolucent region separating the enamel and dentin limited to the cervical region, suggestive of separation of enamel from dentin [Figure 3]. At 700°C, a linear radiolucent band separating the enamel and dentin was noticed above the Dentino-enamel junction (DEJ) in specimens from Groups B and C. Specimens from Group A showed similar separation though limited to the cementoenamel junction [Figures 4-6]. However, at 1000°C, the enamel layer was completely separated and was detached from the dentin in specimens from Groups B and C [Figures 8 and 9]. In Group A, the enamel was still attached to the dentin with a significant increase in the width of separation between enamel and dentin [Figure 7].

Dimensional changes were minimal at 400°C in all the groups [Table 4] Due to fragmentation of tooth structures at 700°C and 1000°C, it was not possible to measure the dimensions as the reference points were destroyed [Tables 5 and 6].

The quantitative measurements are provided in Tables 4-6. Statistical analysis was not performed due to missing values as they were not available due to destruction of tooth structure after the thermal exposure.

Discussion

Behavior of teeth under extreme temperatures was studied, and researchers have attempted to explain the changes based on the structure and composition of teeth. The extent of damage to the teeth caused by thermal insult depends on the temperature range and duration of exposure. House fires rarely reach temperatures of 1200°F (649°C), but chemical fires can exceed several thousand degrees.[1] According to Delattre, the teeth of burnt victim show four phases that reveal progressive changes in their structure: They may
Table 3: Morphological and radiographic changes of elderly permanent teeth (Group C) at different temperature levels

<table>
<thead>
<tr>
<th>Mode of observation</th>
<th>Structure</th>
<th>Parameter</th>
<th>400°C</th>
<th>700°C</th>
<th>1000°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual observation</td>
<td>Crown</td>
<td>Color</td>
<td>Brownish-yellow with patches of black</td>
<td>Color of enamel is dark gray with patches of bluish gray. Color of dentin along the DEJ is light bluish-gray. Color of dentinal surfaces exposed as a result of fracture of coronal dentin is dark bluish-gray</td>
<td>Color of enamel was determined from fragments as insufficient enamel was present on any of the samples. Color of enamel is grey with patches of bluish-gray. Dentin color is light bluish-gray</td>
</tr>
<tr>
<td>Translucency</td>
<td>Translucency observed</td>
<td>Loss of translucency</td>
<td>Enamel has a shiny appearance. Coronal dentin has a dull, chalky appearance</td>
<td>Enamel fragments have a shiny appearance. Coronal dentin has a dull, chalky surface texture</td>
<td></td>
</tr>
<tr>
<td>Surface texture</td>
<td>Loss of glossiness</td>
<td>Enamel was visibly separated from underlying coronal dentin. In some samples, the enamel layer was detached as an intact body. Small fragments of dentin, notably at the cusps, were detached along with the enamel layer</td>
<td>Enamel layer completely lost. Coronal dentin shows fracture lines and some fragmentation but remains largely intact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morphology</td>
<td>No other morphological changes observed</td>
<td>Fracture lines seen on surface</td>
<td>Fracture lines seen on root surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root</td>
<td>Color</td>
<td>Black to brownish-black</td>
<td>Color of root ranges from light bluish-gray, with patches of gray seen</td>
<td>Color of root is light bluish-gray. Some samples show a generally darker gray</td>
<td></td>
</tr>
<tr>
<td>Translucency</td>
<td>Loss of translucency</td>
<td>Surface appears shiny</td>
<td>Dull, chalky appearance</td>
<td>Dull, chalky appearance</td>
<td></td>
</tr>
<tr>
<td>Surface texture</td>
<td>Fracture lines</td>
<td>Very few (3 or less) lines of fine thickness present in coronal portion of tooth. Lines appear to be confined to dentin only</td>
<td>Fracture lines are present in increased numbers and width than at 400°C, present in coronal and radicular portion of tooth and involve both enamel and dentin</td>
<td>Fracture lines present in increased numbers and width than at 700°C. The lines are present in coronal and radicular portion of tooth and involve both enamel and dentin</td>
<td></td>
</tr>
<tr>
<td>Morphology</td>
<td>Enamel separation</td>
<td>Enamel separation was not appreciable in most of the samples. Some samples did show beginning of enamel separation</td>
<td>Radiolucent line separating enamel and dentin extends along the entirety of the DEJ</td>
<td>Enamel layer was completely lost</td>
<td></td>
</tr>
<tr>
<td>Radiological observations</td>
<td>Fracture lines</td>
<td>Radiolucent region separating the enamel and dentin is present only at the cervical margins of the DEJ</td>
<td>Loss of enamel layer in some samples but all showing a largely intact coronal dentin</td>
<td>Enamel layer is completely lost. Coronal dentin shows fracture lines and some fragmentation but remains largely intact</td>
<td></td>
</tr>
</tbody>
</table>

DEJ: Dentino-enamel junction

remain intact, teeth that suffer a superficial discoloration, become charred, burned, and burst apart.[2,3]

The color changes after thermal exposure are similar for a particular temperature regardless of age group. The enamel surface showed yellowish-gray discoloration with dark brown patches at 400°C, dark gray with bluish-gray patches at 700°C, and gray with bluish-gray patches at 1000°C. Similar observations were reported in the previous studies.[4-6] The loss of glossiness on the surface of crown and root after 400°C was recorded by Rotzscher et al. and was explained as invisible carbonization.[7] The root surface of the teeth exposed to 1000°C shows the pinkish discoloration. Similar observations were made by previous researchers though the reason for the discoloration is not identified.[8,9]

The color changes were comparable between the teeth from three different age groups for a specified temperature. The influence of age-related changes and structural difference between teeth may not have a significant role in color change of teeth under thermal stress.

At 400°C, no morphological changes were observed to teeth from any age group. At 700°C, the deciduous teeth showed minute dimensional changes. The young permanent teeth and elderly permanent teeth exhibited fragmentation. This observation is in contrast to the study of Karkhanis et al. and Palamara et al.[9,10] At 1000°C, the deciduous teeth also showed fragmentation but still retained most of their crown structure. The young permanent teeth show complete loss of enamel layer and fragmentation including the coronal dentin.
Complete loss of crown was observed in a few specimens. At 1000°C, the teeth from Group C showed fragmentation of enamel layer. Most of the enamel is lost, but some amount of enamel can still be found attached to the crown. In contrast to the young permanent teeth, coronal dentin in elderly teeth was intact. It is observed that the coronal dentin of the elderly teeth is more resilient even at 1000°C as compared to the coronal dentin of young permanent teeth.

The deciduous teeth were more resistant to fragmentation under thermal stress. The high resiliency of the deciduous teeth to thermal stress may be attributed to lesser mineral concentration gradient from cervical to occlusal region. The deciduous enamel has uniform coefficient of thermal expansion under thermal stress as compared to permanent teeth. This probably causes uniform thermal expansion and reduces the risk of fragmentation of the enamel.[11] The numerical density of enamel rods is higher in deciduous teeth than in the permanent teeth.[12] Higher the density of enamel rods in deciduous teeth, the higher the strength of the enamel cap during the thermal stress due to the compactness of the enamel rod at DEJ. The high resiliency of deciduous enamel under thermal stress may also be due to larger diameter of the enamel prism in deciduous teeth than permanent teeth.[13,14] The enamel prism of deciduous teeth is more densely arranged than permanent teeth at the DEJ which may contribute to the structural integrity of enamel cap under thermal stress.
NA: Tooth structure destroyed after thermal exposure and unable to measure the distance, CEJ: Cemento‑enamel junction

The hydroxyapatite crystals are disposed parallel to each other and perpendicular to enamel surface on teeth in the prismless enamel layer deciduous teeth. This characteristic feature forms a uniformly thick layer in deciduous teeth which may allow a more uniform thermal expansion and reduce the fragmentation of the enamel cap under thermal stress.

The S-shaped curvature in the course of dentinal tubules in permanent teeth may increase the risk of fragmentation during thermal stress. The majority of primary teeth dentin showed straight course dentinal tubules, whereas in permanent teeth, the tubules show S-shaped curvature. The S-shaped curvature in dentinal tubules causes the inconsistent thermal expansion due to the presence of the high organic component in the curvature of dentinal tubules near the DEJ. This feature will lead to an increase in gradient of coefficient of thermal expansion in dentin of permanent teeth near the DEJ. The straight course of dentinal tubules in deciduous teeth allows uniform thermal expansion in deciduous dentin which can be attributed to the consistency in coefficient of thermal expansion.

The mineral content of the primary teeth enamel is lower than that of the permanent teeth. The amount of calcium and phosphate was higher in permanent teeth enamel when compared to deciduous teeth. The mineral content is 81.3–94.2 wt% for primary teeth enamel whereas it is approximately 97 wt% for permanent enamel, which is close to pure synthetic apatite with the remainder consisting of water and organic matrix. Matrix proteins are essentially removed during maturation of enamel.

The coronal dentin of the elderly teeth was more resilient compared to the coronal dentin of the young permanent teeth. This may be due to the presence of the sclerotic dentin in the elderly teeth. The sclerotic dentin appears to be the result of the occlusion of dentinal tubules due to the deposition of mineral into the lumen of the tubule. It was found that sclerotic dentin was hypermineralized with the mineral/matrix ratios 2–3 times higher than those of normal dentin, which was caused by both the increase of mineral content and decrease of organic matrix (collagen) content in the sclerotic dentin. The mineralization is 40% more in sclerotic dentin compared to normal dentin. The higher mineralization in the sclerotic dentin compared to normal dentin increases the strength in the coronal dentin of the elderly teeth.

The mean size of the crystallites in sclerotic dentin is smaller compared to normal dentin. The reduction in mean crystallite size could be due to precipitation of new, but smaller crystallite within the matrix. The average crystallite size of teeth varies from approximately 12 nm (old age) up to 38 nm (young age). This feature explains the increased density of the crystallite structure in the sclerotic dentin and reduced organic matrix content, which further strengthens the sclerotic dentin to withstand the thermal stress.

There are studies which reported the presence of sclerotic dentin in teeth of individuals aged between 12 and 19 years. It is difficult to draw a conclusion toward effect of thermal stress based on the presence or absence of sclerotic dentin.

There is a decrease in crystalline nature of human dental apatite as the age advances. The patterns from teeth up to 45 years old indicate highly crystallized material whereas the patterns from older-age teeth show an increasing
broadening of the Bragg peaks, indicating an increasing loss of crystallinity of human dental apatite as a function of age.

The radiographic changes in teeth from all the three age groups exhibited increasing degree of fracture as the temperature increases. This is represented as radiolucent lines increasing in number as well as width from lower to higher temperature.

Exposure to high temperatures can induce evaporation of the organic components of tooth and lead to separation of the enamel layer allowing the dentin to get exposed and burnt.[2] Separation of enamel was minimal at 400°C in teeth from any group. When present, it was usually restricted to the cervical portion of the crown. Enamel separation was obvious at 700°C and above in teeth from all age groups. At this temperature, the separation ran along the entire DEJ and was not restricted to the cervical portion. Similar observation was made by Prakash et al. in 2014 has reported similar observations in teeth at 600°C.[26,27]

At 1000°C, teeth from the deciduous group showed more pronounced enamel separation than at lower temperatures. At 1000°C, teeth from the young permanent group showed complete loss of their enamel layer and loss of most of the underlying coronal dentin. Teeth from the elderly permanent group also showed a complete loss of their enamel layer at 1000°C. However, in contrast to the young permanent group, the teeth retained most of their coronal dentin.

The age factor and type of the dentition may influence the heat-induced changes in teeth. Comparative dental identification methods should be applied with caution while the dental tissues are exposed to high temperatures. The present experimental pilot study has its limitations due to small sample size and variations in the storage time. Further studies with larger sample size are suggested to determine the range of temperature till which dental evidence are useful for comparative identification methods.

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**Conflicts of interest**

There are no conflicts of interest.

**References**

George, et al.: The effects of temperature on extracted teeth


