Original Article

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.

Access this article online	
	Quick Response Code
Website: www.jfds.org	
DOI: 10.4103/jfo.jfds_25_16	

How to cite this article: George R, Tan WJ, Shih Yi AL, Donald PM. The effects of temperature on extracted teeth of different age groups: A pilot study. J Forensic Dent Sci 2017;9:165-74.

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

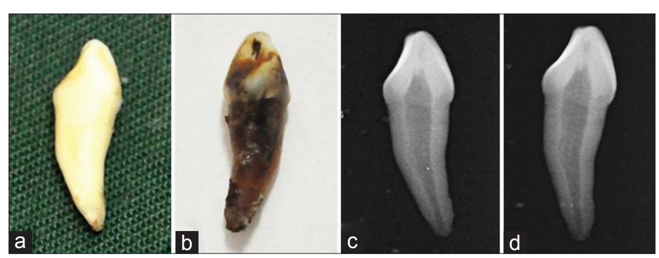

Figure 1: Morphological and radiographic changes in sample specimen from Group A at temperature 400°C. (a) Preheating photograph (b) postheating - enamel lost the glossiness and root shows amber color (c) preheating radiograph (d) postheating radiograph showing minimal fracture lines

Table 1: Morphological and radiographic changes of deciduous teeth (Group A) at different temperature levels

Mode of observation	Structure	Parameter	400°C	700°C	1000°C
Visual observation	Crown	Color	Yellowish-gray with dark brown and black patches	Dark gray with patches of bluish-gray	Enamel color is gray with patches of light bluish-gray Dentin color is light grayish-white
		Translucency	Translucency observed	Loss of translucency	Loss of translucency
		Surface texture	Shiny appearance	Loss of glossiness	Enamel has a shiny appearance. Coronal dentin has a dull, chalky appearance
		Morphology	Fracture lines seen on enamel	Fracture lines seen on enamel	Partial fragmentation of enamel, exposing underlying dentin. Fracture lines are also present on the underlying coronal dentin. Some samples show partial fragmentation of both enamel and dentin, exposing pulp chamber
	Root	Color	Color ranges from black to amber brown with dark/black patches	Color ranges from white to light bluish-gray, with pale yellow tinge	Bluish-gray with patches of dark gray present on root surface. At sites of resorption where dentin is uncovered by cementum, the color is pale yellow
		Translucency	Translucency observed	Loss of translucency	Loss of translucency
		Surface texture	Smooth white appearance	Dull, chalky appearance	Dull, chalky appearance
		Morphology	No morphological changes observed	No morphological changes observed	Fracture lines seen on root surface
Radiological observation	Crown and root	Fracture lines	Present. 1-2 lines of fine thickness seen. Lines appear to involve both dentin and enamel	Present. Increased number of lines and width compared to those seen at 400°C	Fracture lines are present in increased numbers and width than seen at 700°C
		Enamel separation	Not observed	Present. Radiolucent region separating the enamel and dentin extends along entirety of the DEJ	Radiolucent region separating the enamel and dentin extends along the entirety of the DEJ and is now wider
		Morphology	No other morphological changes observed	No other morphological changes observed	No further morphological changes observed

DEJ: Dentino-enamel junction

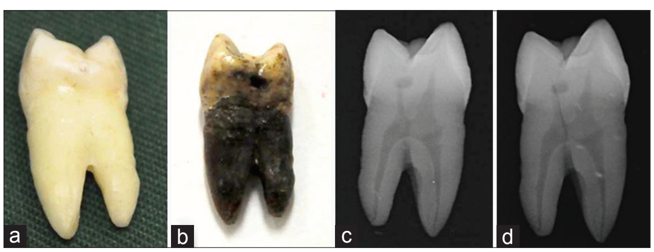

Figure 2: Morphological and radiographic changes in sample specimen from Group B at temperature 400°C. (a) Preheating photograph (b) postheating photograph showing loss of glossiness of enamel and brownish black discoloration of root. (c) Preheating radiograph (d) postheating radiograph showing fracture lines confined to coronal and root dentin

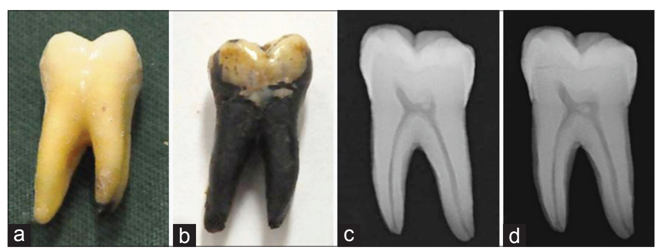

Figure 3: Morphological and radiographic changes in sample specimen from Group C at temperature 400°C. (a) Preheating photograph (b) postheating photograph showing loss of glossiness and partial discoloration of enamel and brownish-black discoloration of root. (c) Preheating radiograph (d) postheating radiograph showing beginning of separation of enamel from dentin confined to the cementoenamel junction region only

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

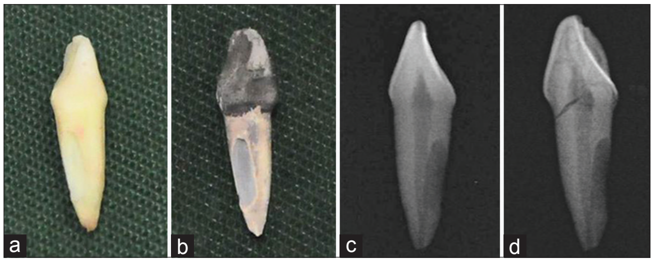

Figure 4: Morphological and radiographic changes in sample specimen from Group A at temperature 700°C. (a) Preheating photograph (b) postheating photograph showing dark grayish discoloration of crown and root color ranging from white to light bluish-gray, with pale yellow tinge. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines. The enamel layer shows separation from dentin near the cementoenamel junction

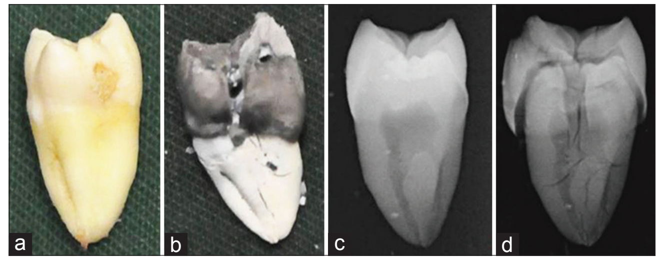

Figure 5: Morphological and radiographic changes in sample specimen from Group B at temperature 700°C. (a) Preheating photograph (b) postheating photograph showing dark grayish discoloration of crown and white to grayish white discoloration of root. Enamel showed some amount of fragmentation and was separated from underlying coronal dentin. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines. A linear radiolucent band separating the enamel and dentin was noticed above the Dentino-enamel junction

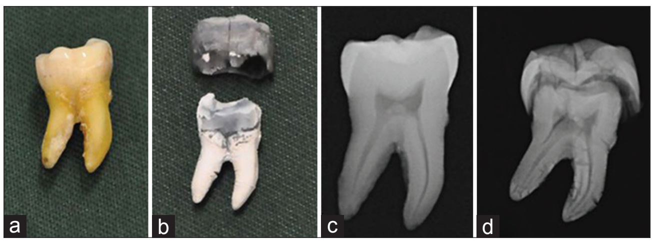

Figure 6: Morphological and radiographic changes in sample specimen from Group C at temperature 700°C. (a) Preheating photograph (b) postheating photograph showing dark grayish discoloration of crown and white to grayish white discoloration of root. The enamel layer is detached from the coronal dentin. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines and completes detachment of enamel layer from dentin

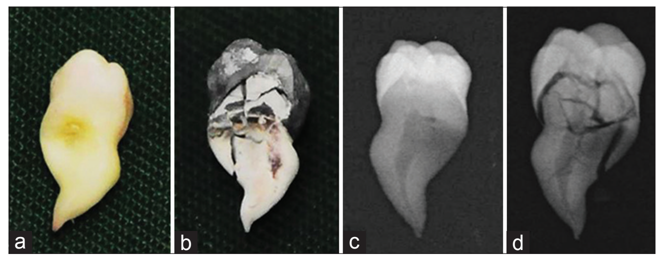

Figure 7: Morphological and radiographic changes in sample specimen from Group A at temperature 1000°C. (a) Preheating photograph (b) postheating photograph showing dark grayish discoloration of crown and showing pinkish white discoloration of root. The enamel layer is detached from the coronal dentin. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines. The enamel was still attached to the dentin morphologically, but the width of separation between enamel and dentin in the radiograph increased

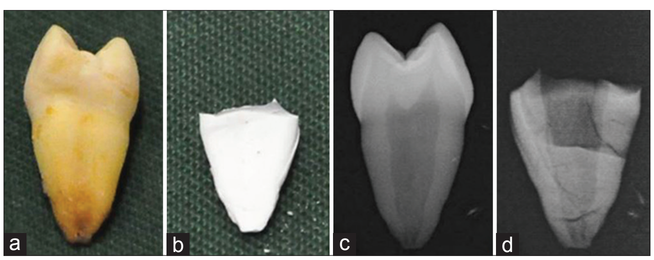

Figure 8: Morphological and radiographic changes in sample specimen from Group B at temperature 1000°C. (a) Preheating photograph (b) postheating photograph showing complete fragmentation of enamel and coronal dentin leaving only the root portion. The root shows white color. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines in the root. The crown was not visualized as it was completely fragmented and lost

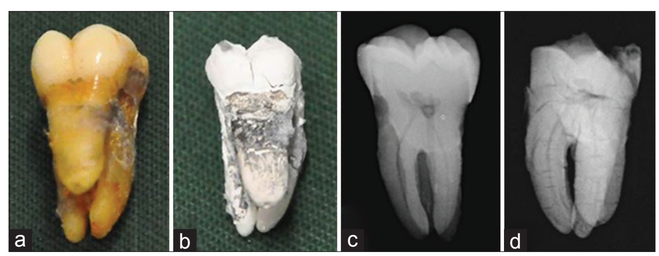

Figure 9: Morphological and radiographic changes in sample specimen from Group C at temperature 1000°C. (a) Preheating photograph (b) postheating photograph showing complete fragmentation and loss of enamel layer. Coronal dentin showed grayish white discoloration and fracture lines. The root shows white discoloration and many horizontal fracture lines. (c) Preheating radiograph (d) postheating radiograph showing increased number of fracture lines in the coronal dentin and root. Enamel layer was not seen as it was completely fragmented and lost

the normal smooth texture to a dull, chalky appearance in all the specimens.

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].

Table 2: Morphological and radiographic changes of young permanent teeth (Group B) at different temperature levels

Mode of observation	Structure	Parameter	400°C	700°C	1000°C
Visual observation	Crown	Color	Grayish-yellow with patches of brown and black	Enamel color is dark gray with patches of bluish-gray. Exposed coronal dentin color is bluish-white	Color of enamel was determined from fragments as no enamel was found attached to any of the samples. Enamel color is gray with patches of light bluish-gray. Dentin color is light grayish-white
		Translucency	Translucency observed	Loss of translucency	Loss of translucency
		Surface texture	Loss of glossiness	Loss of glossiness. Coronal dentin has a dull, chalky surface texture	Very little enamel remained on the crown. Enamel fragments have a shiny appearance. Coronal dentin has a dull, chalky appearance
		Morphology	No other morphological changes	Fragmentation of the enamel layer only, exposing the underlying coronal dentin. Some samples also showed fragmentation of the coronal dentin	Complete fragmentation of enamel and coronal dentin
	Root	Color	Color ranges from black to amber brown, with black patches	Color ranges from white to bluish-white	Bluish-gray with patches of dark gray present on root surface
		Translucency	Loss of translucency	Loss of translucency	Loss of translucency
		Surface texture	Shiny appearance	Root surface has a dull, chalky surface texture	Dull, chalky appearance
		Morphology	No other morphological changes observed	Small fracture lines can be seen on surface of root	Fracture lines seen on surface of root
Radiological observation		Fracture lines	Very few (3 or less) lines of fine thickness. Present in both coronal and radicular portion of tooth and appear to be confined to dentin only	Radiolucent lines present in increased numbers and width than at 400°C. Lines are present in both coronal and radicular portion of tooth and extend up to enamel	Fracture lines are present in increased numbers and width than seen at 700°C
		Enamel separation	Enamel separation is not appreciable	Radiolucent region separating the enamel and dentin extends along the entirety of the DEJ	Enamel layer was completely lost
		Morphology	No other morphological changes observed	No further radiographic changes observed	Crown was lost completely

DEJ: Dentino-enamel junction

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 the 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

Mode of observation	Structure	Parameter	400°C	700°C	1000°C
Visual observation	Crown	Color	Brownish-yellow with patches of black	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	Color of enamel was determined from fragments as insufficient enamel was present on any of the samples. Color of enamel is gray with patches of bluish-gray. Dentin color is light bluish-gray
		Translucency	Translucency observed	Loss of translucency	Loss of translucency
		Surface texture	Loss of glossiness	Enamel has a shiny appearance. Coronal dentin has a dull, chalky appearance	Enamel fragments have a shiny appearance. Coronal dentin has a dull, chalky surface texture
		Morphology	No other morphological changes observed	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	Enamel layer completely lost. Coronal dentin shows fracture lines and some fragmentation but remains largely intact
	Root	Color	Black to brownish-black	Color of root ranges from light bluish-gray, with patches of gray seen	Color of root is light bluish-gray. Some samples show a generally darker gray
		Translucency	Loss of translucency	Loss of translucency	Loss of translucency
		Surface texture	Surface appears shiny	Dull, chalky appearance	Dull, chalky appearance
		Morphology	No other morphological changes observed	Fracture lines seen on surface	Fracture lines seen on root surface
Radiological observations		Fracture lines	Very few (3 or less) lines of fine thickness present in coronal portion of tooth. Lines appear to be confined to dentin only	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	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
		Enamel separation	Enamel separation was not appreciable in most of the samples. Some samples did show beginning of enamel separation	Radiolucent line separating enamel and dentin extends along the entirety of the DEJ	Enamel layer was completely lost
		Morphology	Radiolucent region separating the enamel and dentin is present only at the cervical margins of the DEJ No other morphological changes observed	Loss of enamel layer in some samples but all showing a largely intact coronal dentin	Enamel layer is completely lost. Coronal dentin shows fracture lines and some fragmentation but remains largely intact

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.

Table 4: Comparison of measurements before and after exposure to 400°C for 15 min

Temperature	Tooth sample	Length of tooth (mm)		Length of crown (mm)		Length of root (mm)		Width of tooth at CEJ (mm)		Length of pulp (mm)		Width of pulp (mm)		Separation of CEJ (mm)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
400°C	A1	32.5	32.7	9.3	10.2	23.2	22.5	7.5	7.4	26.1	26.1	2.4	2.7	0	0
	A2	30.9	31.6	8.2	9.1	22.7	22.5	8.2	8.3	25.5	25.4	3.2	3.2	0	0
	A3	26.5	26	9.3	8.8	17.2	17.2	11.2	11.2	18.6	15	0.9	1.1	0	0.3
	A4	29.5	29.2	10.4	10.2	19.1	19	9	9	24.4	23.9	3.8	3.7	0	0
	A5	33	32.5	11.9	10.7	21.1	21.8	9.5	9.6	26.8	26.5	3.7	4	0	0
	B1	43	42.9	16	15.9	27	27	18.6	18.4	33.8	34.1	8.9	8.8	0	0
	B2	44.2	44.4	15.3	15.4	28.9	29	15.8	16	34.5	34.3	4.9	4.9	0	0
	B3	31.9	31.5	13.8	13.6	18.1	17.9	14.7	14.1	22.3	22.4	6.4	6.3	0	0
	B4	33.7	34.1	11.8	11.9	21.9	22.2	15.2	15.3	24.6	25.2	5	5	0	0
	B5	40.3	40.1	16.6	16.2	23.7	23.9	18.5	18.5	31.3	30.7	8.2	8	0	0
	C1	35.1	34.7	13.2	14	21.9	20.7	18.9	18.7	24.2	22.8	8	8.1	0	0
	C2	37.8	38.1	14.6	14.7	23.2	23.4	10.3	10.3	29.1	30.4	2.3	2.4	0	0
	C3	35.8	35.4	12.9	12.6	22.9	22.8	16.1	16.6	25.5	26	5.9	6	0	0.5
	C4	37.2	36.9	13.7	13.6	23.5	23.3	11.3	11.2	30.8	30.6	2.7	2.9	0	0
	C5	33.9	34.2	13.9	14.9	20	19.3	18.3	17.8	23.1	23.6	8.9	9.1	0	0

CEJ: Cemento-enamel junction

Table 5: Comparison of measurements before and after exposure to 700°C for 15 min

Temperature	Tooth sample	Length of tooth (mm)		Length of crown (mm)		Length of root (mm)		Width of tooth at CEJ (mm)		Length of pulp (mm)		Width of pulp (mm)		Separation of CEJ (mm)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
700°C	A6	30.3		11.2	NA	19.1	NA	9.5	NA	22.3	NA	3.9	NA	0	NA
	A7	27.2	27.1	9.6	10.1	17.6	17	7.7	7.9	21.5	21.5	3	3.1	0	0.2
	A8	27.9	28.6	10	11.1	17.9	17.5	10.4	10.5	22.1	21.3	2.8	3.5	0	1
	A9	26.9	28.5	10.3	NA	16.6	NA	7.6	NA	22.1	NA	2.7	NA	0	NA
	A10	30.9	29.9	9.5	11.3	21.4	18.6	9.5	8.9	24.9	23.4	3.9	3.4	0	0.5
	B6	37.4	37	15.2	16.7	22.2	20.3	14.6	13.5	29	27.3	5.8	5.4	0	1.7
	B7	33.1	25.6	13.7	NA	19.4	NA	18.5	NA	21.6	NA	9.3	NA	0	NA
	B8	41.9	41.7	16	17.2	25.9	24.5	15.8	15.4	32.5	32.1	7.4	8.4	0	1.1
	B9	32.6	32	13.8	16.2	18.8	15.8	17.9	17	20.6	19	7.7	7.1	0	1.6
	B10	42	37.2	16.1	NA	25.9	NA	12.5	NA	32.7	NA	4.8	NA	0	0.4
	C6	36.9	29.8	13	NA	23.9	NA	16.9	14.5	29.3	27	7.8	5.1	0	NA
	C7	36.8	36.2	13.8	15.4	23	20.8	9.5	8.9	26.2	25.4	2.2	2.1	0	1.3
	C8	33.4	28.7	11.2	NA	22.2	NA	16.7	15.4	24.6	23	7.8	8	0	NA
	C9	36.2	38.6	11.4	13.2	24.8	25.4	13.3	13	26.2	27.4	4	3.9	0	1.4
	C10	36.9	39.7	12.5	14.5	24.4	25.2	12.9	11.9	26.2	28.6	3.5	3.3	0	1.3

NA: Tooth structure destroyed after thermal exposure and unable to measure the distance, CEJ: Cemento-enamel junction

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.

Table 6: Comparison of measurements before and after exposure to 1000°C for 15 min

Temperature	Tooth sample	Length of tooth (mm)		Length of crown (mm)		Length of root (mm)		Width of tooth at CEJ (mm)		Length of pulp (mm)		Width of pulp (mm)		Separation of CEJ (mm)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1000°C	A11	30.9	29.6	8.1	9.4	22.8	20.2	8.9	7.7	26.8	24.9	3.2	2.8	0	1
	A12	23.2	22.2	8.2	9.6	15	12.6	10.3	10	15.3	13.5	0.7	0.9	0	0.7
	A13	26	25.2	7.2	7.9	18.8	17.3	7	6.2	20.4	19.2	2.8	2.5	0	0.7
	A14	19.5	19.8	11.3	11.9	8.2	7.9	9.3	6.2	12.4	13.4	3.8	2.2	0	0.8
	A15	29.6	30.2	8.6	12	21	18.2	8.3	6.4	24.8	21.9	2.4	2.4	0	2
	B11	33.4	NA	14.8	NA	18.6	NA	15.5	NA	26.1	NA	7.8	NA	0	NA
	B12	28.2	NA	11.7	NA	16.5	NA	17.6	NA	18.8	NA	7.7	NA	0	NA
	B13	44.1	NA	15	NA	29.1	NA	15.2	NA	35.6	NA	4.8	5.3	0	NA
	B14	32.2	NA	14	NA	18.2	NA	17.4	15.3	21.4	24.1	8.9	8.1	0	NA
	B15	33.7	NA	13	NA	20.7	NA	11.5	9.6	25.4	22.1	3.9	3.3	0	NA
	C11	38.6	NA	12.4	NA	26.2	NA	12.8	11.5	27.2	25.5	3.7	3.1	0	NA
	C12	37.1	NA	13.5	NA	23.6	NA	16.2	16	25.5	23.9	6.4	6.4	0	NA
	C13	35.1	33.9	13	14.9	22.1	19	15.6	14.1	25.6	24.1	6.6	6.4	0	1.4
	C14	34.6	NA	11.7	NA	22.9	NA	15.7	12.3	25.7	24	5.5	2.3	0	NA
	C15	39.3	39.5	11.7	15	27.6	24.5	12.4	10.8	29.1	27.9	3.8	3.2	0	NA

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.[15] 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.[16] 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.[12] 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.[17-20]

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.[21] 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.[22,23] 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.[22] The average crystallite size of teeth varies from approximately 12 nm (old age) up to 38 nm (young age).[22,24] 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.[25] 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.

Acknowledgment
We acknowledge Professor Dr. Abdul Rashid Hj Ismail (Dean, Faculty of Dentistry, Melaka-Manipal Medical College) Professor Dr. Sumanth Kumbargere Nagraj (Department of Oral Medicine and Radiology, Faculty of Dentistry, Melaka-Manipal Medical College) Associate Professor Dr. Prashanti Eachempati and Mr. Vikram Surendranath (Department of Prosthodontics, Faculty of Dentistry, Melaka-Manipal Medical College) and Assistant Professor Dr. Htoo Htoo Kyaw Soe (Department of Community Medicine, Melaka-Manipal Medical College) for all the logistic and statistical assistance.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

References

1. Norrlander AL. Burned and incinerated remains. In: Bowers CM, editor. Manual of Forensic Odontology. Colorado Springs: American Society of Forensic Odontology; 1997.
2. Fereira JL, Fereira AE, Ortega AI. Methods for the analysis of hard dental tissues exposed to high temperatures. Forensic Sci Int 2008;178:119-24.
3. Delattre VF. Burned beyond recognition: Systematic approach to the dental identification of charred human remains. J Forensic Sci 2000;45:589-96.
4. Merlati G, Savlo C, Danesino P, Fassina G, Menghini P. Further study of restored and un-restored teeth subjected to high temperatures. J Forensic Odontostomatol 2004;22:34-9.
5. Patidar KA, Parwani R, Wanjari S. Effects of high temperature on different restorations in forensic identification: Dental samples and mandible. J Forensic Dent Sci 2010;2:37-43.
6. Moreno S, Merlati G, Marin L, Savio C, Moreno F. Effects of high temperatures on different dental restorative systems: Experimental study to aid identification processes. J Forensic Dent Sci 2009;1:17-23.
7. Rotzscher K, Grundmann C, Benthaus S. The effects of high temperatures on human teeth and dentures. *Int Poster J Dent Oral Me*d 2004;6: p. 213.
8. Muller M, Berytrand MF, Quatrehomme G, Bolla M, Rocca JP. Macroscopic and microscopic aspects of incinerated teeth. J Forensic Odontostomatol 1998;16:1-7.
9. Karkhanis S, Ball J, Franklin D. Macroscopic and microscopic changes in incinerated deciduous teeth. J Forensic Odontostomatol 2009;27:9-19.
10. Palamara J, Phakey PP, Rachinger WA, Orams HJ. The ultrastructure of human dental enamel heat-treated in the temperature range 200°C to 600°C. J Dent Res 1987;66:1742-7.
11. Wang LJ, Tang R, Bonstein T, Bush P, Nancollas GH. Enamel demineralization in primary and permanent teeth. J Dent Res 2006;85:359-63.
12. De Menezes Oliveira MA, Torres CP, Gomes-Silva JM, Chinelatti MA, De Menezes FC, Palma-Dibb RG, *et al*. Microstructure and mineral composition of dental enamel of permanent and deciduous teeth. Microsc Res Tech 2010;73:572-7.
13. Fosse G. A quantitative analysis of the numerical density and the distributional pattern of prisms and ameloblasts in dental enamel and tooth germs 3. The calculation of prism diameters and numbers of prisms per unit area in dental enamel. Acta Odontol Scand 1968;26:315-36.
14. Mortimer KV. The relationship of deciduous enamel structure to dental disease. Caries Res 1970;4:206-23.
15. Costa LR, Watanabe I, Fava M. Study of prismless enamel in non-erupted human deciduous teeth. Braz J Morphol Sci 1996;13:219-223.
16. Chowdhary N, Subba Reddy VV. Dentin comparison in primary and permanent molars under transmitted and polarised light microscopy: An *in vitro* study. J Indian Soc Pedod Prev Dent 2010;28:167-72.
17. Angker L, Nockolds C, Swain MV, Kilpatrick N. Quantitative analysis of the mineral content of sound and carious primary dentine using BSE imaging. Arch Oral Biol 2004;49:99-107.
18. Cuy JL, Mann AB, Livi KJ, Teaford MF, Weihs TP. Nanoindentation mapping of the mechanical properties of human molar tooth enamel. Arch Oral Biol 2002;47:281-91.

19. LeGeros RZ. Calcium phosphates in oral biology and medicine. Monogr Oral Sci 1991;15:1-201.
20. Veis A. Mineralization in organic matrix framework. In: Dove PM, De Yoreo JJ, Weiner S, editors. Biomineralization. Reviews in Mineralogy and Geochemistry. Vol. 54. Washington, DC: The Mineralogical Society of America; 2003.
21. Vasiliadis L, Darling AI, Levers BG. The histology of sclerotic human root dentine. Arch Oral Biol 1983;28:693-700.
22. Kinney JH, Nalla RK, Pople JA, Breunig TM, Ritchie RO. Age-related transparent root dentin: Mineral concentration, crystallite size, and mechanical properties. Biomaterials 2005;26:3363-76.
23. Xu C, Karan K, Yao X, Wang Y. Molecular structural analysis of non-carious cervical sclerotic dentin using Raman spectroscopy. J Raman Spectrosc 2009;25:1205-1212.
24. Leventouri T, Antonakos A, Kyriacou A, Venturelli R, Liarokapis E, Perdikatsis V. Crystal structure studies of human dental apatite as a function of age. Int J Biomater 2009;2009:698547.
25. Metska E, Stavrianos C, Vasiliadis L. Estimation of dental age using root dentine translucency. Surgery J 2009;4:21-8.
26. Savio C, Merlati G, Danesino P, Fassina G, Menghini P. Radiographic evaluation of teeth subjected to high temperatures: Experimental study to aid identification processes. Forensic Sci Int 2006;158:108-16.
27. Prakash AP, Reddy SD, Rao MT, Ramanand OV. Scorching effects of heat on extracted teeth – A forensic view. J Forensic Dent Sci 2014;6:186-90.