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Heat-Related Changes in Tooth Color: Temperature Versus Duration of Exposure

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INTRODUCTION

While a great deal of research has been conducted regarding thermal alterations to bones (e.g., Shipman *et al.*, 1984; Nelson, 1992; Holden *et al.*, 1995; Symes *et al.*, 2005), comparatively little information has been produced specifically regarding the effects of heat on the human dentition (Endris and Berrsche, 1984; Muller *et al.*, 1998; Myers *et al.*, 1999; Schmidt *et al.*, 2005). The study of burned bones has produced standards for documenting the changes in color and texture that bones pass through as it experiences higher temperatures or a greater duration of heat. In general, the bone first darkens, becoming charred. This is eventually followed by calcination of the bone, which renders the bone starkly white as the organic content is lost (Shipman *et al.*, 1984). It is generally assumed that teeth also go through these changes, especially since they do discolor in a manner similar to bones. The following study involved experimentally burning teeth in order to systematically document thermal changes. AU1

Since the make up of the dental hard tissues is notably different than that of bones, reactions to the effects of heating, likewise, should be different. For example, enamel has a much lower organic content than bones, and, therefore, may not go through the same color changes since in bones these changes are related to collagen loss. Moreover, enamel has a different fundamental organization (rods rather than osteons), which may also yield a unique pattern of heat-related alteration. However, Endris and Berrsche (1985) found in their study of burned teeth that the progression in dental color change as a result of thermal exposure was similar to bones. The teeth first turn black and/or brown. These colors then give way to blues and grays, which are eventually replaced with white.

The objectives of the current study are threefold:

(1) To document the gross morphological changes to the dental structures as they are exposed to specific temperatures for specific durations

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(2) To understand the relationships of time and temperature in heat-related alterations
(3) To contribute to an updated standard of heat-related alterations specifically developed for teeth

MATERIALS AND METHOD

A sample of 32 adult human cheek teeth (premolars and molars) was obtained from an oral surgeon. The teeth were extracted during routine dental procedures and placed immediately into a saline solution to prevent dehydration. Before heat alterations were conducted, the teeth were individually cleaned of any adhering soft tissue using dental tools and tap water. Once the teeth were processed they were returned to the saline solution until experimentation could begin.

The teeth were weighed on a digital scale accurate to 0.1 g. They were then placed in a BLUE M™ Lab-Heat muffle furnace where they were exposed to a constant temperature for the entire duration of their heat exposure. Each tooth was placed in an individual crucible to prevent commingling of the specimens. The samples were heated in the muffle furnace at temperatures ranging from 204°C to 593°C (400°F–593°F), at 38°C (100°F) intervals (Table 9.1). The samples were heated for either 30 min or 1 h.

After the heating intervals, the teeth were allowed to cool to room temperature. The gross morphological changes and the effects of dehydration (weight loss due to collagen and water loss) were then observed after the teeth cooled to room temperature. One approach to the study of thermally induced dental changes is to use a scanning electron microscope (SEM) (Fairgrieve, 1994; Muller *et al.*, 1998). This device allows for outstanding observations of morphology, but it uses an electron beam rather than a light to produce an image, making it undesirable for the study of color changes in teeth. Therefore, the current study relies upon the direct observation by the unaided eye as well as with a standard stereoscope (6×–40×). A Munsell Soil Color Chart (2000) was used to determine color values of enamel and dentin after incineration.

TABLE 9.1 Temperature, Duration, and Sample Size for Each Experimental Burn

Temperature, °C (°F)	Duration of heat exposure (min)
204 (400)	30
	60
260 (500)	30
	60
316 (600)	30
	60
371 (700)	30
	60
427 (800)	30
	60
482 (900)	30
	60
538 (1000)	30
	60
593 (1100)	30
	60

Sample size is two (2) for each of the 16 experiments.

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RESULTS

At 204°C (400°F) no significant morphological differences were noticed after 30 min. After 60 min at 204°C, a slight color change was noted in the dentin. The root structures of both teeth changed from the pale yellow color (5 y 8/3) typically associated with unaltered dentin to a yellow (10 yr 7/8) color. No color change was noted in the enamel. During microscopic examination at low power (between 6× and 40×), slight enamel flaking was noted around the cementoenamel junction (CEJ). No other differences were noted. Average weight losses due to dehydration are presented in Table 9.2. AU2

Major color changes occurred in specimens incinerated at 260°C (500°F) for 30 min. The enamel exhibited a very pale brown (10 yr 8/2) color. The dentin exhibited the greatest amount of change turning a dark reddish brown (2.5 yr 2.5/3) color. This is in stark contrast to the first test at 204°C for 30 min when the dentin showed no signs of color change. Interestingly, the enamel at the CEJ appeared to be translucent. Accordingly, the dark reddish brown color of the dentin could be seen through the enamel. Slight enamel flaking was again noted around the CEJ. Upon microscopic examination it appeared as though the enamel of the crown was being detached from the root structure (Figure 9.1). The only difference between specimens incinerated for 60 min, as opposed to 30 min, was that the enamel appeared to be slightly darker (10 yr 8/2). All other attributes were consistent with the 30-min incineration.

TABLE 9.2 Average Percentage of Weight Loss for Teeth from Each Duration

Temperature, °C (°F)	Average percentage of weight loss at 30 min	Average percentage of weight loss at 60 min
204 (400F)	16.3	13.1
260 (500)	17.3	17.3
316 (600)	13.3	23.1
371 (700)	16.9	21.3
427 (800)	37.9	22.5
482 (900)	25.1	30.9
538 (1000)	27.4	24.1
593 (1100)	36.0	33.3

FIGURE 9.1 Crown patina and flaking/separation of crown at cementoenamel junction (CEJ). (see Plate 19)

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No notable changes occurred between samples incinerated at 206°C and 316°C (600°F) for a period of 30 min. The enamel and dentin discoloration remained consistent and flaking around the CEJ was still apparent.

Several major changes occurred during the 371°C (700°F) interval. The most significant change was to the color of the dental hard tissues. After the incineration the enamel exhibited a very dark grayish brown (10 yr 3/2) color with a glossy appearance. The gloss of the enamel gave it a metallic appearance. Upon magnification, many small nonuniform cracks occurred over the majority of the enamel. This patina-like appearance occurred on nearly every aspect of the crown (Figure 9.1), with the exception of the CEJ. Major changes continued to occur around the root structure. The color of the root dentin turned from very pale brown to black (GLEY-1 2.5/N) color. No major morphological differences were noted between the time intervals. The only difference between time intervals at this temperature was the percentage of weight lost.

Several major degradational changes affected the dental hard tissues of both the crown and the root structures at 427°C (800°F). The crowns in three of the four specimens separated entirely from their roots. The CEJ around the fourth specimen showed extreme enamel flaking and appeared to be almost completely separated from the root. The color of all the crowns remained constant from the tests conducted during the 371°C interval (10 yr 3/2). Likewise, the patina-like appearance continued to be present. It should also be noted that the crowns were extremely friable and were easily subject to breakage during the postincineration handling and analysis. The root structures AU3 of the 30-minute remained unchanged. However, the color of the roots from the 60-minute AU4 incinerations and exhibited an olive brown (2.5 y 4/3) color. A significant change was the light gray color (5 y 7/1) of the mantle dentin from the olive brown color exhibited by the remaining dentin of the root structure (Figure 9.2). The morphology of the root structures remained fairly unaltered with the exception of a few cracks.

For the most part, at 482°C (900°F) the color of the specimens remained unchanged from the previous incineration cycle. The only difference worth noting is the color of the crown between the two time intervals. While specimens that were incinerated for 30 min remained unchanged, the specimens that were incinerated for 60 min exhibited a light gray (5 y 7/1) color. In addition, the crowns of the specimens incinerated at 482°C had separated from their roots and were extremely

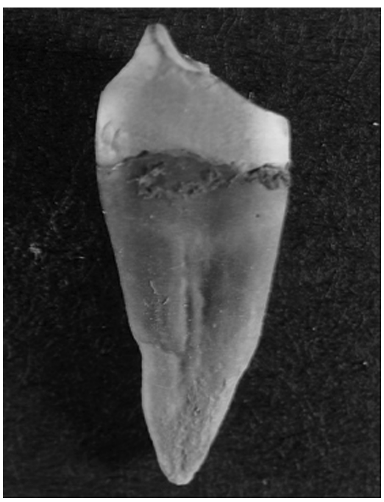

FIGURE 9.2 Differences in dentin color above and below the cementoenamel junction (CEJ). (see Plate 20)

friable. The glossiness of the crown noted at lower temperatures was absent from these crowns. The structural integrity of the roots remained similar to that described for the 427°C group.

Four changes were noted during the 538°C (1000°F) incinerations all of which applied to all specimens regardless of the time interval. Two of these changes were apparent in the crown. First, the crown color changed to a light gray (5 y 7/1) color with patches of grayish brown (2.5 y 5/2) and gray (2.5 y 6/1). Second, the integrity of the crowns was severely compromised. In all specimens the enamel was completely disintegrated into many small fragments. Third, the color of the root structures was in the process of changing from olive brown to patches of light gray (5 y 7/1) and gray (2.5 y 6/1) colors. Finally, the root apices were highly friable and broken off from the rest of the root.

Only minor changes were observed when comparing the 538°C and 593°C (1100°F) incinerations. The crowns from all specimens, regardless of the time interval, were highly fragmented and still exhibited the light gray color previously described. The color of the root structures for all specimens was still in transition from an olive brown to a light gray (5 y 7/1) to the white color typically associated with calcined bones (the Munsell edition that was utilized during the experiment did not have a color value that accurately described the calcined while color). The root apices on all specimens were completely disintegrated.

DISCUSSION

The general progression of the dentin color change from lower temperature to higher was (1) typical light yellow color of unaltered dentin; (2) black; (3) brown/olive; (4) gray; and (5) white. This finding is consistent with what was reported by Endris and Berrsche (1985). A steady change was observed in the color of the dentin, although the mottling of the dentin (Figure 9.1) may cause confusion if the root has become fragmented. Therefore, it is recommended that a careful examination be conducted upon the root structure if it has become fragmented.

It is worth noting that when working with dental hard tissues that have been heat-altered, the root structure seems to be the most reliable source of information for two reasons. First, dentin seems to be much less susceptible to the effects of heat alteration than enamel. The examination of specimens altered in the upper heat ranges revealed that the root structure remained relatively intact. The only exception to this observation is the apical portion of the root structures that tended to disintegrate at higher temperatures. Second, the integrity of the enamel tissue begins to minimally flake away from the cementoenamel junction as early as half an hour at 204°C. At 427°C–482°C the crown enamel is extremely friable and susceptible to breakage. Similarly, Endris and Berrsche (1985) noted that the structural integrity of the root was much more reliable than that of the crown enamel. In addition, the extreme friability and small enamel fragments may make color assessment very difficult when compared to an entire specimen of dentin. Finally, the progression of colors exhibited on the roots is much more static and tend to exhibit only one color at a time. If multiple colors are exhibited on the root, which from our experience is not more than two colors, a majority of the root is dominated by one color. Conversely, some enamel fragments exhibited as many as three colors during some of the upper-limit heat tests. A complete listing of observed colors and morphologies is given in Tables 9.3 and 9.4.

One of the most notable findings during experimentation was the continuity exhibited between specimens incinerated for 30 min and specimens incinerated for 60 min. A majority of the morphological changes that were observed during the half-hour interval were also observed after an hour of incineration. This seems to suggest that a longer incineration period does not necessarily mean that there will be more observable changes. The greatest amount of change was observed within the first 30 min of incineration. No significant changes occurred during the last 30 min of

TABLE 9.3 Enamel Dentin Color and Features at 30 min

Temperature, °C (°F)	Enamel		Dentin	
	Munsell value	Feature	Munsell value	Feature
204 (400)	No change	CEJ flaking	5 y 8/3	No change
260 (500)	10 yr 8/2	CEJ flaking	2.5 yr 2.5/3	No change
316 (600)	10 yr 8/2	CEJ flaking	2.5 yr 2.5/3	No change
371 (700)	10 yr 3/2	Enamel gloss Patina	GLEY-1 2.5/N	No change
427 (800)	10 yr 3/2	Separation of crown Extreme CEJ flaking Patina	GLEY-1 2.5/N	No change
482 (900)	10 yr 3/2	Crown separation Extreme CEJ flaking Patina	GLEY-1 2.5/N	No change
538 (1000)	Multiple colors	Enamel Disintegration	5 y 7/1 and 2.5 y 6/1	Apical deterioration
593 (1100)	Multiple colors	Enamel disintegration	5 y 7/1 and 2.5 y 6/1	Extreme apical deteriorations

TABLE 9.4 Enamel and Dentin Color and Features at 60 min

Temperature, °C (°F)	Enamel		Dentin	
	Munsell value	Feature	Munsell value	Feature
204 (400)	No change	CEJ flaking	10 yr 7/8	No change
260 (500)	10 yr 8/2	CEJ flaking	2.5 yr 2.5/3	No change
316 (600)	10 yr 8/2	CEJ flaking	2.5 yr 2.5/3	No change
371 (700)	10 yr 3/2	Enamel gloss Patina	GLEY–1 2.5/N	No change
427 (800)	10 yr 3/2	Separation of crown Patina	2.5 y 4/3 (mantle = 5 y 7/1)	No change
482 (900)	5 y 7/1	Extreme enamel degradation	2.5 y 4/3 (mantle = 5 y 7/1)	No change
538 (1000)	Multiple colors	Enamel disintegration	5 y 7/1 and 2.5 y 6/1	Apical deterioration
593 (1100)	Multiple colors	Enamel disintegration	5 y 7/1 and 2.5 y 6/1	Extreme apical deteriorations

incineration suggests that a longer incineration period does not necessarily cause more alterations to dental hard tissues.

However, a difference does exist between 30- and 60-min incineration intervals between the average losses of weight due to dehydration. Overall, the teeth incinerated for 60 min lost more weight than the teeth incinerated for 30 min. For example, teeth incinerated for 1 h lost an average of 20% of their weight at 316°C and above. This 20% loss did not occur in the 30-min specimens until temperatures reached 427°C–483°C. Finally, one shared characteristic between the two incinerations is the steady, progressive weight loss from the lowest temperature tested to the highest temperature. On average, both incinerations lost between 13–16% of their weight at 204°C and 33–36% of their weight at 593°C.

CONCLUSION

The application of heat to dental hard tissues produces changes in color that are similar, but not identical, to those reported for bones. A steady change in the color of both dentin and enamel was observed as temperatures were increased. In addition, the loss of weight due to dehydration is directly proportional to a rise in temperature and increased duration of heat exposure. In general, the dentin provides a more sensitive indicator of heat alteration than the enamel, which eventually shatters and becomes difficult to analyze.

When comparing temperature and duration, it appears that temperature is the more important variable when it comes to interpreting tooth color. Teeth that were burned for a longer period of time, but at a lower temperature, did not mimic teeth burned at higher temperatures, despite the fact that the dehydration increased.

Additional research is needed to determine if the observed trends presented herein remain consistent after very long exposures to lower temperatures (i.e., over 1 h). This study should use time intervals of less than half an hour in order to determine more precisely when the degradation of dental hard tissues commences.

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Query No	Contents
AU1	Reference Endris and Berrsche (1984) is cited in the text but not provided in the list. Please add it to the list or delete it from the text.
AU2	Should "5 y 8/3" be changed to "5 yr 8/3" here and in subsequent occurrences? Please advise.
AU3	Should "The root structures of the **30-minute** remained unchanged" be changed to "The root structures of the **30-minute incineration** remained unchanged"? Please advise.
AU4	Shall we change "However, **the color of the roots** from the 60-minute **incinerations and exhibited** an olive brown (2.5 y 4/3) color" to "However, **the roots** from the 60-min incinerations **exhibited** an olive brown (2.5 y 4/3) color".