

Effects of high temperatures on different dental restorative systems: Experimental study to aid identification processes

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DOI: 10.4103/0974-2948.50883

Abstract

This “*in vitro*” study was to observe the effects of high temperatures on teeth restored by (1) amalgam overlaying glass ionomer bases, (2) composite/adhesive system overlaying glass ionomer bases, (3) ZnO modified temporary filling material vs. unrestored teeth. Fifty un-restored teeth (control group), 50 teeth with class I amalgam restorations and glass ionomer bases, 50 teeth with class I composite/adhesive system restorations and glass ionomer bases and 50 teeth with class I ZnO modified temporary filling material restorations were placed in a furnace and heated at a rate of 10°C/min. The effects of the predetermined 200, 400, 600, 800, 1000 and 1200°C temperatures were examined macroscopically and then observed microscopically by means of a stereomicroscope. Our observations showed that the class I restorations made of amalgam on glass ionomer bases as far as the class I restorations made of ZnO modified temporary filling material can be identified till 1200°C because they maintain their shape despite the disintegration of the crowns, whilst the class I composite/adhesive system and the underplayed glass ionomer bases remained in place in an altered shape.

Key words: Dental identification, dental materials, dental tissues, forensic odontology, forensic sciences, high temperatures

Introduction

Historically teeth and dental materials were studied to aid the identification process of human remains: particularly forensic odontology has shown to be useful when a damage caused by the heat occurred.^[1-3] In fact, teeth are the components of the body that often survive severe fires because of their high resistant composition and also because they are protected by the soft and hard tissues of the face and other materials or elements which may be present.^[4-13]

Norrländer^[14] classified body burns in five categories: (1) superficial burns, (2) destroyed epidermis areas, (3)

destruction of the epidermis and dermis and necrosis areas in underlying tissues, (4) total destruction of the skin and deep tissues and (5) burned remains. Since the destruction of burned victims of the third, fourth and fifth category, is extensive, such remains cannot be identified by conventional methods like visual recognition or fingerprints. In these cases the odontologists are called to assist the identification by means of a comparison between the postmortem records of the burned, charred or incinerated individual teeth and the antemortem clinical history supported by the oral-maxillo-facial system.^[6,15]

Under this situation, when the postmortem conditions of the evidence or the quality and quantity of the antemortem

information are no effective on the identification process of burned victims, the usage of other methods applied on certain dental specific tissues exposed to high temperatures is very limited.^[16-18]

From experimental literature, macroscopic color variations of unrestored teeth could be related to the temperature rise and time of application, from natural color through black, brown, blue, gray, white and finally pink; then, it was relieved that the temperature levels and the combustion time were inversely proportional to the rate of color changes.^[19] Color change from light yellow to bluish-white, passing through brown, were pointed out also by Merlati *et al.* and Muller *et al.*, when unrestored teeth are exposed to temperatures in the range of 150-1150°C.^[10,20]

At the same temperature range, microscopic variations of unrestored teeth could be detected by SEM, and the enamel and dentin could be identifiable after an exposure temperature of 1000°C for periods greater than 3 hours.^[21] But, Muller *et al.*, pointed out that, in the same conditions, the prismatic structure of the enamel was difficult to identify above the 1100°C while the dentin tubules were identifiable at 1150°C.^[20]

Macroscopic behaviour of dental restorative materials at the range 200-1000°C was performed by Robinson *et al.* They pointed out that glass ionomers were decomposed at 200°C, while the compomers, and three different composite materials were deeply altered at 200-500°C.^[22] Microscopic behaviour of dental restorative materials were studied by Bush *et al.*, where they identified the remains of ten different composite materials after a 900°C exposure for 30 minutes by EDS-SEM.^[23] But these studies were performed on samples of restorative materials.

First experimental studies on restored teeth were performed by Merlati *et al.* and Savio *et al.*, which reported on teeth filled by amalgam or composite exposed to temperature between 200-1100°C. They pointed out that a macroscopic observation could identify composite fillings till 800°C and amalgam fillings till 1000°C.^[10,24,25] The same experience was performed also by Bose *et al.* that studied amalgam, composite and glass ionomers.^[23] But this studies did not involved bases under restorative materials neither temporary fillings, so the aim of this study was to observe the effects of high temperatures (200-400-600-800-1000-1200°C) on teeth restored by (1) amalgam on glass ionomer bases, (2) composite/adhesive system on glass ionomer bases, (3) ZnO modified temporary filling material vs. unrestored teeth.

Materials and Methods

200 teeth (premolars and third molars), extracted for orthodontic and periodontal purposes, no showing any

cavities, restorations, endodontic treatments, pulpar pathology and congenital malformations, were collected once the research was approved by the Ethics in Humans Committee of the Universidad del Valle in comply with Article 11 of Resolution 008430 of the Colombian Republic Social Protection Ministry^[26] and the ethic principles for medical investigations in human beings indicated by the World Medical Association in Helsinki's Declaration.^[27] After the authorization from the School of Dentistry directives and patients signature, the samples were collected at the Oral Surgery Clinic from the Odontology School of the Universidad del Valle.

After the extraction, every tooth was washed with non sterile water to eliminate blood residues and introduced in a dark container with a disinfection solution T Chloramine at 5% (100 grams of sodic Tosilchloramine diluted in 2 liters of distillated water) for one week. Later, the teeth were stored in a 0,9 % sodium chloride aqueous solution, at room temperature, with a relative humidity of 100%, changing the solution every 2 weeks according to the ISO/TS 11405/2003.^[28]

The 200 teeth were divided in 4 groups of 50 teeth as follows: Group 1 consisted of unrestored teeth as control group, Group 2 consisted of teeth restored with amalgam fillings (GS-80 SDI®) on glass ionomer base (Vitrebond® 3M-ESPE), Group 3 consisted of teeth restored with composite/adhesive system (Z100®/Single Bond® 3M-ESPE®) on glass ionomer base (Vitrebond® 3M-ESPE), and Group 4 consisted of teeth restored with ZnO modified temporary filling material (Coltosol® Coltene-Whaledent®). An operator proceeded to make a Class I cavity on the samples by a high speed diamond bur at a depth of 3 mm, mesiodistal length of 3 mm and bucolingual length of 2 mm. The cavity was disinfected by a 12% hydrogen peroxide aqueous solution. Then, the teeth were restored following the producers and manufacturer's instructions at the state of the art.

Once fillings were performed, teeth were set in individual custom made trays made of dental investment material (Cera-Fina® Whipmix®) to facilitate their manipulation according to the prototype established by the Dental materials Unit of Odontostomatology Department of Pavia University (Italy), and they were exposed to direct heat inside an oven with a muffler chamber (Thermolyne®) previously calibrated to six different temperature degrees (200°C, 400°C, 600°C, 800°C, 1000°C and 1200°C) at an increasing rate of 10°C per minute. As soon as each target temperature was reached, the samples were removed from the oven and allowed to cool to room temperature. Once they were cold, they were sprayed with hair shellac with the purpose of giving them certain degree of resistance and facilitate their handling.^[6,15]

An examiner observed and described the macro structural



Figure 1: Restored teeth with amalgam filling subjected to 200°C. Amalgam showed an alteration of the marginal seal, loss of brightness and small bubbles on the surface



Figure 2: Un-restored teeth subjected to 400°C. Enamel fissures in the cervical area and dark brown color of the cement



Figure 3: Un-restored teeth subjected to 800°C. Separation of the enamel in the cervical area. Fissures of the cement which show a blue-gray colour

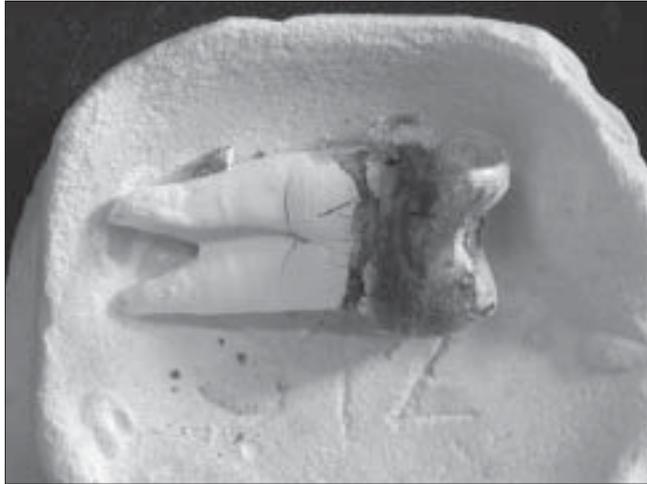


Figure 4: Un-restored teeth subjected to 1000°C. 1. Separation of the enamel in the cervical area and cracks of the enamel and root



Figure 5: Restored teeth with amalgam filling subjected to 400°C. Bubbles in amalgam, marginal contraction of amalgam and fissures of the enamel



Figure 6: Restored teeth with amalgam filling subjected to 800°C. Contraction and cracks in amalgam filling

changes of the dental tissues and materials by direct vision of the samples; finally some images were taken by a digital camera (Olympus C3000).

Results

Group 1

At 200°C there is a loss of brightness on the enamel and cement; on the crown some parts showed a slight brownish color and some cusps turn white [Figure 1]. At 400°C the crown showed a darkest tonality, enamel fissures particularly in the cervical area, and the cement acquired a brown color [Figure 2]. At 600°C the crown presented a dark brown color with black stains, separation of the enamel-dentine interface at the level of the cervical margin, longitudinal cracks of the enamel and the cement; at the root level can be observed longitudinal cracks and a brown color of the cement. At 800°C the crown was gray with the cusps colored white, the cement showed a blue-gray color [Figure 3]. At 1000°C in some teeth there was a fragmentation of the enamel, the dentine showed a white color with blue-gray stains, and the cement turned to a chalky white color with cracks [Figure 4]. At 1200°C the enamel and the dentine were fragmented in most of the samples and longitudinal and transversal cracks of the root were observed. In some teeth exposition of the pulp chamber was observed, allowing the identification of changes like pulp calcinations and inner transversal cracks of the dentine continuing in the root.

Group 2

At 200°C and at 400°C the amalgam showed an alteration of the marginal seal, loss of brightness and bubbles on the surface [Figures 1 and 5]. At 600°C the amalgam showed an opaque black color and an increased alteration of the marginal seal. At 800°C the amalgam showed a corrugated surface with fissures between amalgam and dental tissues [Figure 6]. At 1000°C there were some cracks in the black filling amalgam [Figure 7]. At 1200°C a fragmentation of the crown in more than half of the samples was observed. The black colored amalgam presented fractures and cracks.

Group 3

At 200°C the composite filling showed marginal retraction and brown color. At 400°C there was an increase in the marginal retraction [Figure 8]. At 600°C the color of the composite turned black-grayish, some cracks appeared and a dislodgement of the obturation in some teeth occurred [Figure 9]. At 800°C the composite showed a chalky white color; in most of the samples there was a dislodgement of the fillings and exposition of the glass ionomer bases, which showed a black color, with cracks and marginal retraction [Figure 10]. At 1000°C the crown acquires a dark gray color; in a half of the samples, enamel pulverization and root fracture occurred, so the exposed dentine is white with gray-bluish stains. At 1200°C the crown changes to a white-

grayish color and in most of the sample a dislodgement of the filling occurred [Figure 11].

Group 4

At 200°C the teeth showed cracks on the surface and dimensional expansion of the ZnO modified temporary fillings for water evaporation, growth of crystals and air capture. At 400°C a break of the cervical enamel occurred; then, we observed longitudinal fissures on the enamel, and brown color of the fillings [Figure 12]. At 600°C the zinc oxide cement was dark gray with cracks and dimensional contraction by several losses of water, fracture of some crystals and agglomerated particles of zinc. At 800°C the material was chalky white and one third of the samples showed a dislodgement of the fillings. At 1000°C the temporary cement showed a white chalk color and cracks, but in the large amount of the samples a dislodgement of the fillings occurred. At 1200°C samples fragmentation of enamel and dentine, and transversal cracks on the root occurred [Figure 13].

Discussion

Within the behavior of the tissues and dental restorations observed in this research, the change of color was the most common characteristic for each range of temperature, and this was directly related with the level of carbonization and incineration of teeth. In the unrestored teeth, the crown turned to a bright brown color at 200°C, therefore the changes of color in the crown were from dark brown at 400°C, brown with black pigments at 600°C, gray with black pigments at 800°C, gray at 1000°C and gray with white veins at 1200°C (this veins are generated by enamel incomplete incineration, which lost its translucent aspect). In the same way, the roots changed their color from dark brown between 400°C and 600°C, white-bluish at 800°C and white chalk between 1000°C and 1200°C. All of these changes of color were also described by Merlati *et al.*^[10,24] the loss of enamel brightness was also recorded by Gunther and Schmidt -quoted by Röttscher *et al.*,^[11] as "invisible carbonization".

In relation to the dental restorations, the amalgam at 200°C and 400°C lost its shine due to the mercury evaporation^[10] and showed an opaque black color from 600°C [Figure 6].

At higher temperatures, we recorded a silvered metallic shine on the roots probably due to a mercury deposition as defined by Gunther and Schmidt^[11] Merlati *et al.*,^[10,24] described pink pigments on the roots and crowns between 1000°C and 1100°C, same as it appeared in this research, but at microscopic observation these pigments were seen in the enamel around the amalgam between 600°C and 1200°C [Figure 6]. By the same microscopic observation, it was possible for us to observe pink pigments in the cavity dentine at 600°C and in the cement at 800°C. Such phenomenon was supposed to be due to volatile copper



Figure 7: Restored teeth with amalgam filling subjected to 1000°C. Cracks of the enamel. Silver bullets and contraction in amalgam filling



Figure 8: Restored teeth with composite filling subjected to 400°C. Composite bright brown color with white pigments



Figure 9: Restored teeth with composite filling subjected to 600°C. Cracks of the enamel. Marginal contraction (gaps between enamel and composite) and composite black colour with gray pigments



Figure 10: Restored teeth with composite filling subjected to 800°C. Marginal contraction and incinerated composite with cracks and white color



Figure 11: Restored teeth with composite filling subjected to 1200°C. Incinerated composite filling. Cracks of the enamel and the root. See separation of the enamel in form of a skullcap



Figure 12: Restored teeth with zinc oxide modified cement subjected to 400°C. Fissures in the filling



Figure 13: Teeth restored with zinc oxide modified cement subjected to 1200°C. Filling dislodgment. See dentine remain and occlusal cavity

oxides at 450°C.^[29,30] Another important feature referring to color in amalgam restored teeth is the formation of a golden thread that surrounds the occlusal surface and the cusps between 800°C and 1200°C [Figure 6]; we supposed that this phenomenon was associated to mercury oxide vapors in reddish and yellowish tones or copper oxides and silver oxides from the 962°C.^[29-31]

The composite restorations turned to a bright brown color with white veins at 400°C [Figure 8], as described by Merlati *et al.*, like yellowish brown^[24] and then increased its shine. At 600°C the resin changed to a grayish black color (given by gray veins) [Figure 9], due to the acrylic matrix combustion, according to Merlati *et al.*,^[10] then, a white chalk color [Figure 10] was observed starting from 800°C up to 1200°C.

Finally, the ZnO modified cement changed its color at 600°C, turning dark gray, and being more dazzling at 1000°C [Figures 12 and 13], such as referred by Gunther and Schmidt.^[11]

In all the unrestored teeth, fissures were observed in the enamel starting from 400°C, which turned in cracks at 600°C as it was described by Gunther and Schmidt^[11] and by Nossintchoux. -quoted by Moya *et al.*^[1] as far as the crown remains at 1200°C [Figure 4]. The enamel fragmentation is described starting at 600°C and its disintegration in some teeth at 1200°C. In the tooth's cement we observed fissures at 400°C and cracks starting from 600°C until 1200°C; furthermore, we observed longitudinal cracks that continue to the root dentine and cause in some specimens fragmentation of the roots, which coincides with the description by Merlati *et al.*^[10] and that in many cases caused root fracture lines. But, Nossintchoux described root fissures and cracking of the roots starting from 175°C.^[1]

In the restored teeth, we observed cracks on the dentine

that continued from the enamel and the cement, and which became visible by the fracture of the crown and of the root starting from 600°C. In the same way, as long as the exposition to high temperatures continues, the dental tissues lost their integrity, and so at 800°C the carbonization caused a decrease in the root volume^[1-25] [Figures 11 and 13] and in the crown a separation of the enamel in form of a skullcap, phenomena that occurred in some specimens from 800°C until 1200°C [Figure 13]. Gunther and Schmidt^[11] in their studies reported that this separation occurred at 400°C, while Merlati *et al.*,^[10] described it starting from 800°C. It was possible, in some specimens between 400°C and 800°C to observe remains of the incinerated pulp tissue, finding that was described by Gunther and Schmidt.^[11] For this, restored teeth appeared to show cracks and crown shattering at lower temperatures compared with unrestored teeth.

At 200°C the amalgams and composite fillings showed a marginal contraction probably due to the evaporation of the mercury and loss of the organic matrix, as it was described by Moya *et al.* and Merlati *et al.*^[1,10] At 400°C all the permanent restorative systems showed a marginal contraction, while the ZnO modified cement showed an expansion. In the amalgam fillings, cracks were observed since 600°C, and starting from 800°C the cracks become macroscopically visible until 1200°C. Some specimens showed fractures of the fillings starting from 600°C and dislodgment of it since the 1000°C, similar to Merlati *et al.*^[24] As for the resin, they observed cracks starting from 600°C and up to 1200°C. Some specimens showed dislodgment of the fillings since the 600°C and fractures at 1000°C. The ZnO modified cement showed cracks starting from 200°C, dislodgment since 800°C and fractures at 1000°C [Figure 12].

Concerning the fillings surface, between 200°C and 400°C, the amalgam showed a corrugated or blistered surface in all of the teeth, which was due to the apparition of small nodules by alloy dissociation [Figure 5], where the mercury evaporated through gaseous bubbles, which form blisters or nodules when temperature decreases. This condition is also reported by Merlati *et al.*, at 200°C.^[10] It is important to mention that the nodules vary their size when the temperature increases until the mercury evaporates completely from the alloy in an boiling rank that goes from 39°C up to 360°C;^[1] from then on the evaporated mercury drags silver particles, that from 800°C confirm what Gunther and Schmidt. called "silver bullets"^[11] [Figure 7]. The composite fillings turned corrugated when temperature increases until they incinerated at 1000°C [Figure 10]. The modified zinc oxide turned also corrugated [Figures 12 and 13].

We would like to emphasize that the glass ionomer bases did not affected the identification of the restorations because no delamination and/or mixing phenomenon were observed.

Our study did not take into account possible variables present in reality such as the protection provided by the

soft and hard tissues surrounding dental elements and/or dental appliances present in the mouth. Such structures protect the teeth from direct exposure to fire that would otherwise produce an early catastrophic evaporation of the organic component with consequent separation of the crowns. In our experiments such a phenomenon was observed above 800°C. In our experiments, once the pre-determined temperatures were reached, the samples were removed from the oven and allowed to cool at room temperature. The materials were therefore subjected to only one controlled and limited thermal shock. In reality many factors may further complicate the effect of the fire on the tissues and materials such as the time of exposure to the fire, the type of fire, the speed of increase in temperature as well as the substances used to the extinguish the fire. All of these factors need to be considered in evaluating the specimens for forensic analysis.

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Source of Support: Nil, Conflict of Interest: None declared