OBSERVATIONS ON DENTAL PROSTHESES AND RESTORATIONS SUBJECTED TO HIGH TEMPERATURES: EXPERIMENTAL STUDIES TO AID IDENTIFICATION PROCESSES

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ABSTRACT

In large scale disasters associated with fire the damage caused by heat can make medico-legal identification of human remains difficult. Teeth, restorations and prostheses, all of which are resistant to even quite high temperatures can be used as aids in the identification process. In this project the behaviour and morphology of teeth and dental prostheses exposed to a range of high temperatures was studied.

Healthy teeth, dental restorations and prostheses were placed in a furnace and heated at a rate of 30°C/min and the effects of the predetermined temperatures 200, 400, 600, 800, 1000 and 1100°C were examined by stereomicroscopy and scanning electron microscopy (SEM). Our observations show that some prostheses and restorative materials resist higher temperatures than theoretically predictable and that even when a restoration is lost because of detachment or change of state its ante-mortem presence can be confirmed and detected by both stereomicroscopic examination and SEM of the residual cavity. We further conclude that a reasonably reliable estimation of the temperature of exposure can be made from an analysis of the teeth and restorative materials. **(J Forensic Odontostomatol 2002;20:17-24)**

Keywords: Identification, forensic odontology, dental materials, dental prostheses, dental restorations

INTRODUCTION

Forensic dentistry has been shown to be of fundamental importance[1] in medico-legal investigations aimed at identifying human remains of mass disasters involving high temperatures.

One of the first studies on identification of human remains by dental examination goes back to 1897 and was carried out following the fire at the Bazare de la Charité.[2] This study laid the basis for the awareness that the morphological features of the oral cavity e.g. changes associated with age, developmental disorders, pathological conditions and a number of dental interventions, are numerous and varied enough to constitute a unique and non-recurring picture. Furthermore, both teeth and dental interventions have a large number of features each of which, alone or in combination, can contribute to a positive identification.

While 16-18 matching elements are usually required for a positive identification by fingerprint analysis, an appropriate number of comparison features for dental identification has not yet been established, precisely because of the enormous number of possibilities. A minimum of 12 points of correspondence has been suggested in order to make a positive identification,[3] but Simpson *et al*.[4] emphasized the importance the qualitative aspect of a finding has compared with a quantitative value and that, in consequence, some characteristic forms of dental treatment must be considered highly significant.

The temperatures reached in many fires vary depending on the site (in a closed environment or in the open), the nature of the oxidant, the duration of the combustion, and the action of any fire-extinguishing products used.[5,6] Indeed, it has been found that in road traffic accidents, strong ground winds and the 'chimney stack effect' of piled up car wrecks can raise the temperature of combustion of petrol to above the known mean range (800-1100°C).[7]

Teeth are skeletal components that readily survive severe fires, not only because of their particularly resistant composition, but also because they are protected by the soft tissues of the face and other materials or elements sometimes present (e.g. glasses, crash-helmet) which cause a delayed and different increase in temperature in the oral cavity,[8] although this effect decreases as the "protection" burns.[9]

Finally, it has been noted that the dental remains of victims of some air disasters associated with fierce fire have many dentinal and enamel fractures which are different from and more numerous than those found in road traffic accidents. It has been hypothesized that this phenomenon is caused by a combination of high temperature and impact force, but this is still under investigation.[10, 11]

Besides direct visual inspection of the dental remains, radiographic examinations are very important in order to reach an identification. There are, however, two problems in carrying out radiography of maxillary or mandibular fragments: the lack of soft tissues often leads to overexposure and, given the absence of the cranium, it is difficult to achieve correct alignment of the fragments.[12]

Optical and/or electron microscopy of the dental parts can be useful for two main reasons: to identify the changes the dental tissues have undergone in order to estimate the temperatures they were exposed to and, furthermore, to characterize the different types of dental treatments.[13]

Dental identification is traditionally based on the comparison of the odontogram and/or dental record of a known person with that reconstructed from human remains and it is essential that there exists an ante-mortem record. It is important to emphasize that radiographic investigations can provide unique and characteristic information on individual anatomy even in the absence of dental treatment.[14] For this reason the Defense Department of the U.S.A. has catalogued the orthopantomographs of all recruited military staff. These images are stored in specific archives and retained when the person leaves the armed forces.[8]

Dental prostheses, besides being of great help in personal identification (from analysis of the type, shape, size, surface features, etc.), can also provide information on the country of manufacture, by analysis of the materials used. This was clearly described in a recent article by Marella and Rossi1[4] who described various factors that can negatively affect the tracing of components of prostheses. The presence of environmental debris and/or products of previous casting, mixtures of metals or traces of elements not registered by the manufacturer may affect the identification of the components of the prostheses.

In this context we considered it important to carry out an experimental study to learn more about the changes that dental remains, restorative materials and prosthetic devices undergo when exposed to a range of temperatures, with the aim of advancing the knowledge base used in the processes of identification of victims involved in fires.

MATERIALS AND METHODS

Various specimens were used for the study: (1) one healthy, unrestored tooth, (2) one molar with one previously existing class I restoration in amalgam and one added class V restoration in amalgam (Valiant*) (specifically carried out for the research), (3) one premolar with a class V restoration of the vestibular surface in composite (Spectrum T.P.H.© **), and one with a class V restoration of the lingual surface with compomer (Dyract AP© **), (4) one fixed prosthetic crown or bridge of aesthetic resinous material (polycarbonate, acrylic based products or composite materials),*** (5) one fixed prosthetic crown or bridge of metal alloy covered with aesthetic resinous material (acrylic based products or composite materials),*** (6) one removable partial prosthesis made of base metal casting alloy and denture base acrylic resins,*** and (7) one fixed prosthetic crown or bridge in metal-feldspatic ceramic dental systems.***

After extraction, the teeth were preserved in normal saline at room temperature for one week. Some of the amalgam fillings in the teeth extracted were old while other restorations such as the class Vs with composite and compomer material were done deliberately for the experiment.

The tests of exposure to heat were carried out in a preheating oven (CF4),† and the specimens were heated to one of the six pre-determined temperatures - 200, 400, 600, 800, 1000 and 1100°C, at a rate of increase of 30°C/minute. As soon as each target heat had been reached the samples were removed from

* *Caulk-Dentsply, Milford, DE, USA.*
** *De Trey Dentsply, Kostanz-D.*
*** *undefined production samples resulting from extraction therapies at the Dental Clinic.*
† *Dentalfarm, Turin, Italy*

the oven and allowed to cool to room temperature. The total time of exposure for each set of specimens was 6,6 mins to reach 200°C; 13,3 mins to reach 400°C; 20 mins to reach 600°C; 26,6 mins to reach 800°C; 33,3 mins to reach 1000°C; 36,6 mins to reach 1100°C. About 10 secs were needed to remove the sets of samples from the oven.

Two complete sets of specimens (groups one to seven) were each subjected to each temperature and 108 observations were made (groups two and three each had two restorations to test). The source of specimens in groups four, five, six and seven, was from the Exodontic Clinic, but in compliance with the rules concerning medical and dental devices in force in Italy and contained in the CE directive 93/42, the materials used have to be standardised. In effect then, for these specimens it was not possible to define the exact composition, but it was possible to assign them to known groups of compounds or alloys: group (4): polymer-based crown and bridge materials;[15] group (5): dental casting gold alloys or dental casting alloys with noble metal content of at least 25% but less than 75%[16]; group (6): dental base metal casting alloys: cobalt-based alloys or nickel-based alloys;[17] group (7): metal-ceramic dental restorative systems[18]. Some metallic devices showed a welded portion which involved brazing materials and alloys whose general composition complied with the Standard.[19] Since the sample collection was difficult because of the great number required, it was impossible to standardize the dimensions of the restorations found in extracted teeth, or the prostheses encountered. All of them were in any case of sufficiently useful dimensions to give reliable data. The restorations created for the project were about 6^3mm in volume (3x2x1 mm.).

Each sample was examined macroscopically and then observed by stereomicroscopy* and SEM† after gold metallization.

RESULTS

The macroscopic and microscopic findings for each specimen at different temperature levels were as follows:

1. Intact teeth:
   200°C: there was a macroscopically evident change of colour, tending to yellow/light brown, of both the root and the crown; stereomicroscopic examination revealed microfractures of the root.
   400°C: the surface colour of the enamel tended to grey whereas that of the cementum and dentine ranged from black to brown; stereomicroscopy (32X) showed cracks and fissures not only in the root but also on the enamel surface.
   600°C: macroscopic evaluation showed black discolouration of the whole tooth, a shattered part of the crown and detachment of the enamel wall from the underlying dentine. Deep cracks were evident in the root.
   800°C: the crown had shattered into pieces whereas the root remained whole. The surface colour of the tooth was chalky-white while its interior was grey-blue. The cracks in the root were more marked.
   1000°C: the crown was reduced to fragments while the root, still whole, was pinkish-white with deep cracks and numerous microfractures; what remained of the pulp cavity appeared greyish-black.
   1100°C: macroscopic observation showed the crown reduced almost to dust and the root portion shattered. The larger fragments were chalky-white with some areas of a pinkish shade and, coinciding with the cementum, a grey colour was seen.

2. Class I and V amalgam restorations of molars:
   200°C: the marginal seal of the class V filling (carried out 24 hours previously) was maintained perfectly, while that of the class I filling (*in situ* for several years) demonstrated slight retraction and with both there were bubbles indicating separation and subsequent evaporation of mercury.
   400°C: macroscopically both the class I and V fillings were in place, although both showed the same phenomenon noted at 200°C, that is the presence of bubbles on the surface. The fact that the fillings had remained in place despite the teeth being fractured in various ways, with the separation of large portions, is an indicator of only modest marginal retraction. Stereomicroscopic observation (32X) revealed enamel

* *Carl Zeiss Italia, Milan, Italy.*
† *Cambridge Stereoscan MK2*

microfractures. The surface of the tooth beneath the amalgam restoration, examined by SEM (1100X), showed the presence of dentinal tubules.

600°C: there was macroscopic detachment of the class I and V restorations. The shape and size of the restorations appeared to be unaltered. Stereomicroscopy (20X) revealed the grooves in the residual cavity produced by the cutting instruments (Fig.1); it was possible to detect metal residues of the amalgam on the root surface. SEM of the dentinal surface below the cavity showed deep cracks and fissures.

800°C: the coronal part of the teeth had shattered and the amalgam fillings were recovered at some distance from the teeth in a partially melted state, altered in both shape and structure (Fig.2). The parts of the cavity that had contained the filling could be identified in the largest fragments of the crown and, particularly by stereomicroscope (20X), signs of the milling instrument were evident.

1000°C: the dental crowns had disintegrated completely and it was possible to recover amalgam residues. The remaining parts of the teeth appeared chalky-white with pink shades both near the class V cavity and in the root bifurcation; the metal residues of amalgam had moved. SEM (1200X) of the dentine below the amalgam restoration showed an irregular surface in which it was difficult to identify tubules.

1100°C: macroscopic examination showed bits of teeth fractured into numerous chalky-white and grey fragments, although in the area of the root corresponding to the cementum there was still some pink staining. The amalgam restorations were partially melted although some fragments could be recovered. Again at this temperature some deposits of metallic matter could be detected on the root portion of the tooth.

3. Premolars restored with composite and compomer:

200°C: no macroscopic changes in colour but modest marginal retraction was noted. Stereomicroscopy (20X) showed a loss of the marginal seal.

400°C: the composite restoration had detached and, although remaining whole, had undergone a change in colour to yellowish-brown; the same colour changes were seen in the compomer fillings but these had remained *in situ*. Stereomicroscopic (16x) and SEM (510x) examination of the cavity containing the composite fillings showed the surface markings caused during the preparation of the cavity (Fig.3).

600°C: there was no trace of the composite or compomer restoration: the almost black dental tissue was crossed by deep fractures and it was possible to identify only part of the preparation of the cavity on the vestibular facets. Stereomicroscopy (32X), revealed the characteristic grooves of milling while SEM (1200X) of part of the dentine underlying the composite filling displayed dentinal tubules and a deposit of well-defined shape that was probably the charred remains of the restoration (Fig.4).

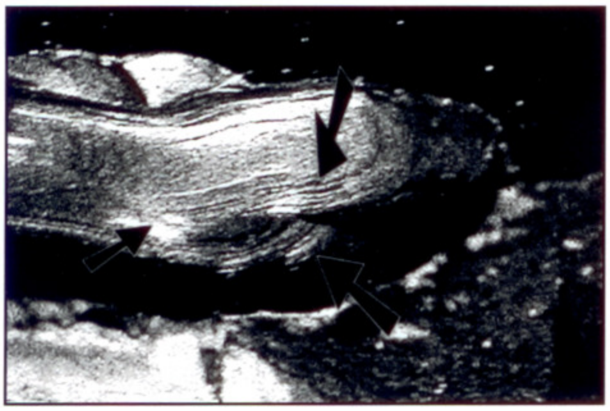

Fig.1. *Stereomicroscopic image (20X) of the V class cavity (of an inferior molar restored with amalgam) after exposure to heat up to 600°C. The grooves produced by the instruments during the preparation of the cavity can be identified (arrows)*

Fig.2: *Stereomicroscopic image (20X) of a class I amalgam restoration recovered at a distance from the residual dental fragments after exposure to 800°C. The amalgam is in a partially melted state, altered in shape and structure and with a piece of dental tissue attached*

Fig.3: *SEM image (510X) of a cavity prepared for repair with composite after exposure to 400°C. The marks caused by the bur during cavity preparation are visible*

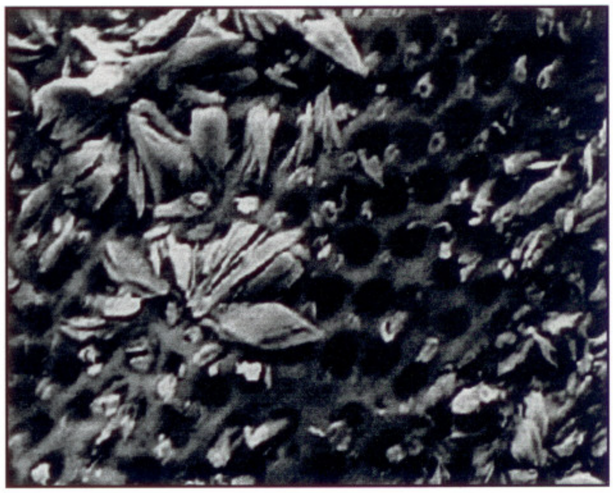

Fig.4: *SEM image (1200X) the floor of a cavity prepared for the filling with composite material after exposure to 600°C. The dentinal tubules and a deposit of solid material, probably a residue of the incinerated composite, can be identified*

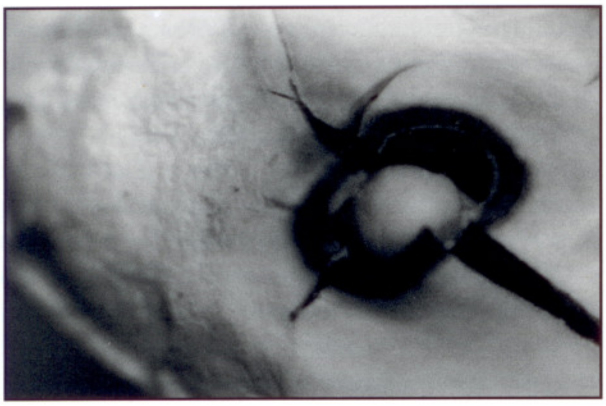

Fig.5: *Stereomicroscopic image (16X) of a fragment of root after exposure to 1000°C. Occasional finding of an endodontic filling material in a premolar repaired with composite and compomer after complete shattering of the crown*

Fig.6: *Stereomicroscopic image (20X) of a bridge covered with acrylic resin after exposure to 400°C. There is partial degradation and loss facing material. The alloy shows the first signs of oxidation with discolouration*

800°C: there was macroscopic shattering of the crown while the roots remained whole and whitish-blue. It was possible to identify the prepared cavities but not residues of the restoration.

1000°C and 1100°C: the crowns of the repaired teeth had completely disintegrated; only fragments of root showing numerous cracks and microfractures remained. An occasional finding of an endodontic filling material in one sample was observed after the complete shattering of the crown (Fig.5).

4. Fixed prosthetic crown or bridge made of polycarbonate, acrylic based products or composite materials:

   200°C: macroscopic observation showed minimal surface changes without loss of substance.

   400°C: the resin showed early signs of flow with loss of material while the residue of the bonding material within the crown remained almost unaltered.

   600 – 1100°C: it was not possible to detect any trace of the acrylic resin.

5. Fixed prosthetic crown or bridge made in metal alloy covered with aesthetic resinous material (acrylic based products or composite materials):
   200°C: direct observation and stereomicroscopy (16X) showed slight retraction of the resin component.
   400°C: macroscopic examination revealed partial degradation and loss of substance on the facets of the aesthetic material (acrylic resin based product or composite material). The alloy showed early signs of oxidation with discolouration (Fig.6).
   600°C: the loss of the resinous component (acrylic based or composite material) could be appreciated macroscopically while traces of the bonding system used at the alloy-aesthetic material interface (silane) could be seen on the surface of the alloy (which remained intact) (Fig.7).
   800°C: there were obvious changes in colour caused by the oxidation of the metal alloy. All the aesthetic material had disappeared.
   1000 – 1100°C: the metal structures had retained their original shape, the bonding cement was still present within them and there was some initial melting of the alloy.

6. A removable partial prosthesis made of base metal casting alloys and denture base acrylic resins:
   200°C: there were no macroscopically evident changes in the alloy while the resin bases and the prosthetic teeth were soft on removal from the oven. Once cooled the colour and shape of the teeth were altered whereas the resin bases retained their original properties.
   400°C: macroscopically the teeth did not differ from those examined after exposure to 200°C, while the resin bases were completely burnt, leaving charred remains.
   600°C: the resin components were no longer detectable and the metal alloy was oxidized. Stereomicroscopy (8X) revealed the casting flaws in the metal.
   800°C: macroscopic examination showed the typical colour change caused by oxidation of the alloy.
   1000°C: there was a macroscopically visible increase in surface oxidation and the areas in which overcasting had been performed during the production of the device were more evident (Fig.8).
   1100°C: the oxidation was more marked but the structure retained its shape almost unaltered without structural collapse or loss of material except in some areas in which reorganization of the alloy showed internal bubbles formed at the time the device was manufactured.

7. Fixed prosthetic crown or bridge in metal-feldspatic ceramic dental systems:
   200°C: there were no macroscopically evident changes in the shape or colour of the crowns.
   400 - 600°C: there was a macroscopically visible slight colour change.
   800°C: the porcelain surfaces were slightly rough

Fig.7: *Stereomicroscopic image (8X) of a bridge covered with acrylic resin after exposure to 600°C. The loss of the facing can be seen while traces of the bonding system used at the alloy-facing material (silane) interface can be found on the surface of the alloy which has remained intact*

Fig.8: *Stereomicroscopic image (8X) of the metal structure of a removable partial prosthesis after exposure to 1000°C. There is increased surface oxidation and in particular, as a result of the flow of the soldered alloy in the areas which were superfused during the preparation of the device*

and porous and had undergone a mild change in colour.

1000°C: macroscopic observation showed splintering and loss of substance of the porcelain covering and bubbles on the surface and the alloy remained unaltered.

1100°C: the porcelain coverings showed the effects of early softening, with surface cracks, while it was still possible to find traces of the bonding cement inside the metal structures.

DISCUSSION and CONCLUSIONS

Our experiments show that dental tissues, prosthetic devices and restorative materials undergo a range of changes which correlate well with the various temperatures to which they were exposed. These changes are a consequence of the nature of the materials and their physicochemical characteristics, but individual components can remain recognizable and identifiable even at very high temperatures. For example, at 1100°C it was possible to recover and identify residues of amalgam restorations while the prostheses in metal-porcelain contained residues of cement (which obviously had not been directly exposed to heat since it was protected by both the porcelain and the alloy). At the same temperature the teeth were well recognizable and not completely destroyed thanks to their mineralized structure. Our experiments did not take into account possible factors present in real-life circumstances, described in the introduction i.e. the protection afforded by soft and hard tissues surrounding the dental components and/or devices, nor any other externally worn items. For example, the root of a tooth should be even more resistant to thermal insults since it is sheltered within the bone. These *in vivo* circumstances prevent direct exposure to fire which would otherwise almost always cause violent evaporation of organic components with consequent explosion of the crown. This phenomenon occurred in our experiments starting from a temperature of 800°C. Incineration of soft tissues and any other organic material can produce a metallic-coloured layer covering the teeth which can modify the real colour change. It is therefore very important to carry out SEM and stereomicroscopic analyses in order to identify the real presence of restorative materials, particularly when only fragments of the teeth remain available for analysis as an example the occasional finding of an endodontic filling material in a premolar repaired with composite and compomer after complete shattering of the crown was observed with the stereomicroscope (Fig.5). Furthermore, amalgam releases mercury vapour which reacts readily in the presence of gold or alloys, further causing colour changes to the tooth; this occurred in our experiments starting at a temperature of 400°C.

At a temperature of 200°C the teeth did not show signs of fractures. As the temperature rose, cracks, fissures and fragmentation of both the crown and the root occurred, although in two cases, at 600 and 800°C, the teeth fractured when handled. This highlights two important points: first, that calcined teeth, being completely dehydrated, are very delicate, and secondly, that fractures may precede the fire because in real-life situations trauma is often associated with the high temperatures caused by major fires.

In our experiments, once the desired temperature had been reached, the specimens were removed from the oven and left to cool, thus all the materials were exposed to a single, brief, thermal insult, whereas in reality various factors can further modify recovered remains: the duration of the exposure to fire, the way in which the fire develops, the rate of increase of temperature, and substances used to extinguish the fire.

We conclude from our experiments that:

(1) some prosthetic devices and restorative materials seem resistant to temperatures higher than those theoretically predicted, for example the glass transition temperature of pure poly(methyl) methacrylate is 120°C[20] but in our experience the facing acrylic material of the bridge (group 4) (Fig.6) was only partially altered after exposure to 400°C while the base portion of the removable partial prosthesis (group 6) showed at 200°C, only a softening of the acrylic. This may be explained by differences in composition and in processing;

(2) when a restorative material is lost because of detachment or change of state, its prior presence can be detected by both SEM and stereomicroscopy of the remaining cavity and its surface morphology;

(3) it seems possible to reach a reasonably reliable estimation of the temperature of exposure from an analysis of the teeth and restorative materials.

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