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Radiologic evaluation of heat-induced shrinkage and shape preservation of human teeth using micro-CT

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A B S T R A C T

Introduction: The most reliable and frequently applied method for identification of fire victims is comparative dental radiography. Forensic investigators are often confronted with fragmented and isolated remains, frequently removed from their anatomical position. Whilst the heat-induced dimensional and morphological changes in bone have been previously studied, precise data for heat-induced changes of human teeth is still lacking.
Objective: The aim of this study was to obtain quantitative micro-CT data to evaluate the three-dimensional shrinkage and shape preservation of human teeth to provide an improved understanding on heat-induced alterations of dental tissues.
Materials and methods: High-resolution micro-CT scans and digital radiographs were carried out on 66 freshly extracted human teeth before and after 30 min exposure to temperatures of 400–1000 °C. Image analysis was performed using 3D Slicer and Fiji imaging packages.
Results: The average volumetric shrinkage ranged between 4.78% (at 400 °C) and 32.53% (at 1000 °C). A major increase in shrinkage occurs between 700 °C and 800 °C, while no significant statistical difference (ANOVA post-hoc LSD, $\alpha < 0.05$) was found between lower temperature groups. Tooth morphology was generally well preserved even at high temperatures, in contrast to observation made for burned bone, where warping and strong deformation can occur.
Conclusions: The results of this micro-CT study add relevant information on shape preservation and allow forensic investigators to account for heat-induced alterations of size, eventually facilitating the odontological identification process in cases where only isolated teeth or dental fragments are present.

1. Introduction

Radiological imaging plays a vital role in the identification process of deceased persons [1–4]. The most reliable and frequently applied radiologic method for identification in cases involving high temperature exposure is comparative dental radiography, which compares features of the dentition (e.g. missing teeth, pathologies and restorations) between ante-mortem and post-mortem dental radiographs [5–7]. Burned human remains are often found after natural disasters, airplane crashes or house fires, as a result of either direct contact with open flames or the exposure to high temperatures [5,6,8]. The positive identification and investigation of severely burned human remains requires careful examination, forensic experience and excellent skills in comparative dental anatomy [5].

Since the thermal stress or the surrounding environment (e.g. destroyed airplane, collapsed building) can lead to extreme fragmentation of the skeletal remains, forensic investigators are often confronted with isolated teeth or fragments thereof [5,9]. Posterior teeth tend to be better preserved than anterior teeth due to their size and the heat protection, offered by layers of skin, mucosa, muscle and fatty tissue and are therefore more likely to be used in the odontological identification process [6]. It has been reported that teeth shrink due to the heat exposure and are therefore often removed from their anatomical position [5,8]. However, whilst heat-induced dimensional changes in animal and human bone have been previously studied, there is no precise data available for the heat-induced dimensional changes of human teeth [10,11]. Therefore, the first aim of this study was to evaluate the volumetric heat-induced shrinkage for a variety of temperatures found in possible archaeological and forensic scenarios by means of quantitative X-ray microtomography (micro-CT).

High-resolution CT imaging has become of increasing importance in forensic radiography [1,12–14]. Recently, Woisetschläger et al. reported on the specific heat-induced alterations of HU

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values in dental tissues and a number of restoration materials analysed with high-resolution CT, providing important information on the characterisation of filling materials exposed to heat [15]. However, with increasing trends in oral health, growing numbers of patients have low incidence of caries and consequently lack restorations, so other features, like the external enamel shape and root morphology need to be considered in the ante-mortem–post-mortem comparison [6,7]. Merlati et al. [16] indicated the importance of qualitative aspects of structural features for positive dental identification, emphasising tooth morphology as a very significant characteristic. In animal and human bone heat-induced warping and deformation can occur at higher temperatures, whilst the extent of morphological changes in human teeth over a large range of temperatures has not been previously evaluated [10,11,16–18]. Therefore, the second aim of this study was to look at shape preservation of dental tissues after exposure to high temperatures, which can add relevant information for comparative dental radiography of isolated teeth and fragments.

2. Material and methods

2.1. Human teeth sampling and preparation

A total of 66 (33 premolars, 33 molars) freshly extracted sound human teeth (ethical approval obtained from the National Research Ethics Committee; NHS-REC reference 09.H0405.33/ Consortium R&D No. 1465) were disinfected and cleaned to eliminate residues. Fifty-six teeth were subdivided into seven different temperature groups (400 °C–1000 °C in steps of 100 °C), with 8 teeth each (4 PM, 4 M). Ten teeth (5 PM, 5 M) were burned at 900 °C for further analysing shape alterations at high temperatures. A Carbolite ashing furnace AAF 11/3 (Carbolite, Sheffield, United Kingdom) was used to simulate the thermal stress. The teeth were exposed to the various high temperatures for 30 min and subsequently cooled down to room temperature according to earlier publications [17,18].

2.2. Standard X-ray protocol

Digital radiographs were taken of 10 teeth before and after heat exposure at 900 °C using a customised Kodak 2100 Intraoral X-ray system (Carestream Health Inc., Rochester, NY, USA) using 60 kV voltage, 7 μA current and 0.1 s exposure time. The setup allowed fixed object-detector distance and size calibration was performed using high-precision ball bearings.

2.3. Micro-CT protocol

The pre- and postscans of 56 teeth were carried out with a SkyScan 1172 micro-CT scanner (SkyScan, Kontich, Belgium) at 13.5 μm resolution using 80 kV voltage, 100 μA current and a 0.5 mm Aluminium filter. The resulting slices were reconstructed with SkyScan's NSRECON package using a uniform attenuation coefficient.

2.4. Image analysis

Following the reconstruction the micro-CT image stacks were converted and a 3-D fast rigid registration of pre- and postscans was performed using 3D Slicer version 3.6.4 (available online: http://www.slicer.org) [19]. After the manual determination of the region of interest (ROI) the registered image stacks were cropped, the images binarised by using the same thresholding values [20] and the resulting values exported to SPSS version 19 (IBM SPSS Inc., Chicago, USA) for further statistical analysis. Three-dimensional models were produced using the Fiji imaging package [20].

2.5. Statistical analysis

The computed differences of the pre- and postscan volumes were statistically analysed with a student t-test, a one-way analysis of variance (ANOVA) and post-hoc Least Significant Difference (LSD) tests using SPSS version 19. Significance levels of $p < 0.05$ (95% confidence interval) were used as an index of statistical significance.

3. Results

3.1. Macroscopic evaluation

A progressive, temperature-dependent shift from a natural colour to predominantly black/dark brown (400 °C), brown (500–600 °C), greyish-blue (700 °C), light grey (800 °C), chalky-white (900 °C) and patches of white, black and pink (1000 °C) was observed (see Fig. 1).

The enamel was fully preserved and attached to the dentine in the 400 °C group, partially separated from the coronal dentine or fragmented between 500 °C and 700 °C and fully separated and fragmented in all teeth ≥800 °C. At temperatures ≥500 °C, the teeth became more fragile, with visible crack formation and fragmentation within the dentine.

3.2. Radiological evaluation

In all teeth of the lower temperature groups (≤600 °C) the micro-CT sections showed multiple small cracks in the apical

Fig. 1. Heat-induced colour alterations. Progressive, temperature-dependent shifts from a natural colour to black/dark brown (400 °C), brown (500–600 °C), greyish-blue (700 °C), light grey (800 °C), chalky-white (900 °C) and white/pink (1000 °C). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)