

## Pulp pathosis in inlayed teeth of the ancient Mayas: a microcomputed tomography study

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### Abstract

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**Aim** To evaluate three-dimensionally, using micro-computed tomography ( $\mu$ CT), the anatomical relationship between the cavity prepared to hold the inlay stone and the pulp chamber in the teeth of the ancient Maya.

**Methodology** Six well-preserved teeth from Maya corpses found in an archaeological site in Guatemala (approximately 1600 year old) were selected and scanned using a high-resolution  $\mu$ CT system (SkyScan 1174v2; SkyScan N.V., Kontich, Belgium). The sample comprised six maxillary teeth: two canines, one premolar, two central incisors and one lateral incisor. All teeth had one or two inlay stones on the buccal surface of the crown. Each specimen was scanned at an isotropic resolution of 22.5  $\mu$ m, a rotational step of 0.70°, a rotational angle of 180° and a 3.1-s exposure time, using a 1-mm-thick aluminium filter. Images of each specimen were reconstructed from apex to the crown with dedicated software (NRecon v1.6.1.5) in approximately 450 slices. CTan v1.11 and CTVol v2.1

were used for three-dimensional visualization and qualitative analysis of the external and internal anatomy of the teeth.

**Results** The tooth modification in all samples was classified as type E1 (one stone on the buccal surface of the crown) or E2 (two stones on the buccal surface of the crown). In the canine teeth, the cavities created to insert the inlay stone did not reach the pulp chamber. Conversely, in the maxillary incisors, the cavities clearly perforated the pulp chamber resulting in massive internal inflammatory resorption or partial calcification of the pulp cavity. In the premolar tooth, a small perforation of the pulp chamber under the buccal cusp, without morphological alteration of the intraradicular dentine, was observed.

**Conclusions** Microcomputed tomography analysis of teeth of the ancient Maya civilization showed that the inlay cavities cut reached the pulp chamber in the maxillary incisors and premolar teeth, with the potential to cause pulp and periapical disease.

**Keywords:** dental modification, dystrophic calcification, internal resorption, microcomputed tomography, root canal anatomy.

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### Introduction

Evidence of body modification can be seen in almost every culture throughout history. Some of the most common forms of body modification include tattooing, body piercing, scarification, the binding of different

parts of the body and the reshaping and filing of teeth (Gonzalez *et al.* 2010). Archaeological records of tooth modification have been found in many areas of the world, but it is most common to the ancient Mesoamerican civilizations (Van Rippen 1917, Whittlesey 1935, Rubin de la Borbolla 1940, Fastlicht 1948, Sweet 1963, Williams & White 2006, Vukovic *et al.* 2009). The Mayas were a Mesoamerican civilization with a highly developed culture that inhabited the Yucatan Peninsula, which comprises the Mexican states of Yucatán, Campeche and Quintana Roo; the

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northern part of the nation of Belize; and Guatemala's northern. The nation's history began about 2500 B.C., but their culture flourished from 300 A.D. to 900 A.D (Whittington & Reed 2006, Williams & White 2006). Based on archaeological findings, at least 60% of the total population was engaged in some form of tooth modification (Tiesler 1999).

In Maya's dental practice, teeth were filed into points, ground into rectangles or cavities were prepared to permit the insertion of round pieces of stone in over a hundred different patterns. This relatively complex procedure was carried out using a hard tube that was spun between the hands or in a rope drill, with slurry of powdered quartz in water as an abrasive, to cut a cavity through the tooth enamel to allow placement of an inlay (Whittington & Reed 2006, Williams & White 2006, Vukovic *et al.* 2009, Gonzalez *et al.* 2010). These inlays were made of various minerals and were ground to fit the cavity so precisely, and the adhesive was so effective that many burials found by archaeologists today still have them firmly in place (Williams & White 2006, Gonzalez *et al.* 2010).

Most of the studies in this field involve the description and classification of artificially modified teeth; nonetheless, only a few examined the consequences on tooth and surrounding tissues (Gwinnett & Gorelick 1979). These studies were performed using X-ray and scanning electron microscopic analysis and have shown that, most of the time, the base of the cavity prepared to hold the inlay remained at a distance from the pulp cavity. However, perforation of the pulp chamber has also been reported, which ultimately led to periapical disease and abscess formation (Fastlicht 1948, Tiesler 2002, Whittington & Reed 2006, Gonzalez *et al.* 2010).

The aim of this *ex vivo* study was to evaluate three-dimensionally the anatomical relationship between the cavity prepared to hold the inlay stone and the pulp chamber in the teeth of the Maya, and its influence within the pulp cavity, using microcomputed tomography.

## Materials and methods

Six well-preserved Maya's teeth donated by a private collector and found in an archaeological site in Guatemala (approximately 1600 year old) were selected. All teeth had one or two inlay stones on the buccal surface of the crown.

For the experimental procedure, each specimen was vertically positioned on a metal holder in the centre of the stage and scanned in a desktop X-ray microfocus

CT scanner (SkyScan 1174v2; SkyScan N.V.) at an isotropic resolution of 22.5  $\mu\text{m}$ , a rotational step of 0.70°, a rotational angle of 180° and a 3.1-s exposure time, using a 1-mm-thick aluminium filter. The system consisted of a sealed air-cooled X-ray tube (20–50 kV, 40W, 800  $\mu\text{A}$ ) with a precision object manipulator with two translations and one rotation direction. The system also included a 14-bit CCD camera based on a 1.3-megapixel (1304  $\times$  1024 pixels) CCD sensor.

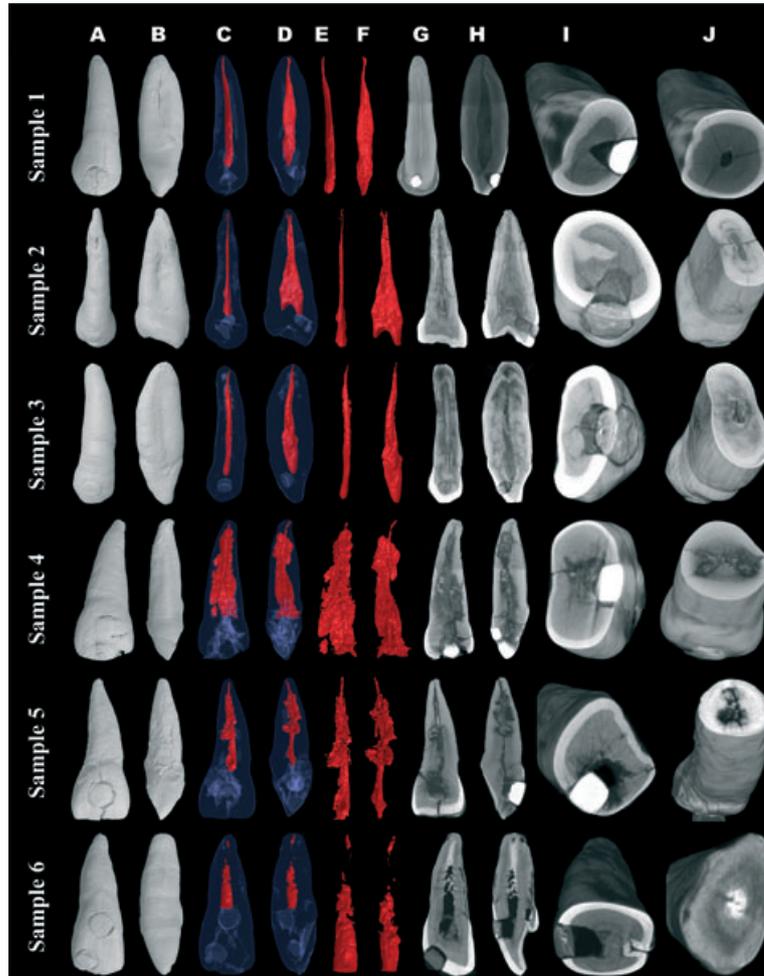
Images of each specimen were reconstructed from apex to the crown with dedicated software (NRecon v1.6.1.5; SkyScan), which provided axial cross-sections of the inner structure of the samples in approximately 450 slices. CTan v1.11 and CTVol v2.1 (Skyscan) were used for the three-dimensional visualization and qualitative analysis of the external and internal anatomy of the teeth.

## Results

The sample comprised six maxillary teeth: two canines (samples 1 and 3), one premolar (sample 2), two central incisors (samples 4 and 5) and one lateral incisor (sample 6). Figure 1 shows the three-dimensional reconstructions of the internal and external anatomy of all specimens. The tooth modification presented in all specimens (column A) was classified as type E1 (one stone on the buccal surface of the crown), except one lateral incisor (sample 6) that was E2 (two stones on the buccal surface of the crown). In the canine teeth (samples 1 and 3), the cavities made to insert the inlay stone did not reach the pulp chamber (columns C to J). Conversely, in the maxillary incisors (samples 4–6), the cavities clearly perforated the pulp chamber (columns G to J) resulting in massive internal inflammatory resorption (samples 4 and 5, columns C to F) and partial calcification of the pulp cavity (sample 6, columns C to J). In the premolar tooth (sample 2), only a small perforation of the pulp chamber under the buccal cusp (column H), without morphological alteration of the underlying dentine (columns C to J), was observed.

## Discussion

Nowadays, white, properly shaped, well-aligned teeth constitute the standard for beauty and are also an indicator of health, hygiene and economic status (Gonzalez *et al.* 2010). Nonetheless, in ancient Mesoamerican civilizations, nontherapeutic tooth modification was a distinguishing mark of high status (Romero



**Figure 1** Three-dimensional reconstructions of the internal and external anatomy of six maxillary Maya's teeth: two right canines (samples 1 and 3), one right first premolar (sample 2), two left central incisors (sample 4 and 5) and one right lateral incisor (sample 6). Columns A and B: external anatomy of teeth on the buccal and lateral aspects, respectively. Samples 1–5 presented only one inlay stone on the buccal surface of the crowns (type E1), whilst sample 6 presented two stones (type E2); columns C and D: internal anatomy of teeth on the buccal and lateral aspects, respectively; columns E and F: three-dimensional reconstruction of the pulp on the buccal and lateral aspects, respectively. In the incisors, it was observed the development of internal resorption (samples 4 and 5) and calcification (sample 6). Intraradicular dentine and pulp cavity of canines (samples 1 and 3) and premolar (sample 2) teeth showed no morphological alteration; columns G and H: coronal slices of teeth on their buccal and lateral aspects, respectively; columns I and J: axial slices of teeth in different levels. From columns G to J, it can be observed the depth of the inlay stone cavity in relation to the root cavity, as well as the extension of the internal root resorption (samples 4 and 5) and the calcification of the pulp cavity (sample 6).

Molina 1970), of belonging to a tribe or clan (Alt *et al.* 1998) or of beauty (Van Rippen 1917, Rubin de la Borbolla 1940, Fastlicht 1948).

A complete classification of artificial modifications to human teeth has been produced by Alt *et al.* (1998). However, the present study used the system of Romero Molina (1970) because it constitutes the Mesoamerican standard for categorization (Williams & White 2006).

Romero defined seven basic types of tooth modifications based on the study of a collection of 1212 teeth. Each type was subdivided into at least five variants, resulting in a total of 59 different types, classified in accordance with the nature of the alteration of the crown contour, the inclusion of decorative details on the buccal surfaces or a combination of both (Gonzalez *et al.* 2010).

Tooth modification was found predominantly in the anterior teeth, commonly the maxillary incisors and occasionally the maxillary canines (Rubin de la Borbolla 1940, Fastlicht 1948), although cases have been documented on maxillary premolar teeth (Tiesler 1999). Regional differences have also been observed concerning the type of tooth modification. López Olivares (2006) has reported that Romero's types E, F and G were more common in Guatemala, supporting the theory that it may represent identification with a local polity or familial lineage (Williams & White 2006). These findings are consistent with the analysed specimens.

In Maya culture, alteration of the crown contour was the most common form of tooth modification, followed by inlays or incrustations (Gonzalez *et al.* 2010). The types of stones used for the inlays varied geographically and temporally but include pyrite, jade, turquoise, jadeite, haematite and obsidian (Sweet 1963). In the present study, the inlays were composed of different minerals, and their radiopacity varied; no attempt was made to identify their constituents because it would damage the samples.

The most convincing evidence that tooth modification was practiced on living subjects of the Maya civilization comes from dental disease associated with excessive tooth preparation (Fastlicht 1948, Gwinnett & Gorelick 1979, Tiesler 1999, Whittington & Reed 2006, Gonzalez *et al.* 2010). Using radiography, dentists and anthropologists observed periapical radiolucencies related to modified teeth (Rubin de la Borbolla 1940, Fastlicht 1948, Romero Molina 1970, Whittington & Reed 2006, Gonzalez *et al.* 2010).

Regarding samples 1 and 3 (maxillary canine teeth), the anatomical relationship between the base of the cavity and the pulp chamber remained distant from the pulp space. As a consequence, it may be inferred that the modification procedure caused no injury to pulp tissue. On the other hand, sample 2 (premolar tooth) had an exposed pulp chamber under the buccal cusp. Inlays were secured by either pressure or cement (Rubin de la Borbolla 1940), and even though its composition was virtually identical to that of Portland cement (Sweet 1963), no hard tissue barrier was observed under the inlay. Multiple levels of responses and interactions occur in reaction to mechanical injuries of the dental pulp. Depending on the severity and duration of the insult and the host response, two distinct hard tissue changes may be induced: resorption or calcification (Torabinejad & Walton 2009), as observed in samples 4–6.

Three forms of internal root resorption have been reported, although varying terminology has been used to describe them: surface, inflammatory and replacement resorptions (Levin *et al.* 2009). The former occurs when just minor areas of the root canal wall have been resorbed; it might be self-limiting and might repair if the pulp is relatively healthy and if the irritating stimulus has been removed (Andreasen *et al.* 2007). The latter is a metaplastic type of change to the dental pulp in which the pulp first is replaced by bone, and then subsequently the dentine is replaced by bone, that appears lamella-like, with entrapped osteocyte-like cells that resemble osteons (Andreasen *et al.* 2007, Patel *et al.* 2010).

In the present study, the three-dimensional reconstruction of samples 4 and 5 suggested that both teeth developed an internal inflammatory resorption, i.e. a progressive destruction of intraradicular dentine and dentinal tubules along the canal walls (Lyroudia *et al.* 2002). Although chronic inflammation is commonly present in pulpal infections, other conditions prevail for the recruitment and activation of odontoclast precursors within the dental pulp (Patel *et al.* 2010), for example the adjacent odontoblast layer and predentine must be disrupted for the activated clastic cells to adhere to the intraradicular mineralized dentine (Wedenberg & Lindskog 1985); the pulp tissue apical to the resorptive lesion must have a viable blood supply to provide cells and their nutrients, whereas the infected necrotic coronal pulp tissue provides stimulation for those cells (Tronstad 1988).

In samples 4 and 5, it is possible that the activation of odontoclasts occurred because of the loss of predentine as a consequence of trauma or excessive heat generated during the modification procedure (Wedenberg & Lindskog 1985) and the presence of an infected necrotic coronal pulp tissue because of pulp exposure to the oral environment (Torabinejad & Walton 2009). Ultimately, as the canal was left untreated, internal resorption continued until the inflamed connective tissue filling the resorptive defect degenerated, advancing the lesion in an apical direction (Patel *et al.* 2010).

Degenerative changes to the pulp such as pulp calcification or pulp atrophy/fibrosis are related to ageing or sublethal injury, resulting in chronic irritation to the pulp (Levin *et al.* 2009). This pathologic calcification is defined as an abnormal tissue deposition of calcium salts, together with smaller amounts of iron, magnesium and other mineral salts and consists in two forms. When the deposition occurs in otherwise normal tissues, it is known as metastatic calcification, and it

almost always results from hypercalcaemia secondary to some disturbance in calcium metabolism. In contrast, the deposition of calcium salts locally in dying tissues is known as dystrophic calcification; it occurs despite normal serum levels of calcium and in the absence of derangements in calcium metabolism. Dystrophic calcification is encountered in areas of necrosis, whether they are of coagulative, caseous or liquefactive type, and in foci of enzymatic necrosis of fat (Robbins et al. 2010).

In the present study, extensive pathologic calcification was observed in the middle and apical thirds of the root canal of sample 6 (maxillary lateral incisor). In this case, one of the cavities made for the insertion of inlay had reached the pulp tissue. As a reaction to tissue damage in a chronically inflamed pulp, thrombi in blood vessels and collagen sheaths around vessel walls have been considered as possible sites for the beginning of dystrophic calcifications. As irritation increased, the amount of calcification also increased, leading to partial obliteration of the root canal (Torabinejad & Walton 2009).

## Conclusions

Intentional modifications of human teeth hold anthropological and social significance. Their study helps to understand past and present human behaviour from a geographic, cultural, religious and aesthetic perspective. Tomography analysis of teeth of the ancient Maya civilization showed that the inlay cavities cut reached the pulp chamber in the maxillary incisors and premolar teeth, with the potential to cause pulp and periapical disease.

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