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Prehispanic Maya dental inlays in teeth with open apices: Implications for age of cultural practices

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ABSTRACT

The present study analyzes three permanent Prehispanic anterior teeth (one maxillary left central incisor, one maxillary right canine, and one mandibular left lateral incisor) belonging to individuals in the (pre)adolescent 7- to 10-year-old age range sporting one circular jade inlay each in the buccal side of the crown. They are currently part of the skeletal collection housed at the Popol Vuh Museum of the Francisco Marroquin University in Guatemala. Age at death was determined by the degree of root formation. Along with gross morphoscopic inspection, each tooth was analyzed by means of X-ray and Cone Beam Computed Tomography (CBCT) to inspect the tooth's inner structure and pulpal chamber. X-rays and CBCTs confirmed that the roots were still forming, validating the morphoscopic estimation of such young ages at death. More important, they highlighted dentine reactions in the roof of the three pulpal chambers. The physiological responses to the mechanical stress exerted on the teeth from the drilling process show that the individuals were still alive when the jade inlays were embedded in their teeth. This finding contrasts with previous bioarchaeological evidence that suggests the process of inlaying teeth was performed only in individuals close to adult age (18–20 years) and raises questions on the extent to which this cultural practice was indeed limited to adults among the ancient Mayas.

1. Introduction

Among the Prehispanic Mayas, dental modifications in the form of filing, engraving and inlays were common practice in the Classic and Postclassic periods (AD 250–900; AD 900–1550); Tiesler (2000, 2004; et al. 2017) reports frequencies as high as about 60 % in adult individuals, though estimates vary by site, chronology, socioeconomic status and sample representativity of the whole population. While skeletal evidence exists for dental extraction for therapeutic purposes (Schnell and Scherer 2021), no evidence suggests that other types of manipulation and modification were performed for such reasons. On the contrary, filing and engraving were performed to give the tooth a particular shape or aesthetic pattern that involved single or multiple teeth. Lithic tools were widely used to produce these patterns (Cadalen et al. 2024; Fastlich 1971, 1976; Tiesler 2024). Inlays were intended to embed stones made of pyrite, jade, and other materials into the crown's surface. This required a three-step procedure. First, the enamel surface, whose hardness corresponds to grade 5 in Mohs' scale (Mukherjee 2011:373), was prepared by creating a small cavity that granted stability to the (likely) obsidian drill point and prevented it from slipping onto the smooth enamel surface. Drilling then created the cavity for the stone inlay, which was polished using abrasive grinding sands (Tiesler 2024). Scanning electron microscopy of existing holes showed homogeneous and regular borders and walls. At this point, the stone inlay, whose shape was carefully crafted to fit the cavity, was inserted and kept in place by an organic-based cement characterized by antibacterial and antiseptic properties (Hernandez Bolio et al. 2022; Ramírez-Salomón et al. 2018).

With the only potential exception at Pusilha in Belize (Braswell and Pitcavage 2009), studies have not reported inlays in subadult individuals among the ancient Mayas; that is, all incrustations have been reported in adults (individuals 20 years of age and older), with few exceptions (see Tiesler 2000, 2024; Tiesler et al. 2017). Fastlich (1971) suggested that this procedure was performed around the age of 18 years

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when most teeth are completely formed, which reduces the risk of damaging the dental pulp. In fact, the crown is fully formed by the time it erupts, but the roots are still developing (because dental formation starts at the occlusal/incisal level and proceeds towards the apex of the root). At least three more years are necessary for the roots to complete their formation and for the apical foramen to close to microscopic size. Therefore, the presence of open root apices is indicative of a still-forming tooth, which is a reliable bioarchaeological and forensic indicator of the age at death of the individual (AlQahtani and Liversidge 2010; Ubelaker 1989).

While archaeological evidence shows that filing and engraving were already performed in 10- to 15-year-old individuals (Tiesler 2024; Tiesler et al. 2017), inlays start materializing in the skeletal record in a very limited number in the 15- to 20-year age category (Tiesler 2024). The present study discusses the evidence of jadeite inlays in three Prehispanic Maya permanent teeth whose root formation was incomplete, placing the individual(s) in the (pre)adolescent category. They represent unique evidence of anthropogenic intervention that has not been previously documented in the Maya realm. The findings question whether socio-cultural explanations of social age and integration of the individuals into the adult community should be extended to the preadolescent category.

2. Materials

Three permanent teeth in the Prehispanic skeletal collection of the Francisco Marroquin University's Popol Vuh Museum in Guatemala were analyzed. This collection consists of either isolated dental elements or complete mandibles and skulls that sport particular and peculiar cultural interventions. Unfortunately, these teeth are not associated with bony skeletal remains (mandible or maxilla), and were decontextualized a long time ago, so we cannot state for certain their origin and whether or not they belong to a single individual or to up to three different ones.

The teeth selected for this study were the only ones in preadolescent age classes that presented a jadeite inlay. They include a maxillary left central incisor (I1′L), a mandibular left lateral incisor (I2,L) and a maxillary right canine (C'R). They all had a jade inlay in the buccal side of the crown. Upon receiving permission, these specimens underwent optical microscopy analysis (Carl Zeiss Omni Pico, Oberkochen, Germany), digital radiography (RVG 5200, Carestream Health, Inc, USA), and Cone Beam Computed Tomography (CBCT, Carestream CS 9600, Carestream Dental LLC, Atlanta, USA). In addition, two digital radiographs were taken of each tooth. The teeth were placed in a vertical position, and using the parallelism technique, the first radiograph was obtained from the buccal (orthoradial) side and the second from the proximal (mesial) side. For tomographic acquisition, the teeth were placed in a vertical position on a hypodense sponge. The parameters were 120 kV and 4 mA with 15 s exposure time. The field of view was 8 x 5 cm and the isotropic voxel size was 150 μm. An experienced radiologist (HKB) performed the acquisition process according to the manufacturer's recommended protocol with the minimum exposure. They were then analyzed using the OnDemanad3d® software by moving the cursor on the Z-axis in the three planes. Finally, the images were obtained in coronal, sagittal, and axial views.

2.1. Maxillary left central incisor (I1′L)

The crown of the maxillary central incisors forms between birth and about 4 to 5 years of age. It erupts above the gingival level by age 7–8 years, and the development of the root ends by age 10 (AlQahtani and Liversidge 2010; Ubelaker 1989). The crown measures 10.05 mm in length and still shows three small mamelons on its incisal edge; no incisal wear can be detected. The root measures 7.97 mm in length. It presents a grade 5 shovel shape based on the ASUDAS standards (Turner et al. 1991).

The crown's buccal side sports a green jadeite circular inlay. It is 3.2 mm in diameter and penetrates the enamel for 1.9 mm. The stone presents a flat and polished surface, and the edges are rounded. It corresponds to Romero's (1984) E1 classification (Fig. 1A). An inspection reveals the absence of fractures and carious lesions around the edges of the cavity. The apical extreme presents sharp edges, as expected in a still developing tooth.

The proximal, lateral radiographic view of the tooth shows that the anthropogenic perforation was limited to the dentine, without reaching the pulpal chamber. The borders of the inlay fit into and match the walls of the cavity. The pulpal and radicular chamber did not show signs of reabsorption, yet calcification is detected along the wall of the pulpal chamber right next to the inlay, which denotes a moderate physiological reaction of the living tissue to the mechanical stress produced by the drilling (Fig. 1B).

Last, the CBCT analysis confirms that the stone inlay did not reach the pulpal chamber; a 0.76 mm thick dentine septum prevented contamination of the pulpal chamber by exogenous material. No infectious lesions can be detected inside the pulpal chamber or around the edges of the inlay, which confirms that no carious processes were in effect when the individual died (Fig. 1C).

The root's tissue is thinner towards the apex, whose rims are open and divergent, corresponding to a still forming tooth – grade 2 of Cvek classification (Cvek 1992). Based on AlQahtani and Liversidge's (2010) and Ubelaker's (1989) charts, this individual died around 8–9 years of age.

2.2. Mandibular left lateral incisor (I2,L)

The crown of the mandibular lateral incisors completes formation by about 4–5 years of age. The tooth erupts at the gingival level by around 7.5 years, and the root completes its formation by about age 10 (AlQahtani and Liversidge 2010; Ubelaker 1989). The crown of this lateral incisor is 10.04 mm long and shows a grade 2 shovel shape (Turner et al. 1991), with mamelons present on its incisal edge. The root is 8.43 mm long, and its stage of formation corresponds to Cvek grade 2 (Cvek 1992). Despite some diagenetic alteration in some portions of the root, its apical extremity is still clearly open, indicating that the tooth had not completed its formation. Age estimation of the degree of crown and root formation and eruption also suggests an age at death of 8–9 years (AlQahtani and Liversidge 2010; Ubelaker 1989).

Similar to the I1′L, a circular green jadeite stone is embedded in the buccal side of the crown (Fig. 2A). The stone has similar characteristics to the one in the central incisor, with the only difference represented by its diameter, which is 3.0 mm and penetrates 1.11 mm into the enamel. The rims of the cavity are smooth, and a tiny fissure runs from the inlay to the incisal edge. No fractures or cavities can be spotted around the cavity. The apical extremity of the root is thin and shows no evidence of fractures or chipping.

Similarities and differences with the I1′ are noticeable when the tooth is inspected by X-ray analysis (Fig. 2B). The cavity was limited to the enamel and did not invade the pulpal chamber or the dentine. The shape of the stone fits and matches the perforation, and the jadeite filled the cavity completely. No infectious lesion (i.e., caries) affected the pulpal chamber or the outer rims of the inlay. No reabsorption is visible in the pulpal chamber, but a calcification is present in the roof of the pulpal chamber next to the inlay. This physiological reaction is also the consequence of the mechanical stress exerted on the living tissue.

The root canal is very wide, with the walls diverging from each other the closer they get to the apical root extremity. Again, this is the typical morphology of a still-growing tooth. The same morphology of the pulpal chamber and root is visible through the images obtained by means of a CBCT (Fig. 2C). The pulpal chamber is separated from the inlay by a 1.05 mm thick dentine layer, and no connection exists between the pulpal chamber and the cavity harboring the inlay.

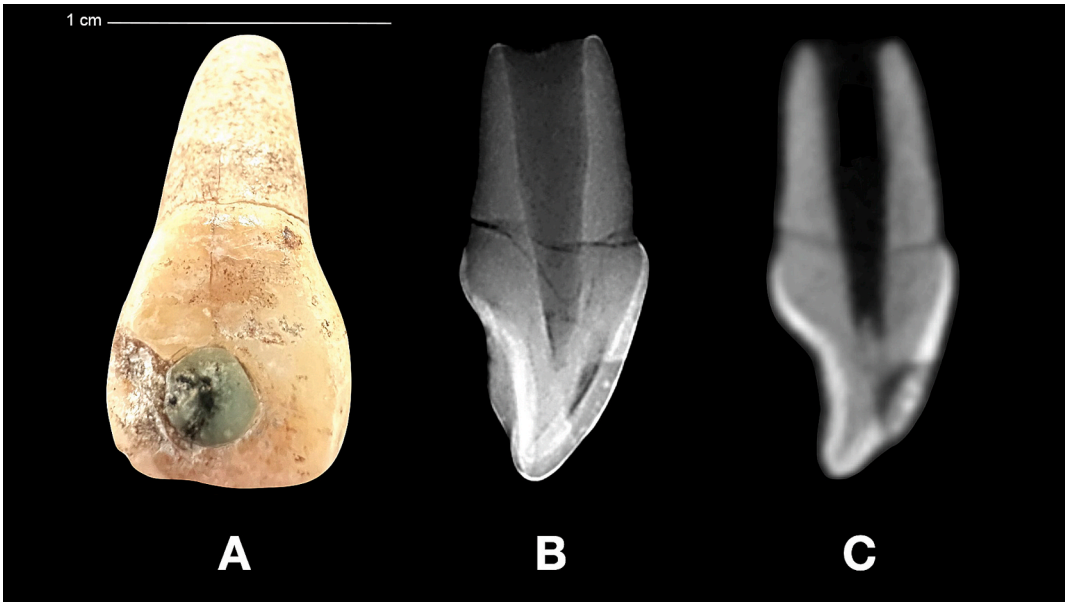

Fig. 1. Maxillary left central incisor. A) buccal view of the incisor. B) proximal radiographic view. C) CBCT sagittal view showing the relationship between the inlay cavity and the pulp chamber, with evidence of calcifications indicating pulp reaction to the intervention.

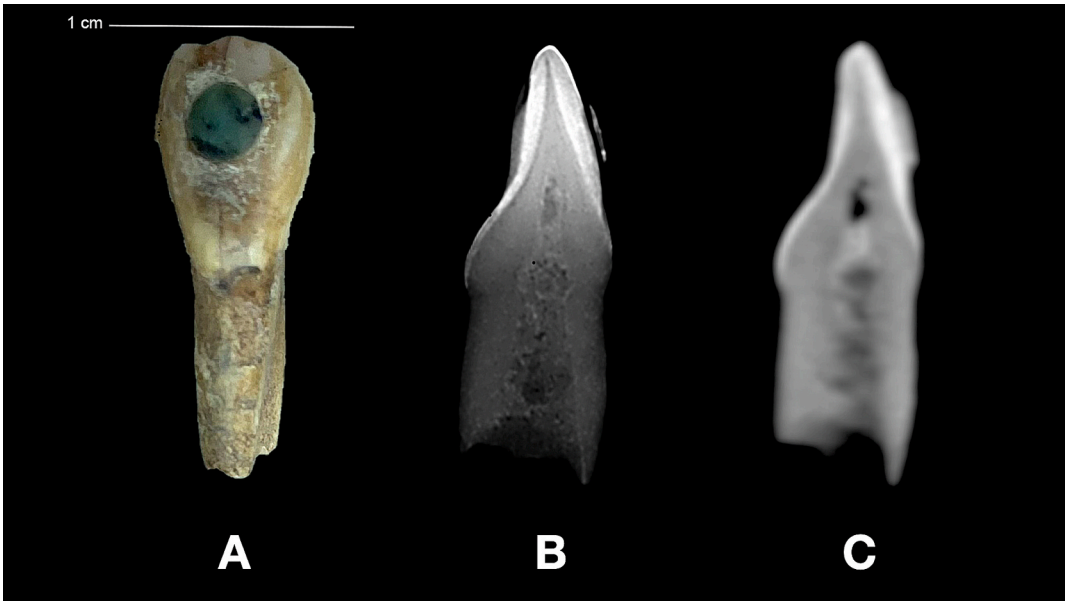

Fig. 2. Mandibular left lateral incisor. A) buccal view of the tooth. B) proximal radiographic view. C) CBCT sagittal view showing the depth of the inlay cavity into the enamel, with evidence of calcifications indicating pulp reaction to the intervention.

2.3. Maxillary right canine (C'R)

The crown of the maxillary canines completes formation by about 7 years of age. The tooth erupts at the gingival level by around age 11–12, and the root completes its formation by about 14–15 years (AlQahtani and Liversidge 2010; Ubelaker 1989).

The crown is 8 mm long and the still forming root is 6.64 mm long, which corresponds to Cvek grade 2 (Cvek 1992). Despite some diagenetic alteration in some portions of the root, the apical extremity is still clearly open, indicating that the tooth had not completed its formation. Estimation of the degree of crown and root formation suggests an age at death of 9–10 years according to AlQahtani and Liversidge (2010) and Ubelaker (1989). On average, the maxillary canine erupts at the gingival level by age 12, even though Ubelaker (1989) reports a standard deviation of about 2.5 years before and after this age.

As with the other teeth in the sample, a circular green jadeite stone is embedded in the buccal side of the crown (Fig. 3A). The stone diameter is 3.0 mm, and the cavity reaches a depth of 2.81 mm. Like the I1'L, the stone inlay does not fill the cavity completely, and some empty space remains between the jade stone and the bottom of the cavity.

X-ray analysis does not show a pulpal chamber physiological reaction (Fig. 3B), which instead is highlighted by the CBCT imaging along the pulpal chamber walls corresponding to the inlay cavity, which is the natural consequence to mechanical stress exerted onto a living tissue (Fig. 3C). The 3D analysis also confirms the absence of fractures and caries along the cavity. The apical extremity of the root is thin and shows no evidence of fractures and chipping.

The pulpal chamber is separated from the anthropogenic cavity by a

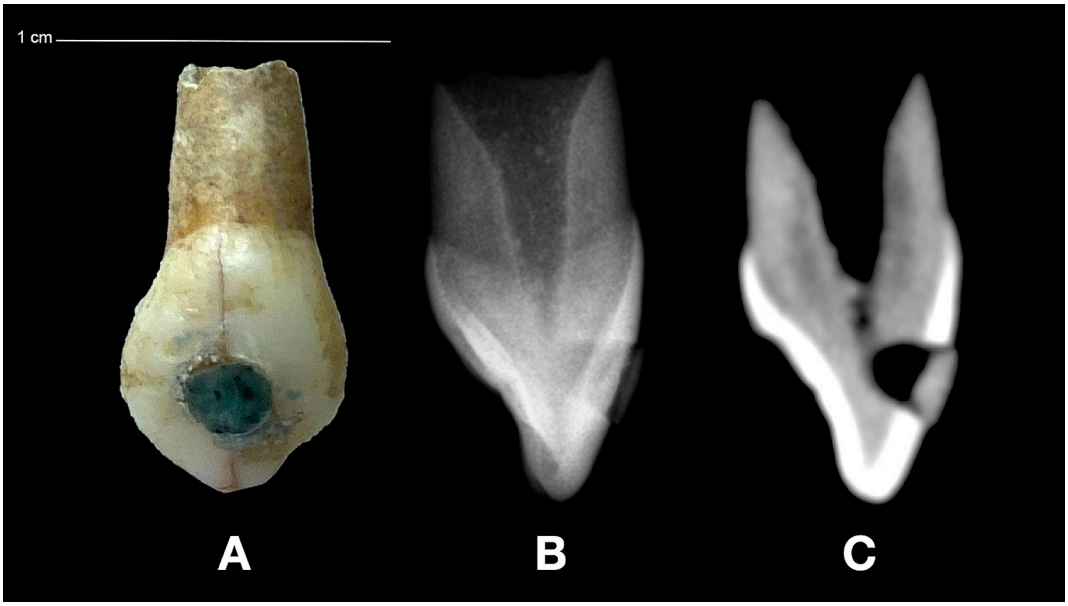

Fig. 3. Maxillary right canine. A) buccal optical view. B) proximal radiographic view. C) CBCT sagittal view showing a close relationship between the inlay cavity wall and the pulp chamber, with evidence of calcifications indicating pulp reaction to the intervention.

0.48 mm thick wall of dentine, and no connection exists between the chamber and the cavity housing the inlay. The cavity does not reach the pulpal chamber, and no infectious lesion (i.e., caries) affected the chamber or the outer rims of the inlay.

The root canal is very wide, with the walls diverging from each other the closer they get to the root apical extremity. Again, this is the typical morphology of a still-growing tooth. The same morphology of the pulpal chamber and root is visible through the images obtained by means of a CBCT.

3. Discussion

Dental modifications in the form of filing, engraving, and inlays were common practice among the Prehispanic Maya (Tiesler 2000, 2024). Skeletal evidence has shown that dental modification was extensively practiced on individuals who had reached the adult (or almost adult) age (Tiesler 2024). Yet, no evidence suggests that such practices were performed on (pre)adolescent individuals. Specifically, inferences are based on the frequency of individuals sporting some sort of manipulation according to the specific classes of age at death, since such interventions are permanent and modified only by occlusal wear or extensive carious lesions. Tiesler (2024; Table 4.2) reported no filing or inlays in the age class between 0 and 10 years (0 %). The earliest appearance of some kind of modification appeared in those aged 10–15 years, with the author reporting filing in 13 % of the individuals. Inlays start appearing in the archaeological record in individuals 15–20 years of age, where 12 % of the teeth analyzed had some kind of incrustation, with the youngest individual being just fifteen years old (Tiesler 2024:67). The preference for filing over inlays in the earliest age class (10 to 15 years) leads to the hypothesis that inlays might have been too invasive a procedure to be performed on such young individuals. This indirect evidence is consistent with Fastlich's (1976) hypothesis and with Romero's (1970) statement that it was rarely performed on people younger than 18–20 years, even though we cannot rule out other social and economic reasons – alongside invasiveness – behind this pattern. After that age class (i.e., from age 20 years and older), the frequency doubles to 60 % and higher, with higher – but not statistically significant – frequencies in females than in males (Tiesler et al. 2017:278).

The fact that intentional modifications do not appear in preadolescent individuals can hardly be related to an underrepresentation of this age class in the archaeological record. Among the Prehispanic Mayas, mortality in the 5–15 years of age classes is drastically reduced after the high peaks of infant mortality (Ortega-Muñoz et al. 2020); nonetheless, preadolescent people in this age class are visible in the human skeletal collections. Therefore, we can rule out that the lack of evidence of dental interventions in preadolescents can be attributed to the underrepresentation of this age class in the archaeological record.

Presence of inlays in young individuals during Prehispanic times is indeed very rare, or almost null. Brasswell and Pitcavage (2009) presented a case of inlays in the two deciduous maxillary lateral incisors of burial 5/1 at Pusilha (Belize) dated to the Late Classic (AD 800–900). The right incisor still retained the jade stone embedded into the crown. The age at death of the child was reported as 4–5 years, even though we consider that, given the completeness of both roots, the age could have been as young as 3–4 years using Ubelaker (1989). This is reportedly the only case of inlays in deciduous teeth so far reported in the Maya realm, but the evidence remains controversial. In fact, the authors discuss different possible hypotheses and consider that the "most likely possibility is that the two teeth were inlayed after the death but before burial" (Brasswell and Pitcavage 2009: 26), which might have been related to a great loss or even to sacrifice (2009: 26). The authors' conclusion of a postmortem process is compatible with the kind of teeth they found because the dentine thickness of deciduous teeth and the frailty of their enamel do not allow for such an invasive technique in the living tissue of such a young individual.

The three teeth described in this paper belong to individual(s) whose age at death is estimated in the range between 7.5 and 10 years. The slight difference in age between the two incisors and the canine may tilt the balance towards the hypothesis that they belong to at least two individuals. Yet the fact that the inlay in the mandibular incisor remained limited to the enamel thickness (i.e., the cavity did not enter the dentine) suggests that they might have been performed by different craftsmen, and therefore that even the two incisors belonged to different subadults.

Regardless of the number of individuals undergoing this practice, what is tantalizing is the young age of the individuals. Leaving aside Braswell and Pitcavage's discovery (2009) at Pusilha, Belize, they are the only evidence of inlays performed at such a young age. Milner (2017:318) stated that " …a healthy dose of skepticism is always appropriate, although caution is too often the first casualty in the rush to publish". With these words in mind, the initial hypothesis to take into

consideration was whether these teeth, like the Pusilha example, were inlaid after the death of the individuals. However, both incisors and the canine show pulpal reaction on the inner surface of the dentine corresponding to the place where the inlay was embedded. After eruption and throughout life, secondary dentine is formed as a physiological response (Berman and Hargreaves 2021). Inserting an inlay requires exerting mechanical stress on the tooth to drill the cavity, and the tooth's physiological response to this process is to react and lay down tertiary dentine to protect the pulp (Ramírez-Salomón et al. 2018). Ramírez-Salomón and colleagues (2018) have extensively described this reaction in inlaid teeth in the region.

3.1. Age of eruption

The age of tooth formation and eruption is essential to understand whether teeth were inlayed before or after death. Little doubt exists that both incisors were inlayed when the individuals were alive, and the teeth had already erupted above gingival level because of the age of eruption and the presence of reactive tissue along the roof of the pulpal chamber. This process was performed not long before the death of these children. Maxillary central incisors and mandibular lateral incisors erupt approximately by age 7–8 years, which about one year before the age when the individuals died. This allowed time for the practitioners to apply the inlays in the buccal side of the incisors' enamel crowns.

The maxillary canine deserves a slightly different discussion. In the first place, digital imaging is not as clear as with the incisors because some reaction may be visible in the CBCT but not from the X-rays. This requires caution in differentiating antemortem or posthumous modification for this tooth. In the second place, the degree of tooth formation suggests an age at death of about 9–10 years. However, based on AlQahtani and Liversidge (2010) and Ubelaker (1989), the upper canine should erupt later at approximately 12 years. Theoretically, there is a chronological gap between formation and eruption that would support the hypothesis that this tooth was inlayed after the death of the youngster. Ubelaker (1989) reports an age of formation and eruption plus/minus a certain number of years of biological variability in a North American sample. In the case of the canine's stage of formation, Ubelaker considers about 24 months below and above the average age, while the author suggests 12 years ± 30 months for eruption. More recently, Ristaniemi et al. (2022) described the range of variability of eruption of the maxillary canine after a longitudinal study on living children from Finland. Though the modal age of natural eruption for both girls and boys is age 10 years, the study reports very few cases of natural eruption starting at age 7 years, with increasing cases of eruption in children in the 8- and 9-year classes. The last cases of eruption occurred at age 12 years.

While minor differences exist on the stage of formation of permanent teeth when different methods are used (Rodríguez et al. 2021), the range of variability involved in the process of eruption is quite large and depends on a wider set of variables, which include ethnicity, biological sex, nutrition, socioeconomic status, craniofacial morphology, hormonal factors, and body composition (among others) (Almonaitiene et al. 2010). Ubelaker's North American sample and Ristaniemi et al.'s Finland collection belong to very different ethnic groups compared to the Prehispanic Maya teeth analyzed in this study. Unfortunately, no standards of eruption are available for the Maya ethnic group; moreover, the teeth lack archaeological contexts so we have no information on the osteobiography of these individuals. Leaving sex aside, because at this age sex cannot be determined morphologically, social status, physical features, growth patterns, and disease histories are not available. However, though not as clearly visible as for the incisors, the canine shows some pulp reaction. Notwithstanding the limitations imposed by ethnicity-related eruption timing, the presence of pulp reaction suggests that it would not be a surprise for the canine to have erupted above gingival level by the estimated age of 9–10 years, adding it to the set of teeth intentionally modified during life.

It will be necessary to reach a better understanding of the time of eruption in Maya populations, which may also benefit other fields like forensic anthropology, but which goes well beyond the goal of this paper. In our case, the overall evidence rules out the hypothesis of posthumous intervention and suggests that all these teeth were inlayed intentionally before the death of the individuals, thus confirming them as the earliest inlayed ones detected and described in the Maya area.

3.2. Methodological contribution

The application of different analytical techniques (morphoscopic, X-ray, and CBCT) has the power of delving deeper and deeper into human and archaeological remains. Radiographic analysis of the samples enables the observation of internal dental structures that would otherwise be impossible to visualize with the naked eye. Depending on the angle of the X-rays traversing the dental structures, it is possible to observe the presence and depth of caries, the depth of the cavity prepared for restoration, the presence of contact between the cavity and the pulp chamber, as well as the presence, location, and extent of calcifications within the pulp cavity, among other features. However, it is essential to note that its limitations are related to the 2D planar images, which result in the superimposition of structures that are located at different spatial levels. This situation leads to a loss of valuable information regarding three-dimensional spatial volumes. This limitation can be overcome using Cone Beam Computed Tomography 3D scanning. This system allows for the acquisition of three-dimensional images of the outer and inner structures, providing accurate 3D relationships both morphologically and metrically. The images provide data on the depth and extent of cavities, precise locations of perforations, calcifications, and more in relation to adjacent structures (Berman and Hargreaves 2021). The 3D technology of CBCT offers valuable information that enables better analysis, diagnosis, and treatment. CBCT is widely used in the odontological and medical professions and in forensic odontology (Izham and Auerkari 2021) and is currently the standard technique in dental 3D imaging (Caruso et al. 2014). On the other hand, its application to archaeological human skeletal and dental remains is still limited to specific cases and has yet to be introduced at a large scale. In our case, the aforementioned advantages of CBCT were leveraged to unveil some secrets of Maya interventions in immature human teeth.

3.3. Cultural meaning

Though the goal of this paper does not extend to an in-depth discussion of the cultural reasons behind filing and inlaying teeth in ancient Maya society, this finding may contribute to expanding the understanding of social roles of children in Prehispanic times. Tiesler (2024) thoroughly discusses the cultural meaning of such procedures, stating (2004:57) that "The bulk of evidence suggests that most initial dental procedures occurred in the years following puberty: the onset of proper manhood and womanhood. In this transition, dental carving consecrated adult self-constitution and permanently sealed the status change of the bearer together with his or her final integration into the community of grown-ups". This represents a step into a social age, a ritual of passage that denotes the acquisition of a certain position within the community. These undoubtfully painful procedures marked the juveniles' life steps into maturity, marriages, and other social roles (Houston 2018; Tiesler 2024).

As mentioned above, intentional filing is first visible in the archaeological record in the 10–15-year-old age category, while inlays appear at a later age. The three individuals in this study fall into the preadolescent category and are about five to six years younger than the youngest individual with inlays known so far, as reported by Tiesler (2024). However, in relation to social roles and life transitions, preadolescents by age 10 were already considered suitable for housework (girls) or to support the adults in the milpas (boys) (Farriss 1984). Therefore, we cannot rule out that these preadolescents might have been

marked by visual adornments in the form of dental modifications that would confer them a status of social maturity. Obviously, the total lack of context and provenance of these teeth limits any interpretation to simple assumptions that would remain as such until further well contextualized evidence of this kind is brought to light and discussed.

3.4. Oral health

The process of inlaying a tooth produces breakage in the enamel, which may represent a potential danger for the health of the tooth and, therefore, of the individual. If not properly sealed, the cavity may leak, allowing oral bacteria to penetrate and proliferate into the tooth's softer tissues and trigger carious lesions. In modern dentistry, a carious lesion that forms in the place of a previously restorative intervention is known as secondary caries and is usually due to an inadequate sealing cement (Anusavice 2011). Ramírez-Salomón et al. (2018) reported that 19.7 % (38/193) of the Prehispanic Maya teeth they analyzed with inlays, either with the stone still embedded in the enamel or with an empty cavity (i.e., the stone had fallen out sometime during the individuals' life or after death) manifested carious lesions. However, only one of them still had a stone inlay in place, while the others were either stoneless or whose filling was of unidentified origins (Ramírez-Salomón et al. 2018:206). Overall, 58.5 % of the specimens they inspected still had inlays in place even after more than a millennium. Hernández Bolio et al. (2022) described the nature of the filling cement and noticed that vegetal resins and essential oils were among the basic components in all the kinds of cements they inspected by combined FTIR, microCT, and XRF analyses, coupled with GC–MS (gas chromatography – mass spectrometry). These materials reportedly possess antibacterial, antifungal, and anti-inflammatory properties, alongside the resins' optimal sealing and binding properties.

The three cases presented in this study do not show any evidence of pulp pathosis or progressive caries in their enamel and dentine tissues. No specific chemical-physical analyses have been performed by the time we present this study on the characteristics of the cement used to keep the jade inlays in place, so we cannot make any inference on the quality and properties of those materials. Nonetheless, the lack of caries indicates that they must have acted as an efficient barrier against oral bacteria, even though they performed this task for a relatively short time before the death of these young individuals.

4. Conclusions

In conclusion, morphological, radiographic, and CBCT scan analyses of three still-growing teeth sporting jade inlays indicate that these individuals ranged between 7.5 and 10 years at the moment of death. The analyses show dentine reaction in the pulpal chamber of all the teeth in correspondence to the place in the crown where the cavity had been drilled to insert the stone. This reaction indicates that the dentine tissue was alive when the drilling was performed and reacted as a physiological way to protect itself from the mechanical stress exerted. Inlays are well known in the Maya area in individuals in their late subadult and adult (>20 years) categories but, prior to this case, have never been reported in children as young as those documented in this paper.

The use of modern CBCT analytical techniques, coupled with common morphoscopic and radiographic inspections, provides more in-depth visual evidence of dental physiological processes that allows us to generate sound hypotheses on biocultural practices among the Prehispanic Mayas. Though CBCT tomography is rapidly becoming common procedure in strictly odontological studies, it is slowly gaining its place in bioarchaeological analyses as well. As this study has shown, its more consistent application will open multiples lines of research in disparate fields of dental anthropology.

Last, the complete decontextualization of these three specimens prevents us from assessing whether they belonged to one or up to three different individuals. Unless more cases are documented, any possible interpretation of the reasons behind performing these permanent modifications in such young individuals remains at the level of assumptions and cannot be generalized to the whole Maya realm.

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CRediT authorship contribution statement

Marco Ramírez-Salomón: Writing – original draft, Visualization, Validation, Supervision, Investigation, Formal analysis, Conceptualization. **Estuardo Mata-Castillo:** Supervision, Resources, Investigation, Data curation, Conceptualization. **María Beatriz Monsreal-Peniche:** Conceptualization, Data curation, Investigation, Methodology, Validation, Formal analysis, Visualization. **Camilo Luin:** Validation, Supervision, Resources, Methodology, Investigation. **Héctor Klee-Bueso:** Conceptualization, Formal analysis, Methodology, Resources, Validation, Software, Visualization. **Andrea Cucina:** Writing – original draft, Visualization, Validation, Formal analysis, Conceptualization, Writing – review & editing. **Elma Vega-Lizama:** Writing – original draft, Visualization, Validation, Supervision, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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