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A taphonomic reassessment of Qafzeh 25 and its implications for violence, health and funerary practices

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The Qafzeh cave preserves one of the most significant Middle Paleolithic human assemblages, offering key insights into health, possible violence, and funerary behavior among human Middle Paleolithic samples. In this study, we present new evidence of sharp-force trauma in the individual Qafzeh-25. The integrated macro-, microscopic, and micro-computed tomography analysis revealed a linear lesion affecting the left mandible and third premolar, consistent with an injury caused by a sharp object. Localized bone porosity and marginal thickening consistent with remodeling indicate that the lesion underwent a healing process, suggesting that the individual survived for a period of time after the injury. This case may represent one of the earliest documented examples of sharp-force trauma in the archaeological record and contributes to the limited evidence of possible interpersonal violence during the Middle Paleolithic. The taphonomic study conducted here confirms that Qafzeh-25 was deliberately buried, reinforcing previous interpretations of the site as a place of formal burials in the early Late Pleistocene. Additionally, we identified additional dental pathologies, including new carious lesion and enamel defects. These findings add to the previous recorded evidence of caries and dental anomalies in the Qafzeh sample, highlighting both biological vulnerability and possible hereditary or environmental factors. Together, the trauma, oral pathologies, and funerary context illuminate the complexity of health, social support, and culture of death in the Pleistocene human fossil record.

Keywords Middle Palaeolithic, Qafzeh cave, Palaeopathology, Caries, Sharp force trauma, Taphonomy

One of the central topics in human evolution is the study of past population behavior. Certain behaviors, such as violence, caregiving, or funerary practices, can leave identifiable traces on skeletal remains and/or in the archaeological contexts in which they are found[1,2]. In this regard, taphonomic and paleopathological analyses are essential tools for inferring such behaviors through bone modifications. By distinguishing antemortem, perimortem, and postmortem modifications, taphonomic analysis offers fundamental insights into funerary practices, site formation, and post-depositional alterations[3,4]. Paleopathological studies are key to identifying injuries of varying severity that affected past populations, and more importantly, for understanding how these populations responded to such conditions[5]. The fossil record shows a wide range of pathologies documented since the Early to the Late Pleistocene[6–13]. Among these, traumatic injuries are frequently documented. In some instances, the lesions show signs of healing, providing indirect evidence of survival as observed at Sima de los Huesos[14], Shanidar[15], Qafzeh[16], Zuttiyeh[17], Maba[18], Krapina[7], St. Césaire[19], or Dolní Věstonice[12]. By contrast, in other cases, the absence of healing suggests that the injuries were likely lethal[14,20,21]. Blunt force trauma is the most common type of lesion recorded in the Paleolithic, whereas evidence of injuries caused by sharp weapons or projectiles is extremely rare, particularly during the Middle Paleolithic (see Sala et al.[20] and references therein). To date, only few cases have been identified, including Shanidar 3, which exhibits a penetrating lesion

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on a rib interpreted as a possible projectile wound, likely associated with interpersonal violence[22,23]. Similar assumption was given for the Middle Paleolithic specimen Skhul IX[24], although it later dismissed by Churchill and colleagues[22] as the result of a post-excavation perforation. Regarding the Upper Paleolithic, Sunghir 1 presents a perimortem penetrating wound associated with a sharp object, which has been interpreted as resulting either from a hunting accident or from a social altercation, and thus represents a possible, though not unambiguous, case of interpersonal violence[25,26]. Similarly, the recently published case from Riparo Tagliente[27], in which an individual shows marks consistent with projectile impact, further contributes to the still scarce evidence of sharp force trauma in the Upper Paleolithic. Even though such lesions could potentially result from accidents, such as hunting injuries, they have generally been interpreted as evidence of interpersonal violence. Other well-documented cases of interpersonal violence appear to become increasingly frequent toward the end of the Pleistocene, particularly in increasingly semi-sedentary societies, such as at Jebel Sahaba in Africa[28]. This pattern seems to intensify further during the Mesolithic, when the archaeological and osteological record shows a marked increase in severe and potentially lethal interpersonal trauma[29]. This interpretation has significant behavioral implications, particularly regarding group or individuals' confrontation, and contributes to our understanding of the evolution of human social dynamics.

In this study, we examine an unusual mandibular and dental alteration in individual 25 from Qafzeh cave, assessing its morphology and taphonomic characteristics in order to evaluate possible etiological scenarios. We further analyze the timing of this alteration and consider its broader implications within Middle Paleolithic contexts. In addition, we explore a series of dental alterations related to oral health and conduct a detailed taphonomic assessment of the Qafzeh 25 skeleton to evaluate whether its preservation is consistent with intentional burial. Together, these lines of evidence contribute to ongoing discussions concerning health, trauma, and key behavioral dimensions such as interpersonal violence and funerary practices during the Middle Paleolithic.

The Qafzeh cave

The Qafzeh cave, located in the Lower Galilee near Nazareth (Israel), has yielded one of the most significant collections of Late Pleistocene human skeletal remains known from Southwestern Asia[30–32]. Initially excavated by René Neuville and Moshe Stekelis from 1933 to 1935, Qafzeh cave has yielded a rich stratigraphic sequence that includes layers from the Holocene, Upper Paleolithic, and Middle Paleolithic periods[33]. The site gained further attention with renewed excavations from 1965 to 1979, led by Ofer Bar-Yosef and Bernard Vandermeersch[31,34–36].

The site has yielded the remains of at least 27 individuals, generally attributed to early *Homo sapiens* but exhibiting considerable morphological variability, with their taxonomic attribution discussed in detail in recent studies[37]; most remains are concentrated within a few square meters in front of the cave entrance, in the Terrace area[38]. Except for two Upper Paleolithic crania (Qafzeh 1 and 2) found inside the cave[32], all fossils were recovered from Middle Paleolithic layers, mainly from layer XVII, with additional individuals found in layers XV, XVa, XVI, and XXII[38]. The hominin collection includes adults and an unusually large number of children and adolescents, most of them deliberately buried, conditions that have made Qafzeh a touchstone for reconstructing health and disease in late Pleistocene foragers of Southwest Asia[38]. Thermoluminescence and Electron Spin Resonance analyses date the Mousterian sequence (layers XV–XXIII) to approximately 92–145 ka[39–41]. Paleoenvironmental records from the Middle Paleolithic sequence of Qafzeh Cave (Layers XV–XXV), which includes Layer XVII from which Qafzeh 25 derives, suggest a xeric grassland-type ecosystem with Afro-Arabian faunal elements, characteristic of the unique climatic conditions of MIS 5e[42]. The archaeological context of the Middle Paleolithic layers, characterized by a sparse Mousterian lithic assemblage, abundant micromammals, and few hearths, supports the interpretation that Qafzeh cave served primarily as a burial ground, with domestic activities likely carried out in the surrounding area[31,38].

The Qafzeh collection has yielded significant evidence of paleopathological cases. The immature individual of Qafzeh 10 (~6 years) presents a benign osteolytic defect of the right femur[43], representing a rare example of a pediatric bone tumor in a Middle Paleolithic context. Regarding the possible traumatic lesions, the juvenile Qafzeh 11 preserves a compound depressed fracture of the right frontal bone, with associated growth delay and probable neurobehavioral consequences, as well as distinctive funerary treatment interpreted as evidence of social care[16]. The adult Qafzeh 6 shows a probable cranial trauma, broadening the scope of head injuries at the site beyond a single case[16,43,44].

Additionally, several individuals present conditions indicative of impaired growth and development. Qafzeh 12 child (~3 years) exhibits cranial abnormalities consistent with hydrocephalus, one of the earliest such cases in the human fossil record[45]. Qafzeh 9 shows a cluster of mandibular growth-related abnormalities, including a non-ossifying fibroma, temporomandibular joint osteochondritis dissecans, and pre-eruptive intracoronal resorption[43,46]. Cases of dental agenesis further highlight the incidence of developmental anomalies in this sample[43,47]. Together, these findings suggest that congenital and growth-related disorders were relatively common among the immature individuals at Qafzeh, with potential functional and social consequences[47].

Lastly, previous research has also documented a wide range of dental abnormalities. These include linear enamel hypoplasia in Qafzeh 26 and 27, with Qafzeh 27 representing the first child from the site showing this defect[48]; hypodontia in Qafzeh 15, characterized by the absence of both lower second premolars[49]; and pre-eruptive intracoronal resorption in Qafzeh 9, leading to structural weakening of the tooth[46]. The adult Qafzeh 6 shows a high number of dental pathologies, with seven of thirteen preserved teeth affected[48]. Tooth rotation is a congenital trait present in Qafzeh 25[50] and also documented in other individuals from the Qafzeh assemblage, including Qafzeh 11 and Qafzeh 15[30,43,51]. Many of these diagnoses were made possible through CT-based approaches, highlighting the importance of virtual imaging for documenting pathological, traumatic, and taphonomic changes.

The lesions recorded in individuals from Qafzeh exhibit varying degrees of severity and likely entailed different levels of risk for the affected individuals. Among the potentially life-threatening cases, individuals such as Qafzeh 11[16], and 12[45] may highlight both the vulnerability of these immature individuals and the possible presence of conspecific care. Claims of documented conspecific care have been proposed for several fossil individuals, including Aubesier 11[52], Dmanisi (D3444/3900)[53] or Sima de los Huesos Cranium 14[8]. However, as noted by DeGusta[54], it is essential to distinguish between conditions that impair quality of life and truly life-threatening pathologies that would have required sustained support for survival. In this regard, Hublin[55], emphasized that chimpanzees with severe impairments, such as amputations, may overcome these disabilities without conspecific care. By contrast, cases of survival, even if not extending into adulthood, have been documented in individuals affected by clearly life-threatening conditions, including SH-Cranium 14[8], Cova Negra[56] and Salé[55]. Within this framework, individuals Qafzeh 11[16] and 12[45], who exhibit evidence of potentially life-threatening conditions, may reflect episodes of group compassion and care.

Yet, despite extensive research on trauma and pathology in the Qafzeh series, a previously overlooked mandibular alteration is presented here. Within this framework, a detailed taphonomic and pathological study of Qafzeh 25 offers an opportunity to further explore health, trauma, and mortuary behavior in early *Homo sapiens* from the Levant.

Material

Qafzeh 25

Qafzeh 25 is a partial adult skeleton discovered in 1979 during the final excavation campaign at Qafzeh Cave[38]. Unearthed from Layer XVII in square C10, the skeleton was found in close association with remains of immature individuals, including Qafzeh 4, 21, and 22[30,31,38,57]. Due to its fragile condition and extensive post-mortem alterations, Qafzeh 25 was removed in a sediment block and later excavated in controlled laboratory conditions[38].

The skeleton of Qafzeh 25 is housed at the anthropological collection of the Dan David Center for Human Evolution and Biohistory Research, Gray Faculty of Medical and Health Sciences, Tel Aviv University. The preserved remains consist of the cranium, mandible, with nearly all dentition in situ, and several postcranial elements (SOM Fig. S1; See SOM for the complete description of the bones preservation). However, much of the lower limbs were lost due to earlier excavation activities in 1934[38].

Dental and skeletal analyses indicate that Qafzeh 25 was a young adult at the time of death. While sex estimation remains uncertain, the overall cranial and mandible robustness aligns more closely with adult male individuals from Qafzeh, such as Qafzeh 3 and 6[50,58].

While there is unequivocal evidence for the funerary nature of this assemblage, including several single burials, with the exception of one double[38], there is no direct evidence of a burial pit in the case of Qafzeh 25. However, the Qafzeh 25 skeleton is in anatomical position, and the remains have not displaced from the space originally occupied by the body, suggesting that the individual decomposed in a filled area, possibly indicating intentional burial[38].

Results

Taphonomic analysis

The entire skeleton exhibits extensive fracturing, with all analyzed fractures showing characteristics of postmortem breakage, many of them modern (SOM). The bones are particularly affected by compressive damage, displaying crushing and collapse of cortical structures. Despite this deformation, the fragments have remained in anatomical association, preserving their spatial relationships even though they are severely compressed (SOM Fig. S1). These fractures display right angles and jagged fracture surfaces, typical of dry-bone fractures[3]. The bones exhibit extensive concretion. Additionally, no signs of weathering, trampling, root etching, carnivore tooth marks, or cut marks were observed on the surfaces free of concretion that could be examined (SOM Table S1).

The mandibular region, particularly around the LP_3, presents complex postmortem fracturing that merits closer examination (Fig. 1; SOM Fig. S3 & S4). The left P_3 shows a combination of displacement and fracturing. Part of the tooth, including the root, as well as portions of the distal and mesial crown margins and the central dentine, remains in its original anatomical position. However, a fragment of the crown, corresponding to the mesiobuccal portion, has been displaced distally due to a transverse fracture crossing the longitudinal axis of the tooth (SOM Fig. S2). This displaced fragment includes the triangular fossa, the apex of the lingual cusp, and part of the apex of the buccal cusp. Both the in-situ and displaced portions of the tooth display multiple longitudinal and transverse fractures, which appear consistent with post-depositional damage. The crown fragment remains attached to the mandible due to calcite concretion, preventing its complete detachment, and traces of a chemical adhesive (SOM Fig. S3 & S4) likely applied during restoration are also visible.

Macroscopic and microscopic observation, together with the micro-computed tomography (mCT) images, revealed a series of bone anomalies affecting the left maxillomandibular region, involving both the bone and the dentition. A relatively deep, linear mark was identified macroscopically on the left mandibular region, affecting both the bone but and the LP_3 (Fig. 1; SOM Figs. S2–S5). The mark exhibits an overall V-shaped cross-sectional morphology and extends approximately 9 mm along the buccal surface, with about 7 mm affecting the tooth itself (Fig. 1). V-shaped morphology generally refers to the convergent configuration of the kerf walls, particularly in the portions affecting only bone tissue (Fig. 1c and 1d). However, as the groove is explored along its trajectory, especially in the sector involving the tooth root, the morphology of the kerf floor may become broader and more open, acquiring a more U-shaped-like appearance (Fig. 1b). At the superior border of the mandible, the mark is associated with a localized loss of both root dentine, with no pulp involvement, and alveolar bone (Fig. 1a–b). This area forms a step-like discontinuity on the bone surface and corresponds to a zone of dentine loss measuring approximately 5 mm along both the longitudinal and transverse axes of the tooth (Fig. 1a–b.) Inferior to this

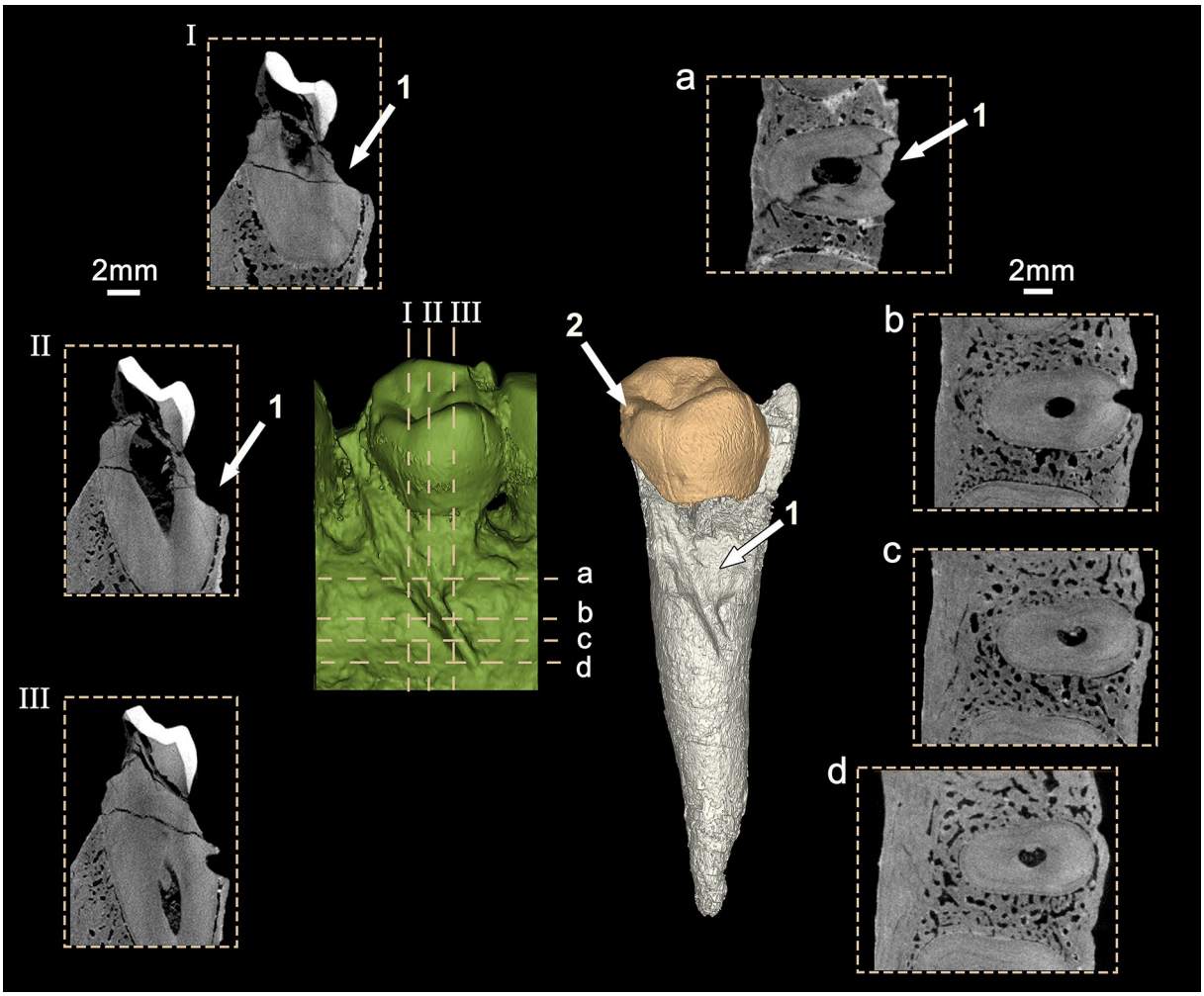


Fig. 1. MicroCT-based analysis of the mandibular mark in Qafzeh 25. (1) Dentine loss; (2) enamel chip on the crown of the LP_3. Images I–III and a–d show coronal (I–III) and axial (**a**–**d**) mCT sections at the level of the LP3, where the mark is visible along with the dentine chipping. The green surface represents the 3D model of the original mandible. In image d, the mark affects only the mandibular bone, while in panel c, the lesion begins to reach the dentine. The 3D model of the P3, shown in white and orange, depicts the reconstructed tooth following alignment (see SOM for details).

area, the linear mark continues for approximately 5 mm in an inferoposterior direction. In its upper portion, the lesion affects both dentine and bone, whereas over the final ~ 2 mm it is restricted to the mandibular bone (Fig. 1b–d). Besides, it is covered with sediment adhering to its surface (SOM Fig. 4).

In the vicinity of the lesion, the bone surface displays localized patches of porosity (Fig. 2), which may correspond to bone remodeling associated with healing process driven by osteoclastic and osteoblastic activity. This porous texture contrasts with other areas of the mandible, which show a smooth compact bone surface and no evidence of pathological alteration or remodeling (Fig. 2). Additionally, the margins of the fracture appear thickened and project buccally (Fig. 2), interrupting the natural curvature of the bone. This localized bone thickening is consistent with callus formation during fracture healing.

Tracing the mandibular linear mark from superior to inferior, a small antemortem enamel chip affecting the crown of the left lower third premolar (P3) is observed (Figs. 1; SOM Fig. S5). Following the classification of Bonfiglioli et al.[59], this feature corresponds to a grade 1 enamel chip. Similar enamel chips are relatively common in paleoanthropological and bioarchaeological contexts and may result from masticatory or non-masticatory activities[60,61]. In Qafzeh 25, the chip is located near the reconstructed trajectory of the mandibular lesion, although a direct relationship between both features cannot be established. No macroscopic features typically associated with dental caries, such as a depression with a roughened surface texture, are observed in this area (SOM Fig. S5).

Additional observations are recorded in the left maxilla. MicroCT imaging reveals a horizontal fracture affecting the maxillary dentition, resulting in the fracturing and displacement of the crowns, which are locally retained in position by concretion (Fig. 3C). This fracture pattern is consistent across the maxillary teeth on the left side, including the upper left canine (Fig. 3C).

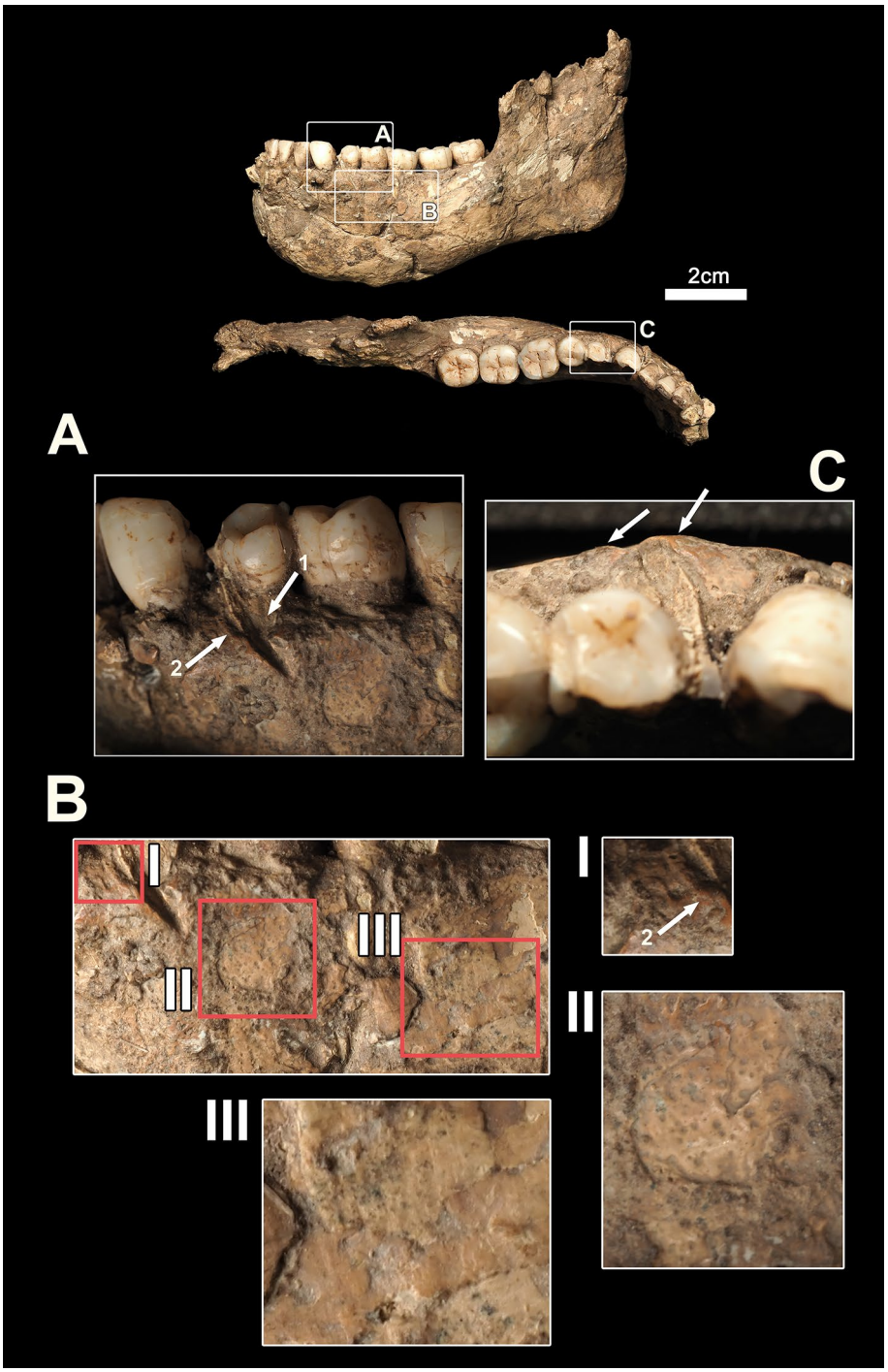


Fig. 2. Analysis of the mandibular mark and surrounding region in Qafzeh 25. (**A**) Detailed lateral view of the mark on the mandible. (1) Localized bone loss; (2) step-like discontinuity associated with bone loss. (**B**) External morphology of the mandibular cortical surface in different regions. Panels I and II show areas interpreted as remodeled bone, whereas panel III illustrates cortical bone without evidence of remodeling. (**C**) fracture margins that appear thickened and project buccally.

In this context, the upper left canine is characterized by the absence of the crown, while the remaining root displays concretion adhering to the fracture surface, indicating that concretion formation postdates the separation of the crown from the root (Fig. 3B). When the trajectory of the mandibular linear mark is projected superiorly toward the maxilla, it corresponds spatially with the position of this tooth (Fig. 3A). The root surface cannot be reliably segmented or visualized three-dimensionally in the microCT data, as it is entirely covered by adherent sediment with radiodensity values overlapping those of superficial dentine. As a result, assessment of the root surface is restricted to two-dimensional microradiographic observations (Fig. 3D). Examination

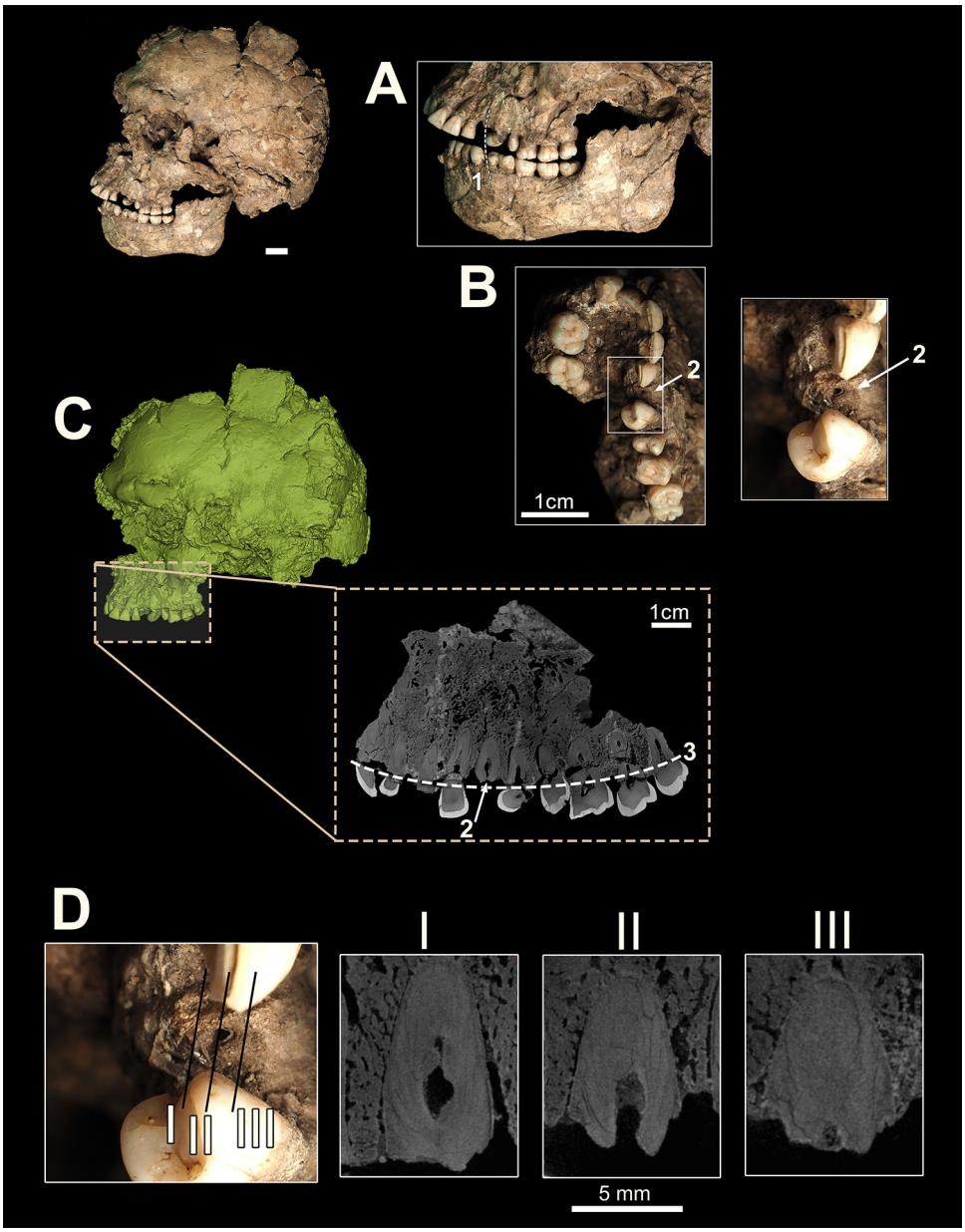


Fig. 3. MicroCT-based analysis of the left maxillary region. (**A**) Left mandibular and maxillary region with the proposed trajectory of the trauma (1). (**B**) Detail of the root of the left upper canine (2); note the in situ preservation of the root, which is covered by sediment. (**C**) CT visualization of fractures affecting the left maxillary dentition. A horizontal fracture line extends across all teeth on this side (3). The white arrow indicates the position of the canine root (2). (**D**) Two-dimensional mCT sections of the root of the left lower third premolar.

of these 2D images does not reveal features indicative of smoothing or wear of the dentine surface that would suggest prolonged functional exposure prior to crown loss (Fig. 3D).

Dental pathologies

In addition, we performed a detailed inspection of the other dental remains of Qafzeh 25 using high-resolution mCT images to identify any lesions not previously reported. This analysis revealed both structural defects and developmental anomalies, and no evidence of toothpick use, providing valuable information about the individual's oral health.

Left P_4

As observed by Schuh and colleagues[50], the LP_4 is rotated. The rotation measures 65° in a distobuccal direction, positioning the lingual surface mesially and the labial surface proximally. This rotation is not observed in its antimere or any other tooth of Q25, and it cannot be attributed to postmortem processes, as the root and the

contact facet with the P_3 remain in their original positions (Fig. 4). Qafzeh 11, a 13-year-old child, exhibits rotation of the same tooth, the left lower second premolar, but with a different orientation, as it is torsioned mesiobuccally[30] (SOM Fig. S6).

Internally, the entire left P_4 exhibits numerous fine fissures affecting both the enamel and dentine. A more prominent transverse fracture is observed in the upper third of the root (Fig. 4A). This fracture is nondisplaced, with the segments remaining in their original positions. The pulp cavity exhibits scattered high-density points corresponding to adhered sediment (Fig. 4A).

Externally, on the mesial interproximal surface of the LP_4, an interproximal facet is observed in contact with the LP_3. Internally, on the distal cervix, 1.5 mm below this contact facet, an elongated, bubble-like enamel demineralization is present (measurements: volume 0.0513 mm^3; buccolingual length 1.5 mm; width 0.25 mm; height 0.35 mm) (Fig. 4B). The demineralization anomaly is affected by a longitudinal fracture that extends

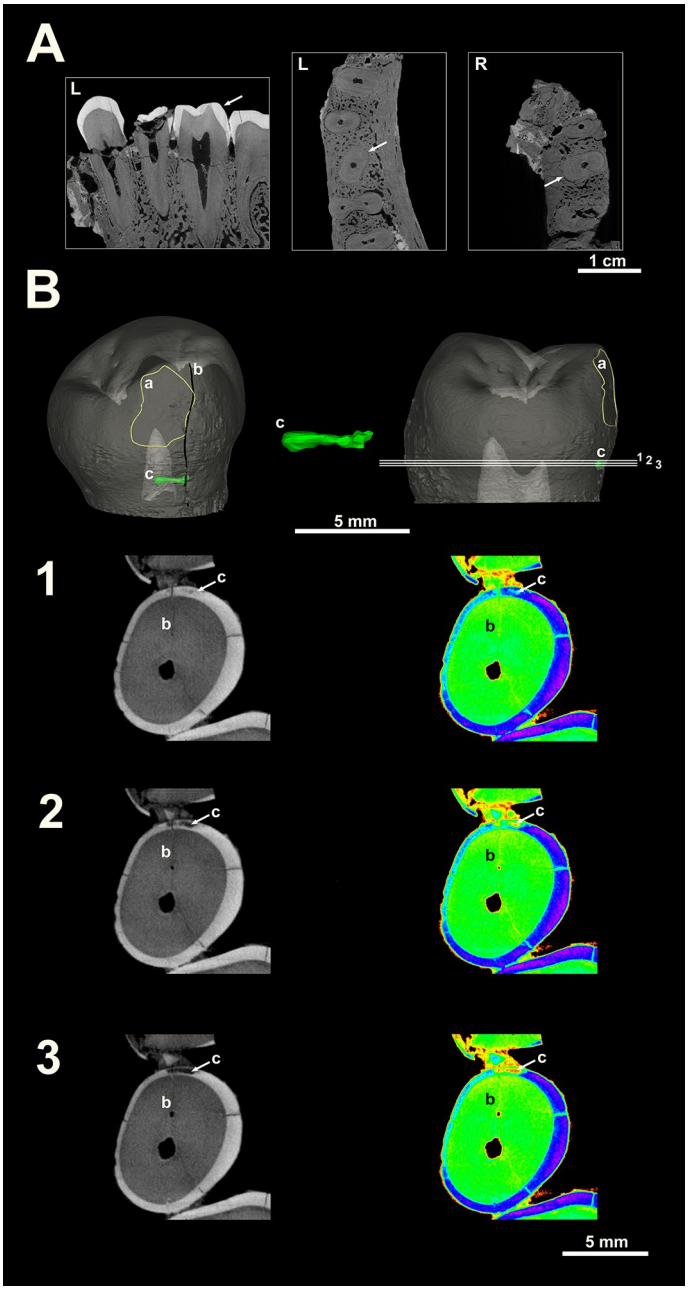


Fig. 4. Internal structure of the left lower P_4. (**A**): Sagittal and horizontal sections of the C-M1 teeth; L: left dental pieces; R: right dental pieces; white arrow indicates left and right lower fourth premolars. (**B**): mesial view of the virtual reconstruction of the left P4: (**a**): contact facet with the P3; (**b**): main linear fracture in the mesial region; (**c**): demineralization bubble; 1, 2 and 3: horizontal slices sowing the internal structure of the demineralized region. The images in grey are the visualization in gray values, the colored images on the right are the images obtained with the Sawtooth color scale visualization (See SOM).

across the entire crown, indicating that the lesion predates the fracture. The bubble does not have an external opening; instead, it remains enclosed by a thin enamel layer that isolates it from the external environment.

To assess the degree of demineralization in this area, we measured the average density values in selected regions, including dentin, healthy enamel, the enamel layer surrounding the bubble, and the sediment deposited between the two premolars. The results show that the density of the enamel around the bubble is higher than that of the sediment or dentine but significantly lower that of healthy enamel, indicating that this structure represents a hidden caries. Thus, the observed demineralization is a consequence of the structural changes caused by the infectious/bacterial process (SOM Table S2).

First lower molars

Following previous reports by Coutinho-Noguiera[58] on the upper and lower first molars of Qafzeh 25, we examined the mCT images to assess whether these features correspond to carious lesions. We identified enamel loss along the mesiolingual margins of both lower first molars, with the left M1 exhibiting a more pronounced surface depression. These lesions are characterised by smooth, polished edges, and are confined to the enamel, with no apparent involvement of the dentine (Fig. 5). Although these features show morphological similarities to the lesions described by Coutinho-Nogueira and colleagues[45] for the left M1 of Qafzeh 9, which were identified as carious lesions (see their Figs. 7 and 8), we cannot confidently interpret the enamel loss observed in Qafzeh 25 as carious in origin. The mCT images do not reveal signs of enamel demineralisation typically associated with bacterial activity. Instead, we suggest that these features more likely represent enamel chipping that occurred during the individual's lifetime, after which the teeth remained functional, as indicated by the rounded margins of the defects.

Conclusive discussion

The analysis of Qafzeh 25 provides valuable insights into the paleobiology and funerary practices of early modern humans in the Middle Paleolithic Levant. The combination of mCT imaging and detailed morphological assessment has enabled the identification of previously undocumented pathological features, reinforcing the methodological advances in virtual imaging applied to fossil specimens[8,10,16,46,62,63].

In this study, we present evidence associating the abnormalities in the dental and bone structures of the left region of the Qafzeh 25 mandible. Specifically, the lesion consists of a linear mark of overall V-shaped morphology, with rounded edges (Fig. 1; SOM Fig. 3), following a trajectory that involves both the premolar and the mandibular bone. The combined characteristics of the mark, including its overall convergent morphology, anatomical trajectory, and orientation support its interpretation as a lesion produced by sharp object trauma. The available evidence indicates that the blow most likely grazed the crown before impacting the superior border of the mandible, resulting in the loss of dentine and bone. The horizontal fracture and displacement visible in the preserved portion of the crown are clearly postmortem, as they follow the same fracture line affecting the adjacent teeth in this region. If the fracture had resulted directly from the impact, this portion of the crown could not have remained distally displaced in its current position. Nevertheless, it remains uncertain whether any missing portions of the crown were detached at the moment of impact or subsequently lost during the fossilization process.

Although the trajectory of the mandibular linear mark aligns spatially with the position of the upper left canine, whose crown is missing, a definitive association between this dental loss and the mandibular lesion cannot be established. The absence of wear-related modifications on the exposed dentine suggests that, if crown loss occurred, the dentine surface was not functionally exposed for a sufficient period to undergo abrasion.

We established that the injury occurred antemortem as it exhibits clear evidence of bone remodeling, including localized patches of porosity (Fig. 2) and fracture margins that appear thickened and project buccally (Fig. 2). Together, these features indicate that the healing process had already begun and suggest that the individual survived for a significant period after the injury.

The absence of infection may be explained because, although the dentine was exposed, the trauma did not reach the pulp chamber, which may explain the absence of evidence for dental infection associated with the lesion. This healing response parallels other cases of craniofacial trauma in the Pleistocene fossil record, such as the healed cranial fracture in Qafzeh 11[64], the remodeled depression in Maba 1[18], the healed vault lesion in the St. Césaire Neanderthal[19], or the several cranial healed lesions documented in the Sima de los Huesos population[14,21]. This evidence supports the notion of resilience and possible care within the community, adding to the growing documentation of survival after serious injuries among Pleistocene human populations.

In this context, Qafzeh 25 represents a new case among the extremely limited number of Middle Paleolithic individuals interpreted as exhibiting signs of sharp-force trauma. Injuries produced by sharp implements are exceedingly rare in the Middle Paleolithic record and are most often discussed in relation to interpersonal encounters, although accidental scenarios cannot be entirely excluded. The only other comparable case is Shanidar 3, which exhibits a rib lesion interpreted as sharp-force trauma most consistent with interpersonal violence, while alternative explanations remain possible[22,23]. In addition to the nature of the lesion itself, its anatomical location may provide further insight. The mark in Qafzeh 25 is located on the left side of the face. Forensic studies of modern human populations have reported that craniofacial injuries resulting from blows are more frequently observed on the left side of the skull, a distribution commonly attributed to the predominance of right-handed assailants in face-to-face confrontations[2,65–68]. While lateralization alone cannot definitively distinguish between violent and accidental mechanisms, the combination of a lesion consistent with sharp-force trauma and its left-sided facial position renders an interpersonal interpretation more plausible than an accidental one, even if the latter cannot be categorically ruled out. Qafzeh 25, an archaic *Homo sapiens* individual from the Middle Paleolithic, would represent the earliest documented case of sharp force trauma in the archaeological record.

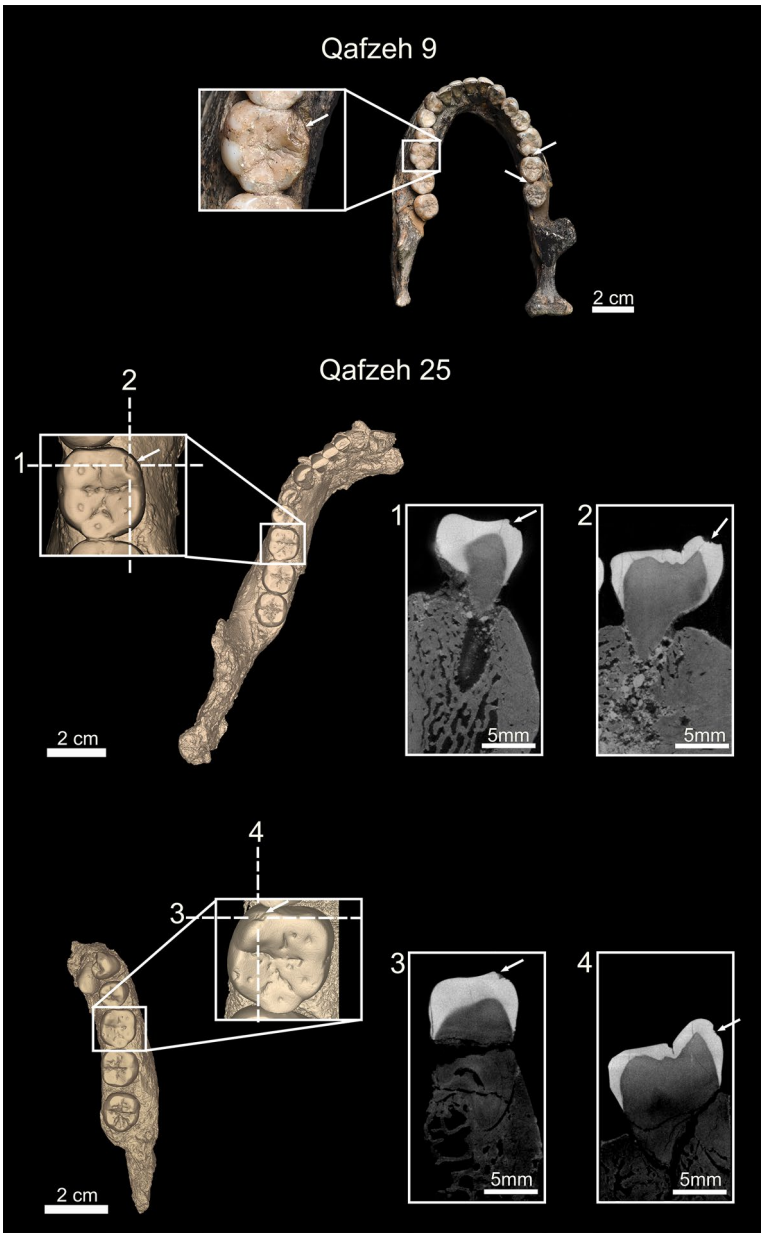


Fig. 5. Superficial enamel loss on the mesiolingual cusps of the lower first molars of Qafzeh 25 and the left lower molar of Qafzeh 9. Qafzeh 9: White arrows indicate the three external lesions that have been previously identified as a carious by Coutinho-Nogueira et al.[58] (for mCT images of these lesions, see Figs. 5, 6, 7, 8 and 9 in Coutinho-Nogueira et al.[58]). Qafzeh 25: withe arrows indicate the superficial enamel defects present in both M_1 mesiolingual cusps. Numbers 1, 2, 3, and 4 correspond to mCT images showing coronal and sagittal sections of the lesion in the left and right M_1, respectively.

By inspecting the mCT images, we also identified a carious lesion on the distal surface of the left P_4. Signs of demineralization were observed within the inner enamel beneath an apparently intact enamel layer, consisted with a non-cavitated lesion, also known as hidden caries. This constitutes the first documented case of dental caries in a premolar within the Qafzeh sample, expanding the known variability of dental pathology at the site. In addition, although we identified morphological similarities between Qafzeh 25 enamel loss on the mesiolingual cusps of both M_1s and the purported carious lesions described in Qafzeh 9 (see Figs. 7–8 in Coutinho-Nogueira and colleagues[46],) , we cannot confidently conclude that the lesions correspond to carious lesions due to the lack of enamel demineralization in the mCT images. Still, we have described new evidence of dental caries contributing to the existing record of oral pathology in the Qafzeh hominin assemblage. Prior to this work, dental caries had already been reported in several individuals from the site, including Qafzeh 3, 4, 6, 7, 9, 11 and specimen H4[43,44,46,69,70] (Table SOM-S3), indicating that carious lesions were not uncommon within the sample. With the inclusion of the lesion identified in Qafzeh 25, the number of documented carious teeth at Qafzeh now reaches at least ten, and represents the first example of a carious lesion in a premolar in this assemblage. While the

occurrence of caries in Qafzeh is not novel, the high number of affected individuals within a Middle Paleolithic population remains unusual. This is particularly striking given the generally low prevalence of dental caries in other Pleistocene human groups (see references in Table SOM-S3). At present, within the Early Pleistocene dental assemblage, only one specimen (SK 15 from Swartkrans), attributed to early *Homo*, presents features consistent with two carious lesion[71]. In contrast, other assemblages, including Atapuerca-Sima del Elefante and Gran Dolina, notably lack evidence of carious lesions, despite detailed assessments of dental pathological conditions[72]. The only remarkable case in the fossil record is that of the African Middle Pleistocene *Homo* specimen Broken Hill 1, which exhibits carious lesions affecting eleven teeth. Several aetiological hypotheses have been proposed to explain this extreme condition, including dietary factors, such as the consumption of highly sugary foods, behavioural factors, such as poor oral hygiene, and developmental causes, including poorly mineralized enamel[73–75]. Later interpretations suggested that lead poisoning during this individual's lifetime, supported by the presence of Tanquerel's lines, has been proposed as the most plausible explanation for this rampant case of caries[76]. Caries appear to be rare among Neanderthals. To date, only a handful of carious lesions have been documented[4,57,77–80], despite the large available sample, which includes populations such as Sima de los Huesos and Krapina, where no carious lesions have been reported. Similarly, carious lesions appear to be rare in early *Homo sapiens*, with only a few individuals reported to exhibit caries, including Zhiren 2[81] and Skhul II[82]. According to the results presented by Lacy[83], the Qafzeh group exhibits the highest percentage of carious lesions per individual (40%) compared with Neanderthals (3.5%), Early Upper Paleolithic populations (15.9%) and Late Upper Paleolithic populations (26.2%). In this context, Qafzeh represents a notable case due to the high number of individuals affected not only by caries but by oral pathologies, demonstrating that, although relatively rare, oral disease was not absent among Middle Paleolithic groups. Finally, previous studies have suggested that the recurrence of dental anomalies, such as tooth rotation and agenesis, across multiple individuals in the Qafzeh hominins may reflect a hereditary component, raising the possibility that at least some of the individuals were biologically related[51]. Similarly, the carious lesions can reflect shared dietary preferences and, ultimately, environmental factors contributing to the oral health status of the Qafzeh sample. Our taphonomic analysis concluded that the preservation of the skeleton, with extensive postmortem fractures lacking weathering, or carnivore modifications, indicates that the remains were buried rapidly in a stable depositional environment, likely in situ and undisturbed, consistent with other Qafzeh burials[38].

Taken together, the pathological findings in Qafzeh expand/broaden the documented rage of dental disease and trauma in Pleistocene human populations. The combined evidence of localized mandibular trauma with probable survival and the presence of a hidden carious lesion in an anatomically rotated premolar enhances our understanding of health, biology, and social care in this sample.

Methods

For the pathological and taphonomic analysis, macroscopic and microscopic observations of the original fossil were complemented with analyses mCT image data (SOM). The application of mCT has become essential in the study of fossilized remains, particularly in taphonomic and pathological analyses[8,10,14,16,18–21,46,62,63,77,84]. As an imaging technique, mCT enables the examination of internal structures without damaging the specimens, preserving their integrity for further research. This method allows for the identification of internal anatomical features that would otherwise be inaccessible through traditional observation techniques, proving particularly valuable in resolving anatomical uncertainties, detecting internal lesions, and assessing bone and dental pathologies. Additionally, mCT facilitates the differentiation between taphonomic alterations and pathological conditions, enhancing the accuracy of paleopathological diagnoses.

In a previous study, the mandible of Qafzeh 25 was reconstructed from CT scans with voxel dimensions of 540 µm in width and height, and a voxel thickness of 625 µm[50,58]. In their analysis, Coutinho-Nogueira[58] noted that the absence of observed pathologies in Qafzeh 25 might be attributed to the inherent limitations of these acquisition parameters. In our study, we have addressed these limitations by employing a resolution 18 times higher, enabling the visualization of microstructures with enhanced precision and detail. The mCT scans of the cranium and mandible were conducted at the Dan David Center in Tel Aviv, using VISCOM X8060 µCT scanner, with a resolution of 30 µm isovoxel size for the maxilla and mandible, and 80 µm isovoxel size for the cranium.

For the Qafzeh 25 virtual reconstruction, a combination of semi-automatic and manual segmentation techniques in Mimics software (v.18) was employed to isolate dental fragments. Manual thresholding was necessary due to the overlapping grayscale values of sediment, bone, and dentine. Additionally, a virtual reconstruction of the left P_3 was conducted to assess its preservation, using the point registration method in Mimics software version 18 (see SOM Fig. 2 and SOM segmentation and reconstruction sections).

Data availability

The data generated during this study are included in this published article. The Computed tomography Scans from Qafzeh cave are available under request in the Virtual Library of Hominins Fossils courtesy of Shmunis Family Anthropological Institute, Gray Faculty of Medical and Health Sciences, Tel Aviv University.

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Author contributions

All authors contributed substantially to this work. APP, LMF and NS were responsible for the conception of the study, data analysis and interpretation, and drafting of the manuscript. HM and IH participated also in data acquisition and manuscript revision.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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