Timing of maxillofacial–oral injuries in an individual of the ancient city of Herculaneum (79 AD, Naples, Italy): a case report

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Running title

Maxillofacial–oral injuries in the ancient Herculaneum

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Conflict of Interest

We hereby declare that there is no conflict of interest of the authors.

Abstract

Background: This study is based on the skeletal remains of an adult female from the ancient city of Herculaneum (Naples, Italy), who was a victim of the eruption of the nearby Vesuvius Volcano on 24-25 August, AD 79.

Results and Discussion: Examination of the maxillofacial region revealed evidence of unilateral condylar fracture and dislocation, as well as traumatic dental injuries. The injuries observed might have been the consequence of a direct blow to the mental region that was transmitted in a direction that raised the mandible, causing an indirect fracture in the right condylar neck when the condylar head collided directly with the temporal glenoid fossa. This indirect impact also resulted in partial fracture of three dental crowns due to the violent impact of the arches between them, and the sharp impact together of the upper and lower teeth. It is suggested that these injuries were sustained due to an accidental fall when the individual was between 7 and 15 years old, which is supported by the morphology, location and extension of the injuries, and the characterisation of the impact.

Conclusion: These results are an illustration of how dental anthropology and forensic approaches can be applied with great benefit to archaeological skeletal remains.

According to the World Health Organisation (1), the term *injury* is used to describe physical damage that results when a human body is suddenly or briefly subjected to intolerable levels of energy. This can be a bodily lesion that results from acute exposure to energy in amounts that exceed the threshold of physiological tolerance, or it can be an impairment of function that results from a lack of one or more of the vital elements (i.e., water, air, warmth), as in drowning, strangulation or freezing.

Injuries are included under external causes of mortality and morbidity, and can be categorised in a number of ways. However, a commonly used method for classifying injuries is according to whether or not they were deliberately inflicted, and if so, by whom. In this way, injuries can be subdivided into three main categories: *(i)* unintentional (i.e., accidental); *(ii)* intentional (i.e., deliberate); and *(iii)* undetermined intent (i.e., when it is difficult to judge whether an injury was inflicted intentionally or accidentally) (2).

One of the most important considerations in any forensic investigation is to associate skeletal injuries with the time of death of the individual, because these might have important legal implications (3, 4). The evaluation of traumatic lesions can provide crucial incriminating evidence in a homicide trial. However, if these injuries occurred at a time before or after the death of an individual, they might not be relevant in a court of law. Using bone characteristics, forensic anthropologists can typically report the timing of traumatic events, through the analysis and differentiation of the skeletal remains of *antemortem* and *perimortem* injuries from *postmortem* damage. Similarly, bioarchaeologists and palaeoanthropologists frequently face the same issue when interpreting skeletal injuries from prehistoric or historic human skeletal remains.

Although it has been argued that the data available to forensic anthropologists rarely allows reconstruction of the physiological events that caused an injury, skeleton remains can provide information about the cause and manner in which injuries might have been produced (4).

The aim of this study is to present a case report on maxillofacial–oral injuries to illustrate how dental anthropology and forensic approaches can be applied with great benefit to archaeological remains. For this purpose, a precise morphological analysis of traumatic lesions was carried out, along with the hypothesis of the most probable cause and manner of the traumatic event.

Materials and methods

The site

Although Herculaneum was discovered at the end of the XVIII century, until 1982, archaeologists believed that the town had been evacuated before the tremendous volcanic eruption that destroyed it. Indeed, only six victims were found in the town, a number that appeared to be consistent with sudden deaths that typically occur in mass panic situations. When archaeologists identified the ancient beach of the Roman town, despite the near-perfect evacuation of the town, human skeletal remains were discovered. Some of these were on the ancient beach, and some were inside the sheds built on the beach that had probably been used to store boats (5-7).

This eruption of Vesuvius Volcano was preceded by a series of earthquakes, and it began on the afternoon of 24 August, AD 79. While some inhabitants remained in the town, the vast majority moved towards the beach, in an attempt to escape from the volcanic eruption. By nightfall the exodus was concluded, as shown by the volcanic rock strata, and as suggested by the oil lamps that some of the victims had in their hands. In the early hours of 25 August, AD 79, the first pyroclastic flow (a swiftly moving, hot mixture of volcanic gasses and ash) swept over the town and the beach, which killed about 250 of the inhabitants. Their deaths were caused by immediate dehydration, and in a number of cases, by thermal shock. The temperature of the first surge ranged from between 350 °C to 400 °C, as indicated by the ultrastructural alterations to the bones, wood and pyroclastic materials (6, 7). During the second hour of the night, when these people were already dead, a second surge arrived. Most of the damage to the human remains was probably caused by violent impacts of boulders, beams, tiles and bricks that were carried by this second flow, which tore through the town and threw material onto the beach (5-8).

Thus, this population from Herculaneum represents a unique and extraordinary sample of anthropological and archaeological value due to the relatively unusual way in which the sample was formed. The biological remains were from a living population; i.e., they were the victims of an instantaneous catastrophe, and so their palaeodemographic data are synchronous (5-8).

Materials

The bones of these ancient inhabitants of Herculaneum are in excellent condition, and the skeletons are almost completely intact. This is partly because the mud was an excellent preservative, and partly because the excavation was carried out painstakingly in 1982 by the anthropologist Sara Bisel, whose work was partially supported by the National Geographic Society (5, 7). From then until today, more skeletons in other parts of the ancient city have been discovered and recovered.

This study was conducted on the skeletal remains of a victim who died while tried to flee by sea from the ancient beach of Herculaneum (Naples, Italy), during the eruption of Vesuvius Volcano on 24-25 August, AD 79. The cranium is complete, although partially fragmented, with a well-preserved mandible. The upper body elements were optimally preserved despite the fragmentation of the cervical vertebrae, ribs, left clavicle, and right humerus, radius and ulna. The lower body elements were also well-preserved. The only absent bones are the majority of the right and left tarsals and carpals, metatarsals, and metacarpals and phalanges (Fig. 1).

The postcranial skeleton does not show any injury, so the material for this study is the cranium.

Methods

The skeletal remains are classified as E109, and following standard descriptive and metric criteria (9, 10) of the cranial and pelvic features, they belonged to a female individual. The discriminant functions of permanent dentition developed by Viciano et al. (11) with this same population were also applied. The estimated age at death (30-35 years) was based on the degree of dental wear (12, 13), the appearance of the pubic symphyseal surface (14) and the ilium auricular surface (15), the epiphyseal union of the long bones (16), and the dental development (17). The skeleton is well preserved and complete, and it is housed at the University Museum of Chieti (Italy).

Examination of the skeletal remains was initially carried out by naked eye. The cranio–maxillofacial region was then re-examined with the aid of a Leica Wild M8 stereozoom microscope at up to 50× magnification, under a Volpi Intralux 5000 ring illumination system. The images were captured with a Nikon D50 digital camera. X-ray analysis of the skull and mandible was carried out at the Villa Serena Hospital (Pescara, Italy) using a digital radiography system. The dental characteristics were analysed using dentistry and dental anthropological criteria, particularly in terms of oral disease. Tooth wear was scored with the eight-stage method of Smith (18). The presence or absence of calculus deposits was scored, as well as its severity, following the Brothwell criteria (19). Hypoplastic defects were classified according to the criteria of the World Dental Federation (*Fédération Dentaire Internationale*; FDI) (20). The tooth notation system used was that proposed by the FDI (21).

Results

Macroscopic analysis

The pathological findings from the cranio–maxillofacial region

The general appearance of the mandible is asymmetrical (Figs. 2a, 3a), with the right mandibular ramus more vertical than the left. The right mandibular condyle is strongly deformed by a complete fracture of the condylar process that has broken through the bone thickness above the pterygoid fovea; this forms a kind of proximal bone stump that comprises all of the condyle, which is folded anteromedially and welded perpendicular to the mandibular ramus (Fig. 2a). Thus, together with the fracture surface of the distal stump, what was initially the lateral surface of the condylar process constitutes a unique neocondylar surface that fits well with the right temporal glenoid fossa (Fig. 4). There are also two cracks in the right mandibular ramus and in the left angle of the mandible. These fractures have a clear *postmortem* origin.

In the mental region, the inferior margin of the mandibular body is uneven and rough (Fig. 3b). The left mandibular ramus is thicker and higher than the right, and the right mental tubercle is more prominent than the left. As a result of the fracture of the condylar process, the right ascending ramus is lower than the healthy contralateral. The right coronoid process shows a slight lateral deviation.

For the cranium, the right temporal glenoid fossa is flattened, with less depth compared to the contralateral. The bone surface corresponding to the right temporomandibular joint does not appear to be remodelled, and is without signs of osteoarthrotic changes (Fig. 5). The walls of the external acoustic meatus have not been affected (Fig. 6).

The pathological findings from the dentition

The dentition is composed of 28 well-preserved teeth. Teeth 12, 28 and 38 are missing, and these have left empty sockets without any sign of remodelling (i.e., *postmortem* tooth loss). Tooth 48 shows no evidence that it has erupted (see the radiographic analysis below). Although present, teeth 27, 32, 35, 37 and 41 are fractured below the level of the cement–enamel junction, which has resulting in the separation of the crowns from the roots. These fractures are clearly due to post-depositional processes or occurred during the archaeological recovery and curation. The roots remain inserted in their respective sockets, while the crowns are isolated or have been glued back on during the restoration. There is no evidence of caries or peri-apical infection. There are low levels of deposition of supragingival calculus deposits for the buccal surfaces of teeth 14, 26 and 27. All of the anterior teeth show linear enamel hypoplasia for the buccal surface. Teeth 11, 21, 22, 31, 32, 41 and 42 have three horizontal lines; teeth 13, 23, 33 and 43 have four horizontal lines. Thus, E109 suffered at least four different hypoplastic episodes, with the estimation that these episodes were in the range of approximately 1.5 years to 6.0 years old, according to the Goodman and Rose method (22). Low occlusal wear is observed, which ranges from unworn or polished with small facets (no dentine exposure) to moderate to full cusp removal and/or some dentine exposure (punctuated to moderate).

The crowns of the first molars show dental injuries, with considerable loss of substance (Figs. 2, 7). Tooth 16 has a fracture of the distobuccal angle that affects two-thirds of the crown, so that there is partial loss of the metacone cusp. Tooth 26 has a fracture of the mesiolingual angle that affects two-thirds of the crown, with a greater extent of fracture compared to the contralateral molar; there is also partial loss of the mesial surface of the protocone cusp. For both of the maxillary first molars, the injuries have affected the enamel and dentine, without pulp exposure or root involvement. Tooth 46 shows the greatest loss of substance. The fracture affected the mesiolingual angle and extends downwards, exceeding the cement–enamel junction slightly. So the fracture affects the coronal enamel and dentine, as well as the radicular cementum and dentine (without pulp exposure), which implies complete loss of the metaconid cusp. No other enamel fractures or cracks are observed.

All of these dental injuries have a rounded and polished contour, giving a softened appearance to the entire exposed fractured surface. In addition, there is no general discoloration of the enamel of the teeth. However, the colour of dentine is light yellow for the exposed fractured surface of tooth 16, while it is brownish for teeth 26 and 46. On the other hand, the fractured surface formed by the brownish dentine of tooth 46 is covered by a fine layer of reparative dentine.

Radiographic analysis

The radiographic analysis of the right hemi-mandible confirms the agenesis of tooth 48 that was observed in the macroscopic analysis. The signs of progress of the condylar neck fracture are also evident, with anteromedialisation of the minor fractured fragment, and an intense sclerosis below the neocondylar surface. The two fractures observed in the right mandibular ramus and in the left angle of the mandible show no signs of bone remodelling, confirming their clear *postmortem* aetiology.

For the dentoalveolar injuries, there is an obliteration of the pulp chamber and root canals in tooth 46 (Fig. 8); this is particularly evident when compared with the healthy contralateral tooth. There are two horizontal radicular fractures in teeth 36 and 37, in the first third of the tooth and near the apex of the distal roots, respectively. These fractures can be caused by post-depositional processes that together have fractured the left mandibular angle and the complete crown of tooth 37 below the cement–enamel junction. No other pathological signs are observed, such as alveolar injuries, cystic lesions, luxations, and periapical disease.

Discussion

There are several pathological conditions that affect both bones and teeth, such as trauma. Analysis of both skeletal and dental traumatic injuries can provide complementary data to contribute to our understanding of the health and disease of past human populations, and an accurate evaluation of such lesions can also provide crucial information in forensic cases. Although it has been argued that the data available to anthropologists rarely allows reconstruction of the physiological events that caused the injuries, in some cases skeleton remains can provide information about the timing, cause and manner in which these injuries were produced, as in the present case report. The difficulties reside in the necessity to differentiate *antemortem* and *perimortem* trauma from *postmortem* damage. While there is an abundance of literature on these distinctions in bone (e.g., 23, 24), there have been few reports in relation to human dentition (25). The main investigations on traumatic dental injuries to human teeth are related to clinical cases; however, the literature is limited for archaeological research (e.g. 26-28).

In the case of bone elements, the assessment of the timing of injuries is dependent upon the evidence of their healing and remodelling, or the lack thereof. The characteristics and morphology of skeletal injuries in fresh and dry bones are used to determine when a trauma appears to have occurred relative to the death of the individual, and thus whether a traumatic event occurred *antemortem*, *perimortem* or *postmortem* (4, 23, 29).

In the present study, the consolidation of the minor fragment observed, which is perfectly welded laterally to the condylar neck, as well as the aspects of the bone remodelling of the temporal glenoid fossa, show that the trauma took place many years before death. On the other hand, traumatic injuries to the mandible can result in partial or complete dislocations, when the articular surface of the condyles is partially or totally displaced from the temporal glenoid fossae. As dislocations cannot occur without damage to the joint capsule and ligaments, complications like osteoarthritis can ensue. Degenerative joint diseases are easily recognizable on dry bones if the injuries occurred some time before the death of the individual and remained unreduced long enough for bone modifications to take place (23). However, in this case, the temporal glenoid fossa does not show any sign of osteoarthritis. Also, the two cracks observed in the right mandibular ramus and in the left angle of the mandible show no signs of bone remodelling; these have a clear *postmortem* aetiology due to their angulated margins and as the resulting fragments were glued back during the restoration of the skeletal remains.

There are three major causes why fractures have occurred in bone remains: *(i)* acute injury (e.g., falls, or road traffic accidents in a modern context); *(ii)* underlying disease, which can weaken bone and make it more susceptible to fracture (e.g., tumour of the bone); and *(iii)* repeated stress (e.g., stress fractures associated with an athletic activity). Many stress fractures are hairline in nature and are difficult to diagnose in skeletal remains, even radiographically, as once they heal, there might be no evidence left to see. Pathological fractures can be induced by general or localised disease in the body. For example, osteoporosis can affect the body generally, and a tumour might affect an individual bone in the skeleton, but both can lead to a weaker structure that makes the bone more susceptible to fracture (30). For E109, no other fractures or microfractures that can be related to stress situations or underlying infectious diseases were observed, which suggests that the mandibular fracture was due to an acute injury.

For the dentition, there are only a few articles on ancient human tooth injuries (e.g., 26, 27, 31-33), although there is relatively abundant literature on fracture types and their propagation in human teeth (e.g., 25, 34-37). This thus allows differentiation of *antemortem* and *perimortem* from *postmortem* trauma based on the different behaviours of the dentine and enamel tissues during the dehydration process. In addition, dental macrowear on the tooth surfaces can also provide information towards this distinction (38-40). The crown fractures observed in the first molars of E109 have a rounded contour, which show the process of wear during the life of the individual due to saliva, tongue action, and functional use of the dentition. Thus, the rounding of the fractured edges as a result of the wear during chewing allows the inference that the trauma occurred *antemortem*, because sufficient time elapsed between the traumatic event that caused the fracture and the death of the individual. Therefore, the health status of E109 was characterised by a traumatic event that affected the facial region, which resulted in complete fracture of the right condylar neck of the mandible, and was associated with the internal dislocation of the condyle and the remarkable loss of substance from the dental crowns during the life of the individual.

There have been various attempts to classify fractures of the condylar process (41). The classification most commonly used is to subdivide the fractures according to their anatomical position (e.g., 42-44). However, in this type of classification, the degree of displacement and dislocation of the fracture is not represented, which is relevant in clinical practice for the correct treatment. Müller (45) classified the degree of displacement and dislocation into three degrees of axial deviation from 10° to 90°. Thus, the classification of fracture types according to Spiessl and Schroll (46), with the explicit differentiation between condylar base and condylar neck fractures by Loukota et al. (47), and the complementary approach of the degree of angulation by Müller (45), enable a more precise classification of the severity of a fracture. Therefore, the unilateral fracture observed in E109 can be defined as a 'high fracture of the condylar neck, with dislocation'.

For the dentition, many means of classification have been proposed for living individuals with traumatic dental injuries on the basis of many factors, such as anatomy, aetiology, degree of severity, pathology, and therapeutic treatment (e.g. 48-50). Recently, Loomba et al. (51) proposed a more complete and comprehensive classification of tooth fractures that can be applied easily to skeletal remains where there is no soft tissue in the oral cavity, as in the present case study. Thus, all of the fractures observed for E109 can be defined as ‘oblique fractures involving the crown [teeth 16, 26] or both the crown and root [tooth 46]’, or as ‘type IV fractures’.

Despite healed and unhealed mandibular fractures being a common modern clinical finding, few have been reported in the palaeopathological literature. This might be due to several factors, such as scarce attention to this condition in past years, or the inadequate state of preservation of skeletal remains.

A healed mandibular fracture was reported from the Téviec population (Morhiban, France) that was dated from the Mesolithic period (52). Ingelmark (53) observed severe injuries due to cuts in the mandibles of warriors from the Battle of Wisby (1361) on the island of Gatland (Sweden). Two healed mandibles and a traumatically conditioned luxation of the right mandibular condyle were described by Breitinger (54) in skeletal remains from Germany. This same author described the mandible of an Early Bronze Age woman of 30-40 years old in great detail, where the fracture line passed through the left mandibular angle, with its subsequent complete loss, and the *antemortem* loss of the second and third molars. Kraus (55) described how luxation of the mandibular condyle can result in the formation of a new articular fossa on the tubercular eminence. From the late Medieval Danish monastery of Æbelholt, Møller-Christensen (56) excavated the skeleton of an adult man with 21 sword cuts. In the attempts made to kill him by separating his head from his body, the temporomandibular joint was hit twice, and the mandibular body was fractured with multiple fracture lines. Zuhrt (57) described the evidence of a double-sided fracture of the subcondylar regions in a mandible dated to the Neolithic period from Braunsdorf (Germany). Brabant and Sahly (58) described and illustrated a mandible with a healed fracture positioned vertically between the body and the mandibular ramus. The body had been displaced medially and dorsally to the ramus. Ortner (24) briefly described a healed sword wound of the mandible in an individual associated with the Battle of Towton. The battle was one of many that were part of the War of the Roses that was fought in Yorkshire (UK) in 1461. The trauma cut through the anterior lateral portion of the left mandibular body. Most of the injury had healed but the posterior portion of the fracture did not unite. Another case of interpersonal violence described by Ortner (24) is the injury caused by an oblique sword cut that passed through the right mandibular body and the left maxilla. The cut sheared off the entire lower right half of the dentition and all of the teeth of the upper jaw, creating a situation in which the remaining teeth were occluded only by the gum. There is evidence of survival and healing in this aboriginal Australian male individual. Keenleyside (59) reported an unreduced condylar dislocation in an Alaskan Eskimo who was dated to between 1400 and 1850. Finally, De Luca et al. (60) described in great detail a bilateral condylar fracture and dislocation of an adult female who was exhumed from the medieval Jewish cemetery of Ronda Sur, on the South Iberian Peninsula.

Mechanism of the traumatic event

There are many studies in the current clinical literature on the aetiology and types of injuries in the maxillofacial region. Such injuries show frequency variations that differ according to the geographical areas and socio-economic status of the populations in different countries, or within the same country (61), and according to their sex and age distributions. Mandibular fractures are extremely frequent, and these account for 41.7% to 74.0% of all of the maxillofacial fractures in previously reported clinical studies (61-67). The mandible is the only mobile bone of the facial skeleton, and it has a prominent position on the face, and despite the powerful muscle attachments, it has a lack of support (68-70), and is more vulnerable to fractures than the other facial bones (69).

Among the reports of mandibular fractures, fractures of the condyle are the most common, with a frequency that ranges from 28.4% to 42.9%, according to the majority of studies (71-75). Atilgan et al. (76), however, studied 744 cases of mandibular fractures, and reported that fractures of the condyle were the second most common fracture, after that of the symphysis/parasymphysis, while in their study of 1994 cases, Rashid et al. (77) reported condylar fractures to be the third most common form of fracture after mandibular angle and parasymphysis fractures. Similar data were reported by Mijiti et al. (78) in their retrospective study of 1860 maxillofacial fractures, with the mandibular body being the most common fracture site, followed by the symphysis and the condyle.

The site of mandibular fractures is usually influenced by the following factors (69, 79-81):

Biomechanical characteristics of the mandible. Bone density, mass and anatomic structures all have important roles, which can create weak areas in the mandible, thus predisposing it to fracture (e.g., the narrow condylar neck has a reduced cross-sectional area, so it is probably weaker than the body or symphysis).

State and eruption of the dentition. The presence of an occlusal loading pattern or teeth that have not erupted might contribute to fractures (e.g., impacted mandibular third molars increase the risk of angle fractures).

Magnitude of the energy of the impact. If the amount of energy imparted to the mandible is above the elastic limit of the bone, a fracture will occur, with most of the energy being dissipated in producing the fracture. However, if the magnitude of the energy greatly exceeds the elastic limit, more fractures are likely to be produced. In the case of E109, a single mandibular fracture was observed.

Direction of the impact. Mandibular fractures generally occur at the point of the impact. However, indirect fractures can also occur in other parts of the mandible as a result of the transmission of the energy of impact through the bone to a weaker part, such as the condylar neck. These indirect fractures frequently occur together and can occur without direct transmission of trauma (e.g., a fall on the chin can result in a fracture to the neck of one condyle or both, without a fracture in the body or at the point of impact), as observed in the present case.

On the other hand, there are several studies on the relationship between dental injuries and maxillofacial trauma (64, 82-85). However, there are only a few studies in the current clinical literature on the aetiology, type and frequency of dental injuries in association with mandibular fractures (70, 86, 87). The occurrence and type of dental injury appear to be related to the fracture site of the mandible. Ignatius et al. (86) and Zhou et al. (70) reported that symphysis fractures are more associated with periodontal tissue injuries (62.0%, 44.1%, respectively), and condylar fractures are more associated with hard dental tissue injuries (65.6%, 57.6%, respectively). However, reports on the relationships between aetiology and type of dental injury are generally not in agreement. Ignatius et al. (86) and Zhou et al. (70) reported that the majority of dental traumas in association with mandibular fractures caused by violence are periodontal injuries, while Silvennoinen et al. (87) showed that road-traffic accidents result in periodontal injury, and violence more frequently results in hard tissue injury. Indeed, these studies are in agreement with Zhou et al. (70), as they highlight that falls (including falls from a height, and falls to the ground) tend to injure the hard dental tissues. Ignatius et al. (86)

and Zhou et al. (70) also revealed a correlation between different fracture sites of the mandible and the location of dental injuries. They showed that the upper premolars and molars are often injured in individuals with condylar fractures.

The following factors characterise the impact and determine the extent of dental injuries during a fracture (88-90):

Energy of the impact. This factor is defined by the mass and velocity. Experience has shown that low velocity blows cause the greatest damage to the supporting structures, with the energy distributed among several teeth, which allows the force to be absorbed by the teeth and to be transmitted to the supporting tissues. In contrast, with high velocity impact, the resulting crown fractures are usually not associated with damage to the supporting structures. In these cases, the energy of the impact is expended in creating the fractures, and it is seldom transmitted to the root of the tooth to any great extent, as in the present case.

Resilience of the impacting object. This factor can determine the injury to the teeth and their supporting structures. If a tooth is struck with a resilient or cushioned object, or if the lip absorbs and distributes the impact, the chance of a crown fracture is reduced. At the same time though, the risk of traumatic lesions that involve the supporting structures is increased, such as for subluxations, extrusive luxations, exarticulations, and fractures of the alveolar process. For E109, the impacting object was hard because there are no luxations, exarticulations or fractures of the alveolar process.

Shape of the impacting object. An impact with a sharp object favours clean crown fractures with minimum displacement of the teeth, where the energy is spread rapidly over a limited area, as in the present case. On the other hand, impact with a blunt object increases the area of resistance to the force in the crown region, which can allow the impact to be transmitted to the apical region, which can cause luxation and root fracture.

Direction of the impacting force. An impact can meet the teeth at different angles. Frontal impact to the labial aspect of the anterior teeth generates forces that tend to produce palatal displacement of the teeth. If a force causes a crown fracture, the greater part of the energy of the impact is expended to create the fracture, and so it is not transmitted to the root portion. On the other hand, if an impact does not result in a fracture, the energy can be transferred to the periodontal tissues, and dislocation of the teeth might occur, depending on the direction of the impact. For E109, the crown fractures were oblique.

Fractures of the mandible usually occur at the point of impact; however, indirect fractures can occur to other parts of the mandible as a result of the transmission of the contact through the bone to a weaker part, such as the condylar neck, which can result in a fracture at the opposite side of the application of a direct force (69). The fine bone neoformations and the remodelled aspects of the inferior margin of the symphyseal region observed for E109 appear to be the result of periosteal damage of the site of application of the traumatic force. Thus, a direct force was applied on the left symphyseal region of the mandible, which can cause an indirect fracture in the right mandibular condyle when the mandible is closed suddenly and sharply against the maxilla. This kind of mandibular fracture often occurs when the mouth is open at the time of injury, so that some of the impacting force is transmitted along the mandible to its weakest link: the condylar neck and subcondylar areas (91, 92). However, dental injuries are uncommon in this type of fracture (93). To produce dental injuries associated with intracapsular trauma, the mouth has to be closed (92). For E109, due to the characteristics observed and the morphology and distinct location of the mandibular injuries, the traumatic action was applied to the bottom of the chin and directed backward and upwards from the left side when the individual had the mouth partly open.

Such an indirect impact would favour crown–root fractures in the premolar and molar region, and especially palatal cusp fractures (86, 89). This is possibly the explanation for the crown–root fractures found related to the chin injuries in the present case report. This takes into account the loss of enamel substance observed at the level of the first molars. In the case of E109, the severe trauma in the region of the chin caused violent impact between the first molars and not between the third molars, as is classically described in the literature. Indeed, the trauma occurred in the last teeth of the arches. Therefore, for E109, it is likely that the trauma occurred when the most distal teeth were the first molars; i.e., at an age in which the permanent dentition had still not completely erupted.

There are a lot of limitations to the interpretation of when a fracture occurred. Modern population studies can look at the actual age distribution of fractures, while in archaeological groups, this is not possible. Even though an individual died at a certain age and had a healed fracture, this does not mean that it was sustained at that age; the fracture might have occurred many years before the death of the individual (30). However, is possible to set the timing of a traumatic event if the fracture occurred around the death, and thus illustrates the very early stages of fracture healing, or as in the present case, the growth period in a young individual can provide important information about this timing, such as the stages of eruption of the teeth. Thus, this injury would appear to have occurred when E109 was aged between 7 years (when the first molar reaches the occlusal plane) and approximately 15 years (when the second molar reaches the occlusal plane) (94). At this time the occlusal plane would have been reached by the first molars, but not by the second molars. Thus a fall forward with a strong blow to the chin would produce the fracture of the right condylar neck of the mandible and the partial fracture of three dental crowns, due to the violent impact of the arches between them. Clinical studies have also demonstrated that most traumatic dental injuries occur in childhood and adolescence, between the ages of 7 and 15 years (95, 96). Most children in this age group still have relatively poor physical coordination, and they cannot evaluate the risk of this danger. These factors might increase the risk of suffering traumatic lesions, and might also be the reason why the majority of paediatric traumatic dental injuries occur outdoors (96).

Complications of mandibular and dental fractures

Trauma is painful, visible and debilitating. Today, people afflicted with trauma try to seek help and have their injuries treated. There are several fracture complications that can occur at the time of an injury or even years later. Some of these can be determined by analysis of skeletal remains, if the fracture was not adequately reduced or correctly healed (30).

In modern clinical findings, the most common complications and symptoms of mandibular fractures and temporomandibular joint disorders include: *(i)* difficulty in opening the mouth; *(ii)* inability to masticate; *(iii)* limitation of mandibular movement, particularly for lateral excursion; *(iv)* difficulty with speech; *(v)* malocclusion of the teeth; *(vi)* facial asymmetry; *(vii)* haemotympanum; *(viii)* pain and tenderness over the affected temporomandibular joint; *(ix)* swelling locally, usually just below the zygomatic arch and in front of the lobule of the external auricle; and *(x)* masseteric spasm on the affected side, caused by irritation of the nerve endings due to an inflammatory response (59, 60, 97, 98).

Asymmetry after condylar neck fracture is common and is influenced by the degree of displacement. This is exemplified as a decrease in mandibular ramus height, which results in a shorter lower facial third of the fracture side (98). The type of fracture observed in the present case study is the typical upward and inward displacement of the mandible, due to the pull of the external pterygoid muscle attached to the base of the condyle. The resulting condylar neck fracture involves shortening of the mandibular ramus on the right side, with anteromedialisation of the minor fractured fragment; this implies that the last molars enter in strong contact under the combined action of the temporal, masseter and internal pterygoid muscles. With the descent of the chin, this means that the dental arches diverge anteriorly, with the appearance of the typical open bite. Due to this angle of the mandible and the shortening on the right side, the chin deviates in that direction.

In general, all fractures belong to one of two categories: *(i)* closed fractures, when there is no connection between the outer skin surface and the fractured bone itself; and *(ii)* open (or compound) fractures, when there is an open connection between the fracture site and the skin surface. This connection is a ready opportunity for bacteria to enter the bone from outside the body, and therefore all of such fractures can potentially be infected, a problem even in modern medical practice. The absence of the soft tissue in skeletal remains clearly makes the placing of a fracture into one or the other category difficult, unless there is clear evidence of infection associated with the fracture (30). For E109, there are no signs of infectious disease associated with the fracture, and the mechanics of the traumatic event (unilateral condylar neck fracture associated with internal dislocation) appear to confirm the nature of a closed fracture.

Following to a traumatic event, if a fracture is not adequately reduced, the shortening and misalignment of the affected mandibular ramus can lead to adjacent joint degeneration and osteoarthritis (30). Nowadays, complications associated with mandibular fractures can be prevented if the treatment is started early. In adults, surgical intervention is required for condylar fractures; however, in children and adolescents, there is functional adaptation with the potential for significant restitution and remodelling (98). It is worth noting that despite the severe disruption of the dynamics of mastication, for E109 there are no signs of osteoarthritis at the level of the right temporomandibular joint, of asymmetric occlusal dental wear, or of severe deposition of the dental calculus, indicating that the masticatory function would have been little affected during the life of this individual.

On the other hand, in high intensity impacts, the impact of the mandibular condyle on the anterior wall of the external auditory canal and/or the posterior dislocation of the condyle can produce laceration of the cartilaginous parts of the external auditory canal, or more rarely, fracture of the tympanic plate, with or without associated condylar fracture (99, 100). However, in the present case report, the cranial X-rays exclude lesions to the external auditory meatus.

For the dentition, complications can occur after a traumatic event, which can allow other possible injuries associated with the hard dental tissues to be observed, and which can confirm the *antemortem* aetiology of a dental injury. The most common complications are: *(i)* failure to continue eruption due to abnormal root development; *(ii)* colour changes to the crown; *(iii)* infection of the necrotic pulp, which can lead to periapical infection and different abscesses; *(iv)* ankyloses, mostly as a result of intrusion injury (for deciduous teeth, this can lead to prolonged retention in the oral cavity); *(v)* post-traumatic cystic lesions; *(vi)* pulp canal obliteration; *(vii)* root resorption; and *(viii)* luxations (40, 46, 88, 101-105). In the present case study, one sign of the healing is seen in the obliteration of the pulp chamber and root canals for tooth

46. Such a response to trauma is characterised by deposition of reparative dentine (or tertiary dentine) in the root-canal space, to protect the pulp tissue in the oral cavity. This reparative dentine matrix is less permeable, and it prevents diffusion of noxious agents from the dentinal tubules, and avoids possible posterior pulp necrosis as consequence of bacterial infection (106-109).

Traumatised teeth often develop varying degrees of discoloration. Such teeth can sustain irreversible pulpal injury, which can be caused by avulsions, intrusions, luxations and subluxations, or by fractures that involve the pulp chamber. Trauma in such cases can lead to intrapulpal haemorrhage and iron sulphide deposition along the dentinal tubules, which produces a bluish-black cast (110). However, under the constant exposure of the teeth to oral fluids and other irritants, and also through taphonomic effects, teeth can become coloured, and can thus become light yellowish, grey, brown or black. Although several studies have reported discoloration of traumatised teeth with pulpal obliteration (111), Oginni et al. (104) suggested that not all teeth with radiographic signs of pulp canal obliteration undergo colour change. For E109, tooth 46 shows the greatest loss of substance (which affected the crown and root), with a brownish dentine colour. This sign might have been due to bacterial infection of the pulp tissue through the dentinal tubules, because other post-traumatic complications were observed, such as obliteration of the pulp chamber and deposition of a fine layer of reparative dentine, which covered the fractured surface. Teeth 16 and 26 show yellow and brownish dentine, respectively, for the exposed fractured surface, but in these cases there is no associated post-trauma complications.

Although, unfortunately, there are no records related to the circumstances of the traumatic event that happened to E109, the application of the vast knowledge used by forensic anthropologists and dental anthropologists can be of great benefit for the archaeological interpretation of such traumatic events. This case study also supplements the existing literature on similar clinical cases, from which only a broad comparison can lead to more certain interpretations. This also requires the collaboration of specialists from several scientific branches, including anthropology, medicine and history.

When *antemortem* maxillofacial–oral fractures can be identified, these can be an indicator of special significance for the reconstruction and broader understanding of past behaviours (e.g., tooth ablation and other dental modifications, such as filing and inlaying, reflect cultural practices, while other forms of dental trauma, such as avulsion or crown fractures, might indicate accidents or intentional violence) (26, 27, 40, 112). The main investigations on traumatic maxillofacial–oral injuries are related to clinical cases; as such, the literature is limited for archaeological research (26, 27).

Conclusions

According to the description of the traumatic injuries presented here, these fractures appear to have been caused by one of two mechanisms: the trauma produced by a blow related to interpersonal violence, or more likely, the trauma from a fall. This has been deduced from the characteristics studied, the morphology and location of the injury, the age of the individual when the traumatic event occurred, and the surrounding environment of the individual. These multiple traumatic lesions thus appear to have arisen from a unique traumatic event, and they are consistent with a blow to the chin as a result of an accidental fall. These injuries appear not to have affected the masticatory functions during the life of the individual.

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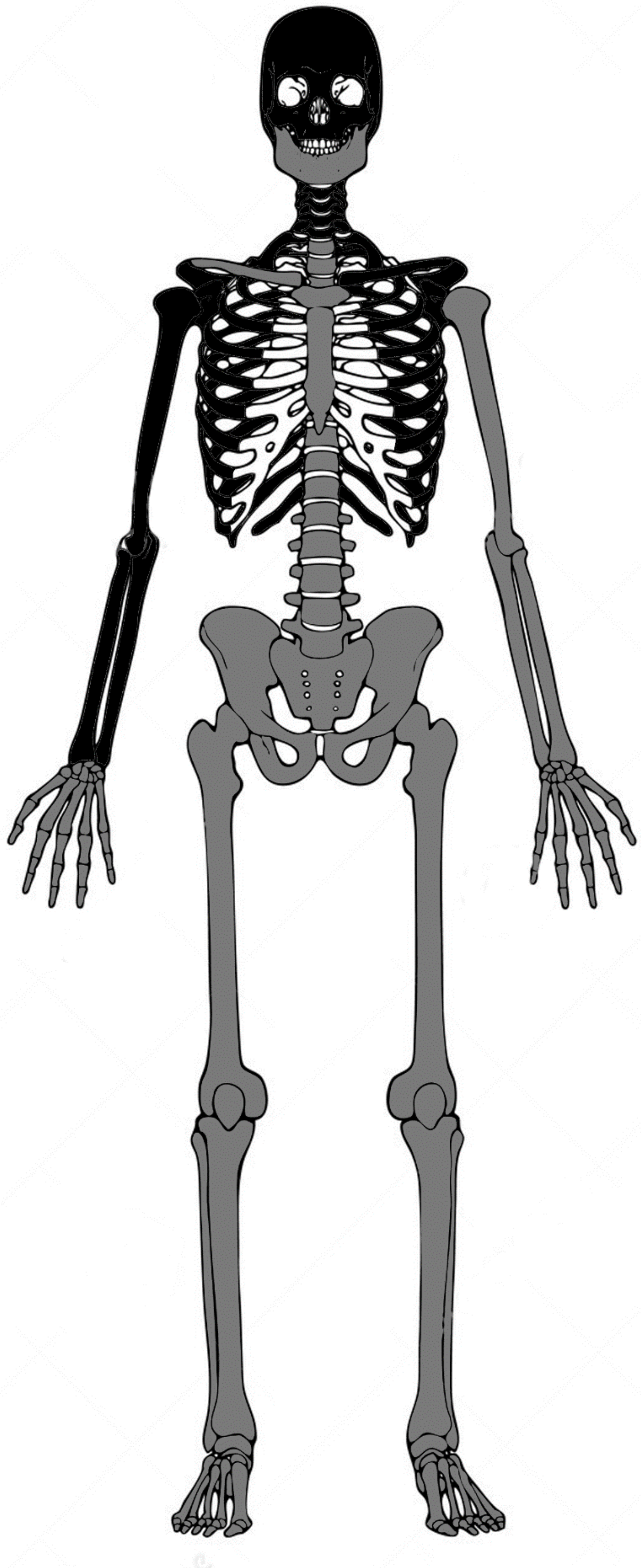

Fig. 1. Skeletal diagram of the individual E109. The complete remains are represented in grey, and the fragmented remains are represented in black.

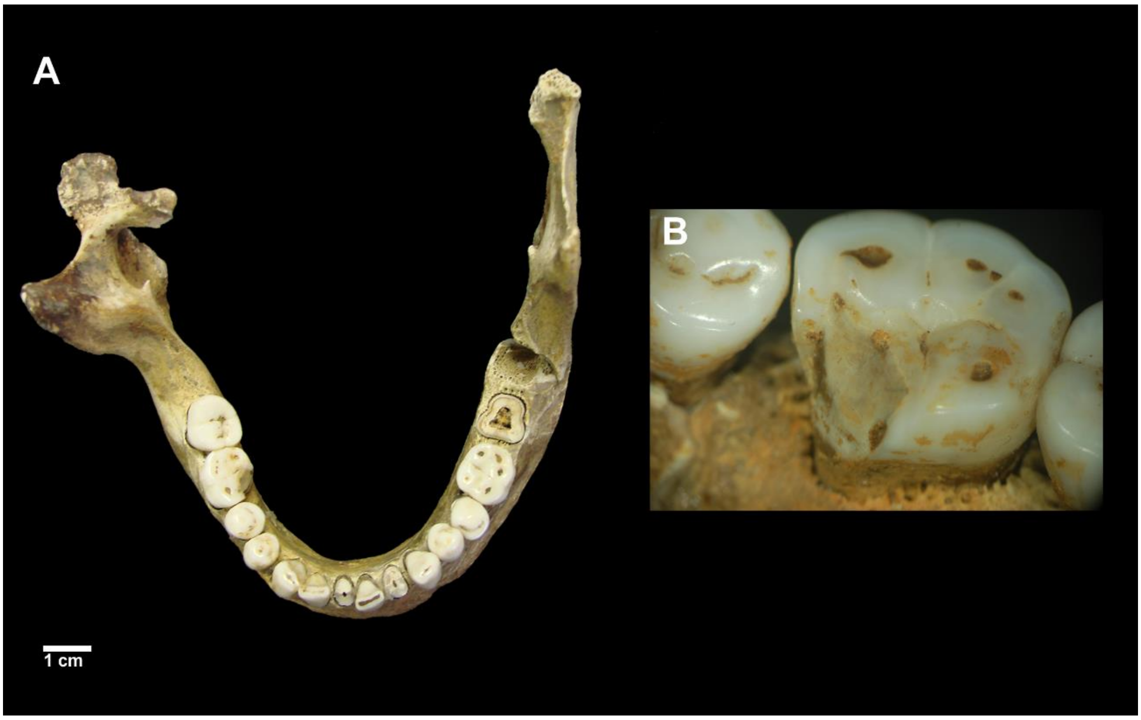

Fig. 2. A. Mandibular arch showing a dental injury and a fracture of the right condylar process, which is folded anteromedially and welded perpendicular to the mandibular ramus. *B.* Detail of the occlusal view of molar 46 at ×6 magnification, with a fracture on the mesiolingual angle.

Fig. 3. A. Inferior view of the mandible showing a great asymmetrical appearance of both mandibular rami. *B.* Detail of the left inferior margin of the mental region showing an uneven and rough surface.

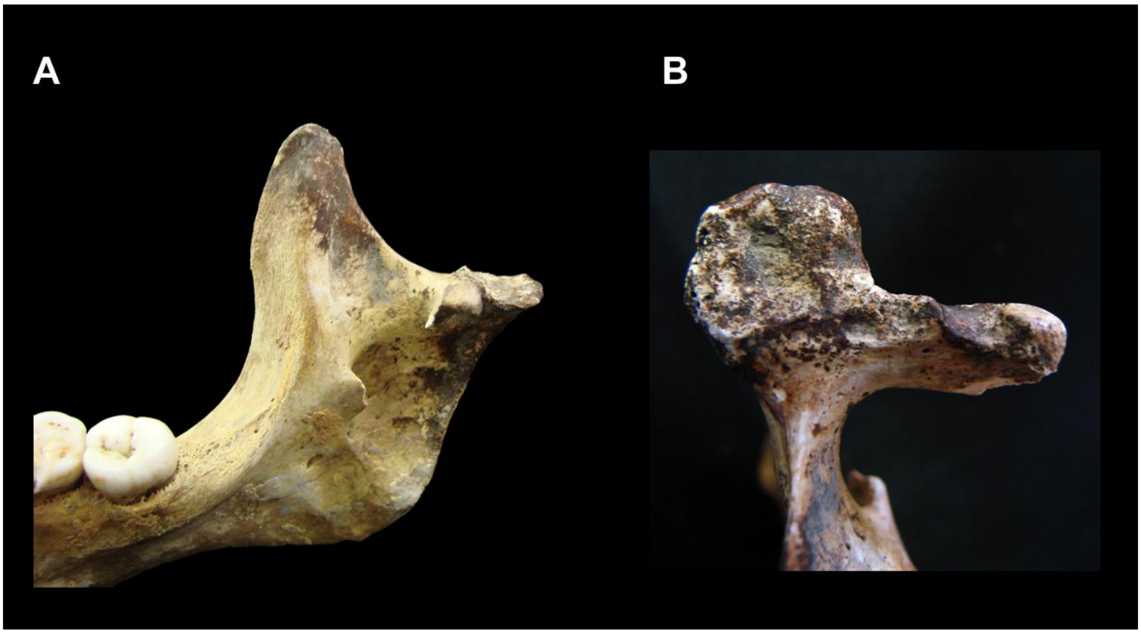

Fig. 4. A. View of the internal surface of the right mandibular ramus showing the high fracture of the condylar neck. *B.* Stereomicroscopic aspect of the fracture surface that become a unique neocondylar surface.

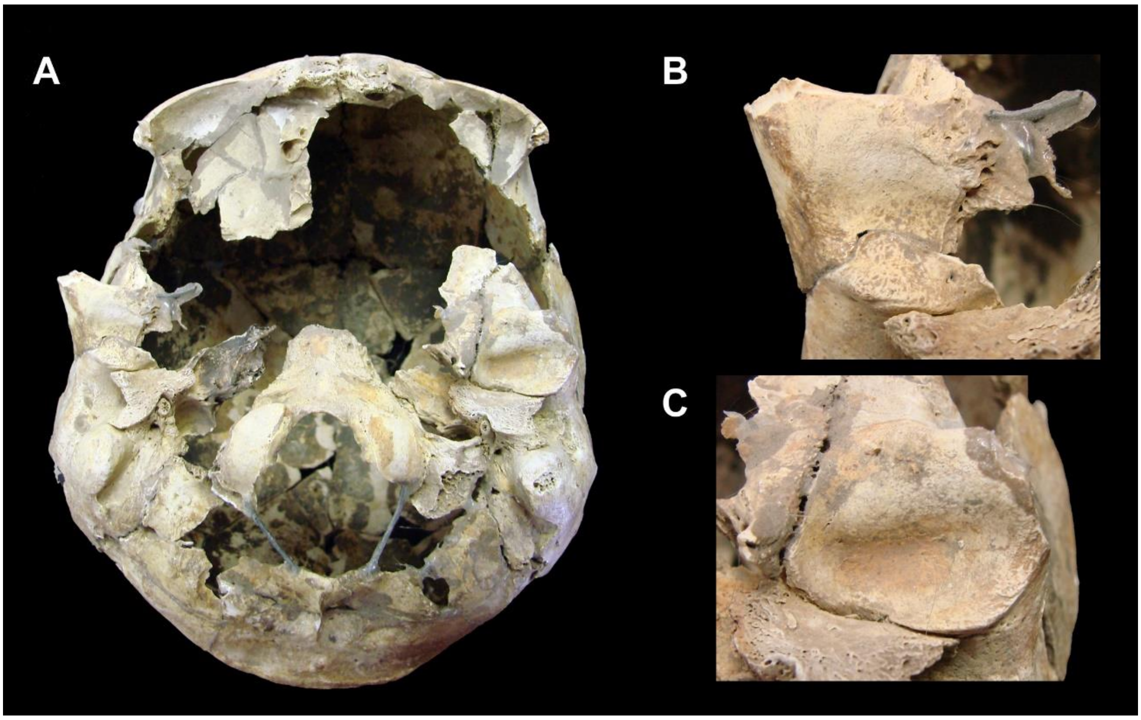

Fig. 5. A. Inferior view of the fragmented cranium. *B.* Detail of the flattened right glenoid fossa, with less depth compared to the left, and without signs of osteoarthrosic changes. *C.* Detail of the left glenoid fossa.

Fig. 6. Detail of the right external acoustic meatus without evident lesions.

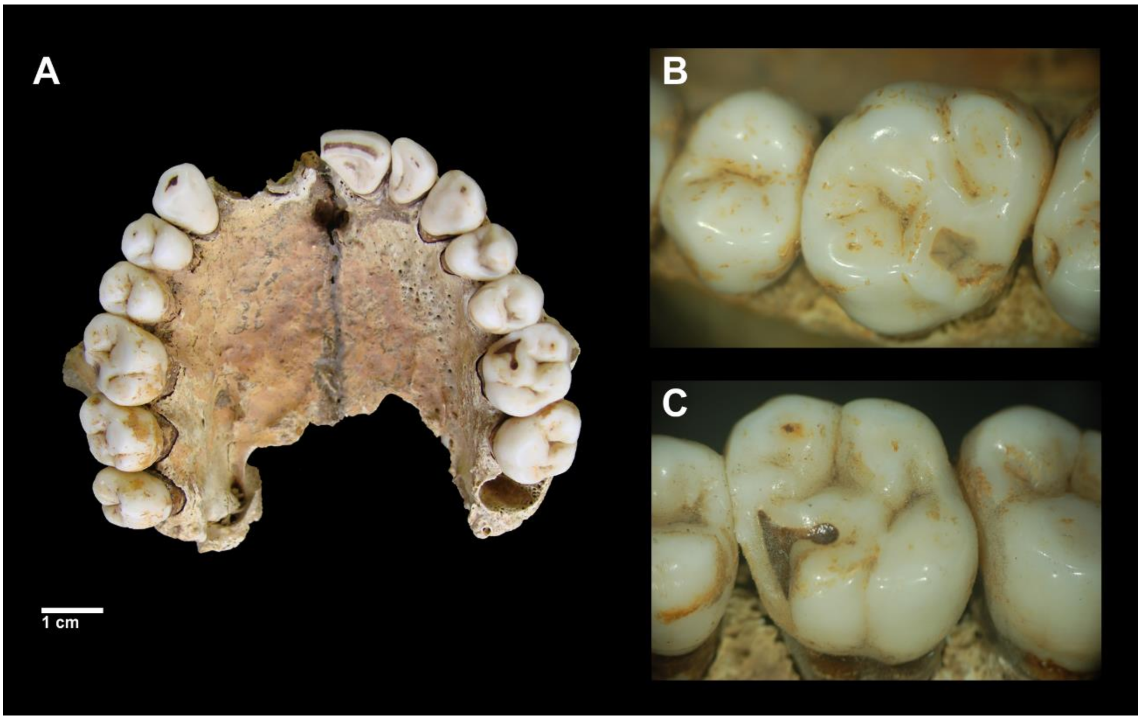

Fig. 7. A. Maxillary arch showing dental injuries with a considerable loss of substance in first molars. *B.* Detail of the occlusal view of molar 16 at ×6 magnification, with a fracture on the distobuccal angle. *C.* Detail of the occlusal view of molar 26 at ×6 magnification, with a fracture on the mesiolingual angle.

Fig. 8. Dental panoramic radiograph which shows an obliteration of the pulp chamber and root canals in tooth 46; this is particularly evident when is compared with the healthy contralateral tooth.