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Evidence of otitis media and mastoiditis in a Medieval Islamic skeleton from Spain and possible implications for ancient surgical treatment of the condition

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Abstract

Objective: To evaluate lesions on a cranium from the Iberian Peninsula and assess its medico-historical and paleopathological significance.

Materials: The skeletal remains of a juvenile individual found in a Medieval Islamic grave (10^{th} -16^{th} century) in Eastern Spain.

Methods: Macroscopic examination of the left and right temporal bones, binocular microscopy, X-ray, and Scanning Electron Microscopy - Energy Dispersive X-ray Spectroscopy (SEM-EDS) were performed.

Results: A sub-oval perforation superior to the right mastoid process and pathological changes on the right temporal bone were identified. SEM-EDS confirmed the presence of copper in the surrounding area of the perforation.

Conclusions: The observed pathological changes are most likely compatible with otitis media and subsequent mastoiditis. The sub-oval perforation could be interpreted either as an abscess or as evidence of a surgical procedure (mastoidectomy) or a combination of both; and the Cu traces may be the result of an associated object or, possibly, the application of a plaster with copper acetate used as medical treatment.

Significance: This case contributes to the paleopathological record and the interpretation of similar cases, and also helps in the understanding of medical care and treatment in Medieval Islam.

Limitations: The lack of similar pre-modern cases of surgical intervention limits comparability to clinical cases.

Suggestion for further research: Exploration into indicators of health care in past populations. Keywords: mastoidectomy, copper staining, Al-Andalus, History of Medicine, Medieval Spain

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1. Introduction

Otitis media (OM) is one of the most common diseases treated with antibiotics in children (Casselbrant & Mandel, 2010; Chole & Sudhoff, 2010; Qureishi et al., 2014). It involves the inflammation of the middle ear and the obstruction of the Eustachian tube, which in turn causes an infection to develop (Abelló & Quer, 1992:55). Two types of OM can be distinguished: acute otitis media (AOM) and chronic otitis media (COM). AOM develops from an acute and usually bacterial infection of the middle ear and is typically found in children (Mora et al., 2014:23). Conversely, COM has a polymicrobial origin and is characterized by the absence of pain, otorrhea, and it is more commonly found in adults (Abelló & Quer, 1992:57-58). OM, especially in infants and juveniles, can result in physical and social disability (Klein, 2000; Rovers et al., 2004; Casselbrant & Mandel, 2010; Chole & Sudhoff, 2010). If the infection is left untreated, two kinds of complications may occur: intra-temporal, and intracranial complications--all of which require surgical intervention (Mora et al., 2014:23). The most common intra-temporal complication is mastoiditis, which is characterized by the spread of the bacterial colonization into the mastoid air cells, causing local destruction (Mora et al., 2014:23). Mastoiditis manifests by fever, suppuration, and painful swelling around the region of the mastoid process of the temporal bone (Abelló & Quer, 1992:63). In pre-antibiotic societies, untreated mastoiditis could have been life-threatening, as the infection could affect the endocranium (Hamidi et al., 2008). This complication is usually found in children suffering from AOM and today is commonly treated surgically to remove pus and exudate (Abelló & Quer, 1992:65; Mora et al., 2014:25). Although surgical interventions to drain suppuration have been undertaken since antiquity, the first recorded clinical case of mastoidectomy dates back to the 18th century (Guerrier & Mounier-Khun, 1980:36).

Ear infection diagnosis in paleopathology is challenging, as diagnosis today relies on soft tissue. However, its identification in past populations provides valuable insights into the population to which the individual belonged, the medical resources available, and care for the sick. Only a few studies of OM within archaeological populations have been published (see Qvist & Grontved, 2001; Flohr & Schultz 2009a; Armentano et al., 2014; Krenz-Niedbała & Łukasik, 2016). Most publications that identify OM include an initial macroscopic assessment of the auditory canal, the middle ear, and the ossicles, which in most cases is combined with microscopy, radiography, and other imaging techniques. These usually identify changes to the auditory meatus and/or ossicles, abscesses, cavitation, and sclerotization resulting from active and recurrent remodelling (v.g. Qvist & Grontved, 2001; Collin & Judd, 2015; Krenz-Niedbała & Łukasik, 2016; Zhang et al.,

2020). Abscesses are more frequent in OM, but may also be a complication of cholesteatoma. Cholesteatoma is an aggregation of dead epidermal cells that causes a cystic lesion that affects the middle ear and petrosal bone causing a serious ear infection (Nevoux et al., 2010). Although uncommon, childhood cholesteatoma tends to be more aggressive than the adult form, but rarely develops a labyrinthine fistula (Nevoux et al., 2010). Paleopathological cases of cholesteatoma have been identified through macroscopic, radiographic, and microscopic assessment (Qvist & Grontved, 2001; Mays & Holst, 2006; Armentano et al., 2014). Most publications that report mastoiditis include radiographs or computed tomography, since the state of pneumatization of the mastoid air cells is essential for assessment (Homøe & Lynnerup, 1991; Homøe et al., 1996; Macías et al., 1999; Flohr & Schultz 2009a and b; Zhang et al., 2020).

This paper aims to analyze an unusual OM sequela from Medieval Spain and to explore whether indicators of medical treatment are present. It is hoped that this case can add to the existing, albeit limited, paleopathological literature and be used as comparative material for scientists investigating similar changes related to ear infection.

2. Material and Methods

In 1995, an archeological rescue excavation uncovered 37 graves, which followed Islamic funerary rites in the town of Vall d'Uixó (Figure 1) (Castellón, Eastern Spain). In accordance with this rite, no associated grave goods were found, but the position and orientation of the bodies provided a wide date between the 10th and the 16th centuries AD (Cara, 1993; Casal, 2001). Contextual information regarding the settlement(s) associated with the cemetery is limited due to the nature of the rescue excavations in the area. For this reason, a wider perspective that focuses on the living conditions in rural populations in Al-Andalus as a whole has been undertaken. One of the graves (Grave 12) contained a partially complete, but well preserved (Grade 1 according to McKinley, 2004), skeleton of an individual aged between 10 and 15 years at the time of-death according to dental development (Ubelaker, 1979) and skeletal maturation (Schaefer et al., 2009). The skull was mostly complete, as well as the limb bones, whilst other elements were only partially recovered (see Supplement Material 1).

Figure 1. Location of Vall d'Uixó in the Iberian Peninsula, marked with a red star. The border between Al-Andalus and the Christian kingdoms is represented as it moved towards the south: in black the frontier in the early 11th century, in red during the mid-12th century, and in blue during the early 13th century. After 1238 the region was conquered by the Christian Kingdoms.

A macroscopic analysis of the skeleton was undertaken. A binocular microscope was used to observe and record the pathological changes on the temporal bone. Radiographs were taken with a portable RALCO XR collimator and a standard adjustment of 66kVx4.0mAh that was modified according to imaging requirements. Scanning Electron Microscopy - Energy Dispersive X-ray Spectroscopy (SEM-EDS) was performed with an EVO MA10 on variable pressure at a magnification ranging from 20 to 50 X and an accelerating voltage of 20 kV.

3. Results

The right temporal bone presented a sub-oval perforation of a maximum diameter of 12mm, located superior to the mastoid process (Figure 2). The edges of this perforation were smooth and rounded, whilst the interior wall of the perforation presented a slight osteoblastic response and pitting (Figure 3). Pitting was also observed on the external lamina surrounding the external auditory meatus, alongside blood vessel canals suggesting intense vascularity (Figures 2 and 3a). New bone formation (irregular woven bone) was identified on the inferior wall (Figure 3a). Slight post-mortem damage was also present on some aspects around the rim, noted as white areas of exposed bone (Figures 3a, 3b, 3c). This perforation reached the petrous pyramid creating an opening

into the auditory canal at the level of the posterior wall of the middle ear (retrotympanum) (Fig. 4). The external auditory meatus and canal showed no signs of pathological alteration, enlargement, or bone resorption. In the middle ear, however, there is bone destruction involving most of the retrotympanum, which connects with the mastoid process perforation (Figure 4). Part of the superior wall (epitympanum) was also affected, but the infection did not perforate the tegmen timpani (Figure 4a). The pyramid also presents some alteration in the form of erosion. However, the structures of the middle ear, such as the oval and round windows (fenestra ovalis, fenestra rotunda) or the vestibule aquaeductus Fallopii, are preserved and have normal appearance (Figure 4a). Likewise, the inner surface of the temporal bone revealed a normal and therefore non-pathological internal auditory meatus, aquaeductus vestibuli, and aquaeductus cochleae. There were no pathological conditions on the left temporal bone.

Radiographs of the right temporal bone revealed a higher density around the edges of the perforation. The mastoid air cells of the left mastoid process displays normal pneumatization, although the tip of the mastoid process, which is affected by post-mortem damage, could be hypocellular (Figure 5a). Meanwhile, the right mastoid process displays abnormal pneumatization that could be compatible with mixed or diploic bone (Figure 5b) (Sadé & Fuchs, 1994; Sethi et al., 2006; Cinamon, 2009; du Boulay, 2016:199-200; Flohr et al., 2019). The ear ossicles were not preserved.

Figure 2. Observed perforation, pitting, and woven bone on the right temporal bone.

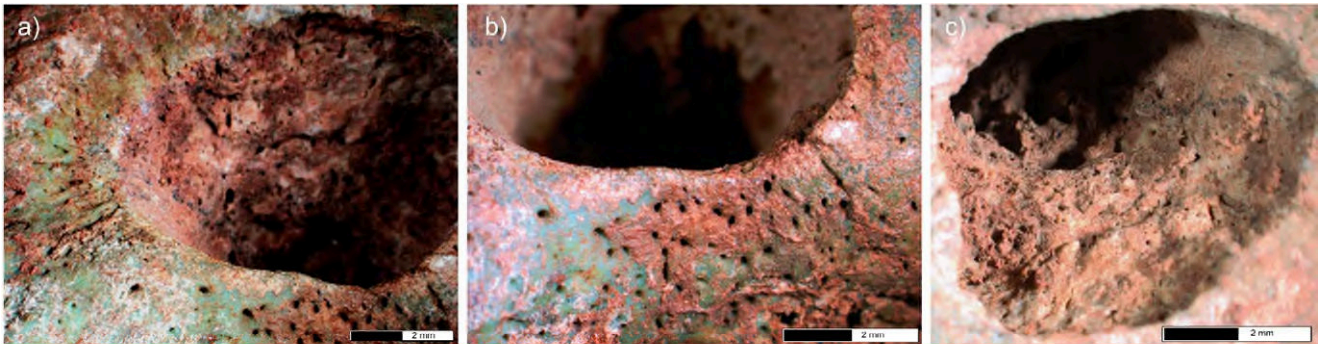

Figure 3. Detailed images of the perforation. a) Edges of the perforation, which appear smooth and rounded. The image is focused on the inferior and anterior aspects. b) Pitting found surrounding the perforation. The image is focused on the anterior aspect. c) Possible woven bone formation and slight pitting. The image is focused on the inferior view of the wall.

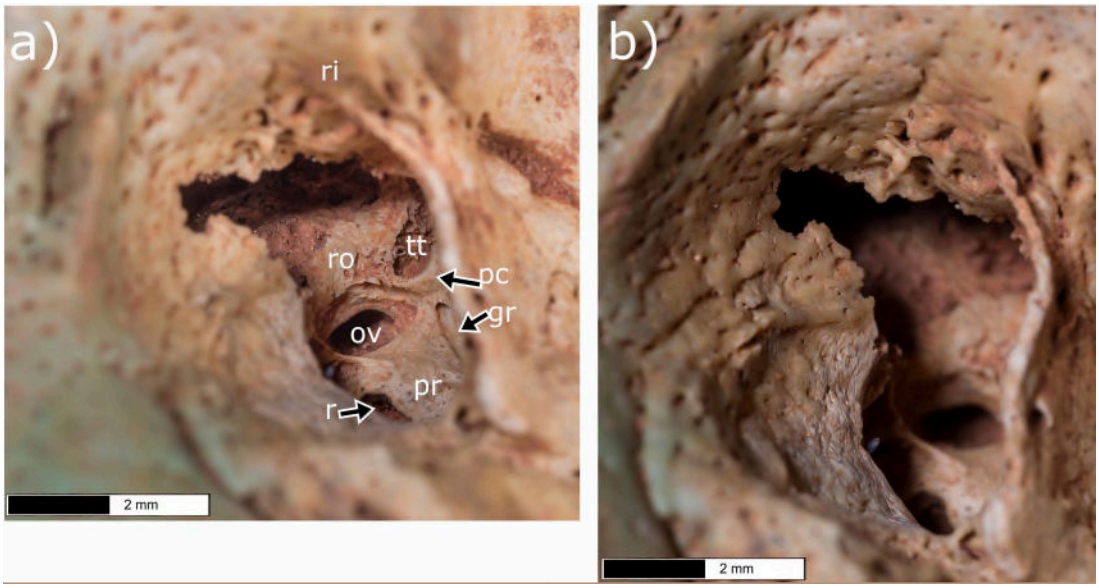

Figure 4. Right middle ear showing preservation of normal structure. a) View of the middle ear's structures. Notes: ri, notch of Rivenus; ro, roof of aqueductus fallopii (canal for facial nerve); tt, canal for the tensor tympani; ov, oval window; pc, processus cochleariformis; r, round window; pr, promontory; gr, groove for tympanic plexus. b) General view of the auditory canal and posterior-superior aspects of the middle ear showing the erosive lesion that connects with the perforation.

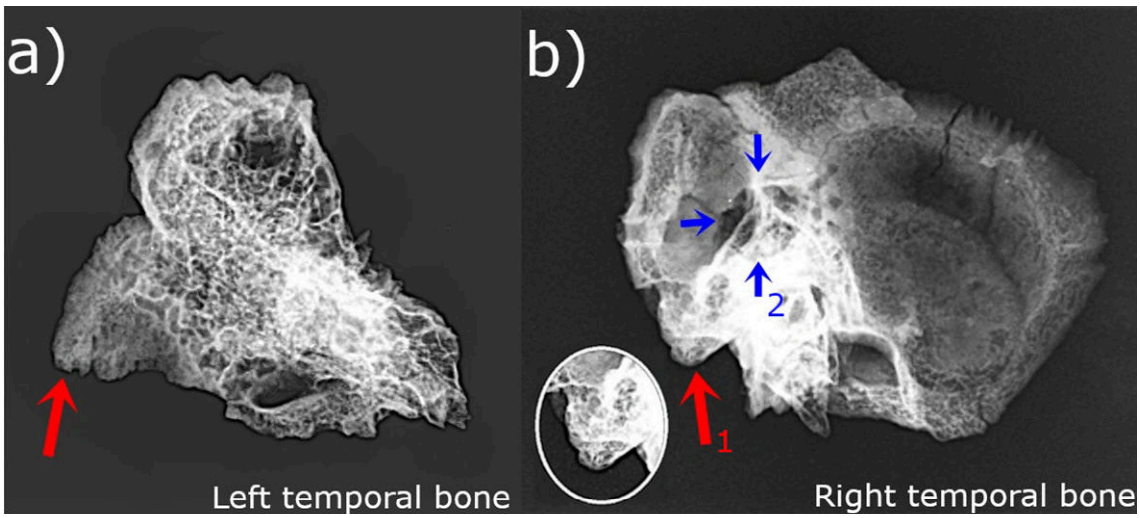

Figure 5. Radiograph of the temporal bones 60kV x6.4mAh. a) Lateral view of the left temporal bone. Arrow points to the mastoid process. b) Lateral view of the pathological right temporal bone. The mastoid air cells show diploic bone. Arrows point at the mastoid process (1), which is amplified inside the circle, and the borders of the perforation (2).

Linear enamel hypoplasia (LEH) was observed on both the anterior dentition (100%, 4/4) and the posterior dentition (10%, 1/10), with the following teeth being affected: the central incisors, the right lateral incisor, the right canine, and the first premolar. No other pathological changes were detected cranially or postcranially.

A green discoloration was present on the right mastoid process. This may have been caused by contact with copper or a copper alloy (Hopkinson et al., 2008; Dupras & Schultz, 2013). Moreover, EDS analysis showed that areas with this coloration had significant copper content (1.5%), while adjacent areas with no coloration had no detectable copper. SEM images show blood vessel grooves posterior to the lesion (see Supplemental Material 2).

4. Discussion

The new bone formation and bone erosion observed on the external lamina of the right temporal's mastoid process, as well as on the wall of the perforation, is compatible with descriptions of OM and mastoiditis in the paleopathological record (Flohr & Schultz 2009a and b; García & Polo, 2011; Krenz-Niedbała & Łukasik, 2016). This is also true for the pitting observed on the anterior margin of the perforating lesion adjacent to the external auditory meatus (Figure 3b).

Regarding the perforation, the relative smoothness of the margins, especially the inferior aspect (Figure 3b), points to an in vivo origin of the perforation in the external table. This fact, together with the vascularity and new bone formation in the inferior wall of the perforation (Figure 3), and a higher density around its edges may be indicative of healing. Although its diameter is wide in comparison to the majority of perforations on the mastoid process diagnosed as abscesses caused by an ear infection, some other cases share similar characteristics. Loveland and colleagues (1990) studied temporal bones with extensive damage and interpreted the damage as resulting from abscesses caused by mastoiditis. Those abscesses with sharper edges were documented as still being active at the time of death. In comparison, this case presented here shows signs of healing; however, an abscess cannot be dismissed. The cavity involved the petrous pyramid, creating an opening into the middle ear. Upon comparison with clinical cases, no signs of an abscess involving the inner ear could be found (Mora et al., 2014:26; Kösling, 2017; Pont & Mazón, 2017). If this was the case, it could point towards circumscribed labyrinthitis, an abscess in the inner ear usually secondary to a cholesteatoma (see

below), which can cause vertigo, and without adequate treatment can lead to intracranial complications (Mora et al., 2014: 25-26).

Clinical literature presents cases of cholesteatoma that can produce penetrating defects in the bone and can be secondary to OM (v.g. Nishihira, 2000; Smith & Danner, 2006; Campbell et al., 2017). The new bone formation (Figure 3a and c), and the presence of pitting on the surrounding area and the inside of the perforation (Figure 3b), may be evidence of an infection and do not seem compatible with what has been reported in the paleopathological literature (Qvist & Grontved, 2001; Mays & Holst, 2006; Armentano et al., 2014). Although both radiographic examination (following criteria from Graham-Hodgson, 1950; du Boulay, 2016:197) and the preservation of the structures of the middle ear did not indicate its presence, the possibility of a cholesteatoma cannot be ruled out.

Taking these observations into consideration, as well as the age-at-death of the individual, a probable diagnosis is that of OM, possibly acute, and which resulted in mastoiditis. As stated above, the perforation could be an abscess caused by the infection. However, it must be considered that this perforation may be intentional (surgical) due to three key observations: 1) the perforation connects the middle ear with the mastoid cells; 2) its location and dimensions, and 3) the possible presence of a mastoidectomy. Similar cases have been identified in bioarcheology, whilst the clinical literature offers many examples (Kvestad et al., 2000; Garap & Dubey; 2001; Vercellotti et al., 2010; Boljunčić & Hat, 2015; Dourado et al., 2016; Magalhães et al., 2017).

According to clinical and surgical literature (Abelló & Quer, 1992), the location of the perforation would support surgical intervention to treat mastoiditis, since its location is less prone to cause complications, avoiding damage to the endocranium, the facial nerve, and the lateral vessel (Abelló & Quer, 1992:63-64). The characteristics are also similar to a Medieval case from Croatia, which was interpreted as the work of an experienced surgeon (Boljunčić & Hat, 2015). A similar perforation described by Brothwell (1974) in a Roman individual from York was attributed to surgical intervention using a trepan. In addition, two other publications present possible cases of mastoidectomies in modern, yet pre-antibiotic, populations from Italy and Portugal (Vercellotti et al., 2010; Magalhães et al., 2017). The latter case on the left mastoid process has an almost identical location to the present case and has been interpreted as having occurred during post-mortem medical training (Magalhães et al., 2017). A review of the medico-historical literature of Medieval Islam shows that physicians had the knowledge to perform interventions, as they were well versed in ear infections and anatomy of the ear (Azizi, 2007; Liñán et al., 2014; Hajdu, 2016). One such physician was Avicenna, who includes a treatise on

otology in his *Canon of Medicine*, where he recommended drainage in case of an abscess (Azizi, 2007; Hamidi et al., 2008).

The green staining surrounding the perforation is likely post-mortem, for example the result of contact with a shroud pin (Schultz, 2012). These have been found in other Islamic cemeteries of the peninsula and could have been part of the shroud used in the Islamic burial ritual (Casal, 2001; Navarro, 2018; López & Martín, 2019). Although uncommon, some excavations find them associated with the skeleton without mention of their exact location (Galve & Benavente, 1992; Baños & Martínez, 1998; López et al., 2014). In addition, other artifacts such as earrings could have caused this coloration (see Casal, 2001; López et al., 2014). However, this is rare in Islamic burial ritual and in the studied population, and no other skulls with similar discoloration have been found. Thus, the above observations and the unilaterality of the discoloration, may suggest another interpretation. Medieval Islamic treatises mention the use of copper acetate or *verdigris* to treat inflammations, clean wounds, and aid cicatrization (Peña & Girón, 2001; Chavoushi et al., 2012; Emami et al., 2012; Liñán et al., 2014). Furthermore, in his treatise on otology, Avicenna mentions the use of *verdigris* in the treatment of various types of ear conditions (Hamidi et al., 2008). This may link the presence of copper around the perforation to surgical intervention and subsequent medical treatment. There is no clear evidence, however, on how *in vivo* medical procedures on soft tissue can alter the color of the bone; unless perhaps the individual in treatment at the time of death had been buried with bandage or any other material that had copper acetate. The study of elemental quantitative composition on different bone types could reveal more information about pre-mortem or post-mortem copper acquisition (López-Costas et al., 2016). Although the interpretation of surgical intervention is undoubtedly a possibility, no conclusive evidence has been reached to date, and it is therefore still a possibility that the staining is due to the burial environment and funerary rite (e.g. shroud pin).

There are several published examples of ear infection in paleopathology**.** Three are of special interest here, as they belong to the same period and cultural group and were populations that lived less than 30 km away from this present case. These consist of two possible cases of OM and a possible case of mastoiditis (García & Polo, 2011; Forner, unpublished). Clinical studies state that cold temperatures, low socioeconomic status, overcrowding in the family home, short duration of breastfeeding, the presence of older siblings, poor hygiene, and malnutrition, amongst other factors, all influence the prevalence of OM and post-treatment complications (Ståhlberg et al., 1986; Uhari et al., 1996; Paradise et al., 1997; Klein, 2000; Garap & Dubey, 2001; Dhooge, 2003; Rovers et al., 2004; Kong & Coates, 2009). These settlements are in the vicinities of *Sierra de*

Espadán, a mountain range where temperatures can drop to -4ºC (IVIA, 2019). Moreover, the current individual presents LEH, which can be related to various factors including nutrition deficiencies, low socioeconomic background, and infectious diseases (Goodman et al., 1988; Lukacs et al., 2001; King et al., 2005; Lewis, 2017:84-85). Therefore, it is possible that both LEH and the OM sequela point towards an individual that suffered chronic stress. In addition, rural Andalusian populations lived in houses with extended family members, and even though most of daily life revolved around the patio, rural homes usually had two to three rooms; thus, it is possible that children were often in contact with each other and that the sleeping space was overcrowded (Trillo, 2006; Orihuela, 2007). In the case of breastfeeding however, women tended to breastfeed for up to two years, and often appear in medical treatises as the ones caring for the sick child (Álvarez et al., 1984; Ávila, 1995; Cabanillas, 2012).

5. Conclusion

Through macroscopic, microscopic, and radiological analysis of the observed alteration to the right temporal bone, and the consultation of clinical and paleopathological literature, specific skeletal changes have been diagnosed as resulting from a major ear infection on the right temporal bone. It is likely that the individual first developed OM, which resulted in mastoiditis. From this point forward, different interpretations can be provided regarding the perforation. On one hand, the perforation could correspond to an abscess, which could be associated with a cholesteatoma; on the other hand, it could be compatible with surgical intervention (a mastoidectomy). Likewise, this lesion could be the result of the combination of both. The paleopathological record presents other cases of extensive damage to the mastoid process region of the temporal bone that have been identified as abscesses; while other pre-modern and clinical studies have proposed that similar lesions were the result of mastoidectomies. At some point after developing the lesion, the presence of copper around the affected area could represent an association with pharmacological treatment through the use of copper acetate; however, other options such as post-mortem contact with a pin or an earring are also possible. Limited contextual and archaeological information, as well as the possible differential diagnoses, do not allow any further precision.

Certainly, this case study presents an unusual lesion in paleopathology with interesting implications for the understanding of medical knowledge, medical access, and everyday life in rural Al-Andalus.

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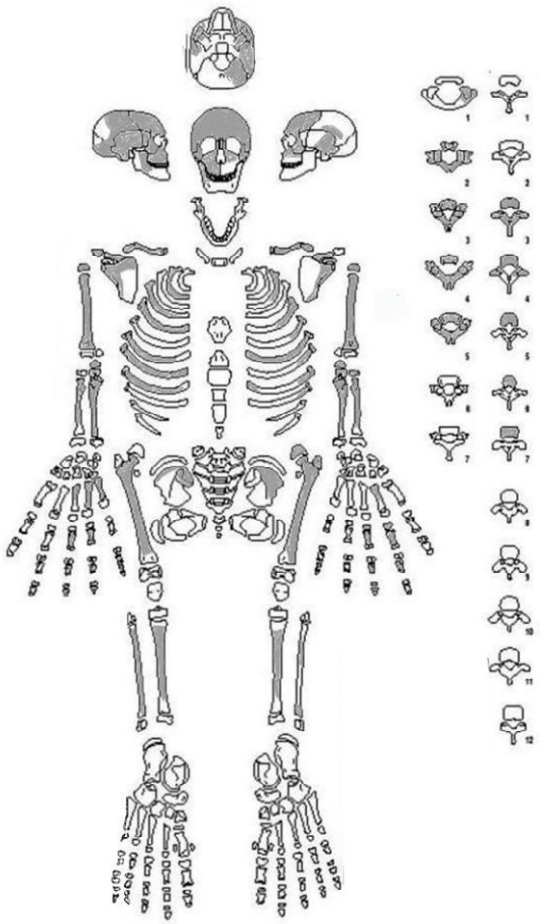
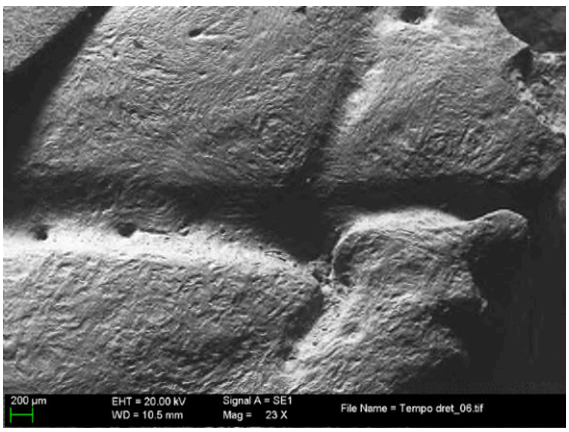
Appendix A. Supporting material

Supplement figure 1. Visual inventory of skeleton.



Supplement figure 2. SEM image showing the smooth surface of the blood vessel grooves located at the posterior external margin of the lesion (at the inferior rim level).


200 µm
EHT = 20.00 kV
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Signal A = SE1
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Evidence of otitis media and mastoiditis in a Medieval Islamic skeleton from Spain and possible implications for ancient surgical treatment of the condition

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