Skeletal lesions consistent with tuberculosis in an adolescent from Qubbet el-Hawa, Aswan, Egypt (Late Period, 664–525 BCE)

Lesões esqueléticas compatíveis com tuberculose num adolescente de Qubbet el-Hawa, Aswan, Egipto (Período Tardio, 664–525 AEC)

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Abstract Tuberculosis has been well established in Ancient Egypt and is defined as an endemic disease during dynastic times. In several tombs of the necropolis of Qubbet el-Hawa (QH) in Aswan, Egypt, unequivocal cases of tuberculosis (Pott's disease) have been identified in adults. The present study examines a well-preserved skeleton of an adolescent (approximately 14 years old) from the Late Period (664–525 BCE), buried in tomb QH33 of the necropolis and likely belonging to a middle-class individual. The individual exhibited a pattern of multifocal le-

Resumo A tuberculose encontrava-se amplamente difundida no Antigo Egipto, sendo considerada uma doença endémica durante o período dinástico. Em vários túmulos da necrópole de Qubbet el-Hawa (QH) em Assuão, Egipto, foram identificados casos inequívocos de tuberculose (mal de Pott) em adultos. O presente estudo examina um esqueleto bem preservado de um adolescente (aproximadamente 14 anos) do Período Tardio (664-525 AEC), enterrado na tumba QH33 da necrópole e provavelmente pertencente a um indivíduo de classe média. O indivíduo apresentava um

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Antrop Port 2025, vol. 42: 51–78 • http://doi.org/10.14195/2182-7982_42_3
Artigo recebido: 3 de abril de 2025 – Aceite: 29 de outubro de 2025/Received: April 3rd 2025 – Accepted: October 29th 2025

sions consistent with the hematogenous dissemination of infection. The objective of this study was to provide new information on this type of lesion pattern attributed to tuberculosis, which may assist in future diagnoses in dry bone, and to offer data on affected locations commonly reported in clinical sources but rarely discussed in paleopathological literature. Likewise, microscopic analysis of the dentition has provided insights into the dietary pattern, offering a broader perspective on the possible presence of the disease in an individual associated with the elite of the Late Period in the region.

Keywords: Infectious disease; zoonotic disease; dynastic period; ancient Egypt.

padrão de lesões multifocais consistente com a disseminação hematogénica da infecção. O objetivo deste estudo foi fornecer novas informações sobre esse tipo de padrão de lesão atribuído à tuberculose, o que pode auxiliar em diagnósticos futuros em ossos secos, e oferecer dados sobre locais afetados comumente relatados em fontes clínicas, mas raramente discutidos na literatura paleopatológica. Da mesma forma, a análise microscópica da dentição permitiu identificar o padrão alimentar, oferecendo uma perspetiva mais alargada sobre a possível presença da doença num indivíduo associado à elite do Período Tardio da região.

Palavras-chave: Doença infeciosa; doença zoonótica; período dinástico; Egipto antigo.

1. Introduction

Diagnosing infectious diseases in human skeletal remains is particularly challenging, especially in non-adults, due to multiple factors. Disease progression depends on pathogen load, virulence, and the host's immune response. Because infections primarily affect soft tissues, fatal cases may leave no skeletal evidence (Ortner, 2008). In active tuberculosis cases, skeletal lesions represent only about 1–5% of all infections (Morris et al., 2002; Resnick and Kransdorf, 2005; Holloway et al., 2011). Moreover, such lesions are not always pathognomonic (Holloway et al., 2013), and the absence of clear bone changes complicates palaeopathological diagnosis (Roberts and Buikstra, 2003; Buikstra, 2019; Dangvard et al., 2019). In addition, the fragility of non-adult bones — due to their morphology, small size, and low density — often results in poor preservation and an underrepresentation of these conditions in the archaeological record (Baker et al., 2005; Lewis, 2007).

Paleopathological investigations have extensively utilized modern osteological series to characterize dry bone lesions associated with tuberculosis in adults, thereby enhancing our understanding of the disease (Kelley and El-Najjar, 1980; Matos and Santos, 2006; Santos and Roberts, 2006; Mariotti et al., 2015; Dangvard et al., 2019). However, comparatively less attention has been directed towards non-adults (Pálfi, 2012; Gooderham et al., 2020; Masiu et al., 2023), with only sporadic summaries available, often

of poorly preserved cases from diverse temporal and geographical contexts (Mays et al., 2002; Dabernat and Crubézy, 2011; Lewis, 2011; Dawson and Robson, 2012; Rubio et al., 2017; Sparacello et al., 2017; Abegg et al., 2020; Spekker et al., 2024, among others). This situation further complicates the identification of new cases in dry bone, due to the limited number of published examples in the palaeopathological record.

Diseases such as tuberculosis, caused by the *Mycobacterium tuberculosis* complex, significantly impacted past populations, particularly in the Fertile Crescent, where early agriculture emerged around 13,000 years ago (Wirth et al., 2008; Hershkovitz et al., 2015; Bendrey and Martin, 2022). This shift led to population growth, reduced mobility, and close human–animal coexistence, facilitating the spread of zoonotic and parasitic diseases (Mitchel, 2003; Stone et al., 2009; Hershkovitz et al., 2015).

In ancient Egypt, tuberculosis has been documented from Predynastic times (5500–3100 BCE) through to the Late Period (664–332 BCE; Zink et al., 2001; 2007; Donoghue et al., 2010; Dabernat and Crubézy, 2011). Ancient DNA analyses of individuals from Abydos (Predynastic/Early Dynastic period, 3650–3500 BCE) and from sites dating to the Middle Kingdom (2100–1550 BCE) and the New Kingdom to Late Period (1450–500 BCE) in Thebes have also been undertaken (Zink et al., 2003). These analyses extracted DNA from individuals with osseous tuberculosis, revealing 66.7% positive results among those with lesions suggestive of tuberculosis, 20.8% among those with non-specific lesions, and 14% among cases without any observable bone lesions (Zink et al., 2003). These findings indicate that, despite the absence of skeletal lesions in many cases, tuberculosis was present in ancient Egypt, supporting the interpretation that the disease was endemic throughout the dynastic period (Zink et al., 2004; 2007; Crubézy et al., 2006).

Regarding palaeopathological findings in ancient Egypt, as in the general pattern, most identified cases involve adults, primarily cases of Pott's disease — the pathognomonic spinal lesion caused by tuberculosis — documented throughout the dynastic period (Elliot-Smith and Ruffer, 1910; Ruffer, 1921; Morse et al., 1964; Strouhal, 1991; 1999). Such cases have also been recorded in tombs from the New Kingdom (1550–1069 BCE) at Qubbet el-Hawa (Botella et al., 2021), the necropolis from which the individual examined in this study was recovered. Specifically, three cases of Pott's disease have so far been identified in tombs QH32 (Figure 1c — left), QH34bb (Figure 1c — right), and QH33 (Figure 1d — centre), confirming the presence of tuberculosis at this site during the dynastic period. Nevertheless, there remains a general underrepresentation of tuberculosis cases in the Egyptian palaeopathological record compared with molecular evidence, and only anecdotal evidence of non-adult individuals documented to date (Dabernat and Crubézy, 2011).

Clinical data may also provide insight into the absence of osteoarticular tuberculosis cases in children observed in archaeological contexts from similar historical periods. It is worth noting that skeletal involvement occurs in approximately 4% of children with active tuberculosis infection (Kritsaneepaiboon et al., 2017). This complexity is further increased by the variation in osseous lesions according to age among non-adults (Rasool, 2001). In general, children in their first decade of life most frequently develop spinal tuberculosis and dactylitis, whereas involvement of the long bones and joints tends to occur during the second decade of life (Cruz and Starke, 2010), although this distinction is not entirely strict (Drobish et al., 2022; Ortiz et al., 2025). Moreover, although multifocal involvement due to tuberculous osteomyelitis is more common in children than in adults, only 5–15% of paediatric tuberculosis cases show multifocal lesions (Muradali et al., 1993; Morris et al., 2002), which partly limits the availability of comparable palaeopathological evidence showing similar lesion patterns.

Despite this, the higher prevalence of osseous lesions among subadults, together with the fact that in developing countries the incidence of osteoarticular tuberculosis can reach up to 20% of all tuberculosis cases (Muradali et al., 1993; Lin et al., 2005; Hong et al., 2010), has resulted in a greater number of reported cases. Consequently, numerous paediatric clinical reports have addressed osteoarticular tuberculosis (Alfer, 1892; Rasool, 2001; Kumar et al., 2003; Teo and Peh, 2004; Hosalkar et al., 2009; Ortiz et al., 2025, among others), thereby expanding current knowledge from the most frequent osseous locations to the more atypical ones (Agarwal, 2020). However, the use of such sources is complicated by the application of diagnostic techniques that differ substantially from those employed in dry bone analysis. Nevertheless, they can provide valuable comparative data for the interpretation of archaeological cases such as the present study, where the lesion pattern observed in the individual requires stronger diagnostic support than that available from the limited palaeopathological literature. The present study highlights the importance of diagnostic synergy between palaeopathology and clinical research, aiming to support future diagnoses in dry bone remains. This analysis focuses on the diagnosis of an unusual lesion pattern in an adolescent individual from ancient Egypt, as well as the application of new analytical approaches — such as dental microwear análisis — which contribute complementary information to the diagnosis and offer new perspectives for palaeopathological research.

2. Material and methods

The individual (QH33-UE35-nº4) was discovered within his coffin inside the main antechamber of tomb QH33 (Figure 1e and f), located at the bottom of a 13-m-deep shaft. Originally, the tomb belonged to the 12th Dynasty (1939–1760 BCE; Jiménez-Ser-

rano and Sánchez-León, 2015); however, the antechamber was reused until the Late Period (664–332 BCE), to which this burial corresponds (Jiménez-Serrano et al., 2016). The skeletal remains were found in a badly deteriorated coffin, together with nine better-preserved coffins that contained mummified adult individuals (Figure 1f and g). The richness of the funerary assemblage, including coffin iconography (Taylor, 2001), Ptah-Sokar-Osiris statues (De la Torre, 2019), bead nets (Silvano, 1980), and pottery (Jiménez-Serrano et al., 2016), allowed for precise dating of the burial to the 26th Dynasty (664–525 BCE).

The individual's age at death was estimated based on the developmental stage and size of the long bones (Cunningham et al., 2016) and by evaluating the dental development and eruption (AlQahtani et al., 2010). A macroscopic analysis of all bone structures was conducted for identification and differential diagnosis (Aufderheide and Rodríguez-Martin, 1998; Roberts and Buikstra, 2003; Lewis, 2018; Buikstra, 2019) and clinical studies (Rasool, 2001; Morris et al., 2002; Teo and Peh, 2004; Agarwal, 2020). Specific references were consulted for the analysis of lesions, such as *cribra orbitalia* (Rinaldo et al., 2019). Enamel hypoplasia was recorded following Goodman and Rose (1990), with age estimations calibrated according to Reid and Dean (2006). Enamel hypoplasia was documented using a 3D digital microscope HIROX KH-8700 using a low-range objective, providing magnifications of 35× and 50× (Lozano et al., 2022).

After cleaning the dentition with ethanol, dental moulds were created on-site using a silicone-based material (Coltene Affinis Precious, light body). High-quality replicas were produced by filling the moulds with epoxy resin (EPORAI 1060) and curing them for 24 hours. Upper and lower molars were analysed with a ZEISS Axioscope A1 optical microscope, capturing 100× magnification micrographs of the buccal surfaces (Hernando et al., 2024). Additional analysis of lower molars and anterior teeth was conducted with a HIROX KH-8700 3D digital microscope at varying magnifications (35×–140×) under ring light conditions to assess dental wear related to diet. Micrographs for microwear analysis were cropped to 0.56 mm^2 (Galbany et al., 2004), and striation parameters (total number, length, width, and orientation) were measured using ImageJ® (Hernando et al., 2024). Striation orientation followed established classification methods (Pérez-Pérez et al., 1994), and dietary proxies (NV/TN, NH/TN, NT/NV) were calculated to infer carnivorous or vegetarian diets (Lalueza et al., 1996).

3. Results

The skeleton was well preserved despite some missing bones (Figure 2.1). It displays notable fragility and lightness, leading to partial breakage in certain areas of the cortical bone. Based on dental eruption and of state of root formation in the upper right M3 (Figure 4a), the individual was estimated at approximately 14 years (range 13–15 years). Long bone diaphy-

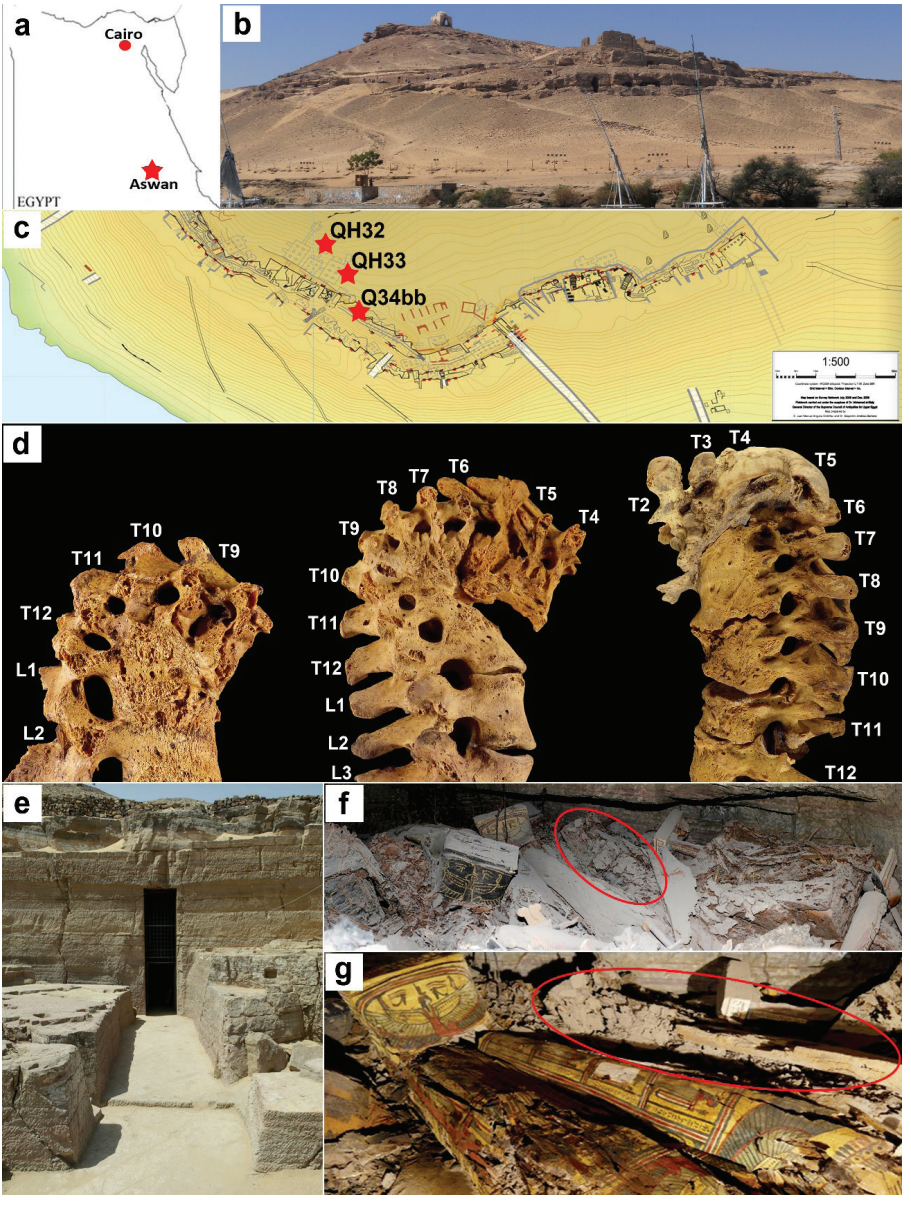

Figure 1. a. Map of Egypt. b. Panoramic view of the necropolis of Qubbet el-Hawa. c. Map of the tombs within the necropolis. d. Cases of Pott's disease in adults from left to right: QH32, QH33, and QH34bb. e. Façade and entrance door of the hypogeum/tomb QH33. f. Antechamber of the shaft at the time of its discovery, showing the level of funerary reuse during the Late Period. g. Detailed image of the deteriorated coffin of the adolescent (red circle).

seal metrics (Right humerus: 224 mm; right femur: 325 mm, and right tibia: 277 mm) suggest an age between 10.5 and 12.0 years, indicating a delay in skeletal growth.

Generalized bone loss was observed in the axial skeleton, with the most significant loss observed in the sternum (Figure 2b), sacrum (Figure 2g), and spinal vertebrae, along with a slight reduction in the height of T10 and T11 vertebral bodies (Figure 3a). Vertebral bodies of T7 to L2 exhibited alternating porosities and macroporosities (Figure 3a — detailed images), also affecting parts of the appendicular skeleton, specifically the region surrounding the radial and coronoid fossae of both humeri (Figure 2c), within the tubero-acetabular sulcus, and extending along the anterior surface of both ischia (Figure 2f).

Furthermore, the presence of lytic lesions has been observed in various regions of the skeleton. Firstly, the right parietal, located 34 mm from the squamosal suture and 8.7 mm from the coronal suture, exhibited a circular erosion (6.7 mm in diameter and 2.1 mm in depth) affecting the external table and diploë without perforating the internal table of the cranium. The lesion exhibited a smooth internal surface with macroporosity and a labiated margin along the entire circumference (Figure 2a). A further lytic lesion was identified in the sternal aspect of the sixth rib, perforating the rib body (Figure 3b). On the visceral surface, two communicating perforations with smooth internal surfaces were observed (Figure 3c — left), except for some postmortem breaks along the margins of the lesion. On the external rib surface, an oval perforation measuring 17 mm in maximum length and 7.4 mm in maximum height was present. The lesion margins were found to be smooth and labiated, with porosities observed along the right margin and the upper edge of the perforation (see Figure 3c — right).

At the distal end of the diaphyses of the right radius and ulna, lytic lesions were present in the cortical bone, particularly accentuated in the radius, where there was extensive destruction of the medial portion of the diaphysis. The elongated erosion (13.5 mm in maximum length) exhibited postmortem breakage, with the exception of the upper margin, which displayed labiated edges. This erosion extended from the initial point to the metaphyseal line, resulting in the destruction of the internal trabecular structure of the radius (Figure 2d).

In the lower limbs, the neck of the right femur exhibited four circular lytic lesions (4.3–7.1 mm diameter), one located on the superior margin of the neck and the other three, larger, on the metaphyseal surface of the greater trochanter (Figure 2h). These lesions affected the cancellous bone of the femur, with the precise morphology of thier margins remaining ambiguous. In a similar manner, the greater trochanter exhibited two lytic lesions that had been extensively altered by postmortem breakage. Lytic lesions were also observed in the distal third and epiphysis of the left fibula and

in the proximal epiphysis of the left tibia. The latter displayed a postmortem break along the medial side, exposing a lytic cavity (5.4 mm diameter) in the medial condyle, which extended internally and exhibited a perforation at the superior aspect of the condyle (Figure 2i). A similar cavity was observed at the proximal end of the fourth right metatarsal, consisting of an oval-shaped perforation (6.1 mm in diameter) with margins alternating between sclerotic areas and porosity along the entire external perimeter of the cavity. The cavity facilitated observation of the internal structure, thus revealing complete destruction of the cancellous bone extending along the diaphysis.

In contrast to the rest of the other bones, both ilia exhibited proliferative lesions on the gluteal surface, restricted to the area of muscle attachment. These consisted of porotic new bone formations with macroporosity along their superior margins (Figure 2.1 [yellow] and Figure 2e).

The individual exhibits evidence of *cribra orbitalia* (Figure 4b), *cribra humeralis*, and *femoralis* (Figure 4c), as well as signs of enamel hypoplasia in the form of two horizontal bands (Figure 5b). The estimates suggest that these disruptions occurred at 4 and 5 years of age.

Optical microscopy of the molar buccal surfaces was hindered by a resin layer from mummification, preventing proper microwear analysis. However, digital microscopy at 140× enabled clear identification and quantification. The second right lower molar showed low striation density (TN = 65) with an average length of 368.46 µm. Striations were mostly vertical (66.15%), followed by mesiodistal (26.15%), horizontal (6.15%), and distomesial (3.07%; Figure 5c). Calculated indices were NV/TN = 0.66, NH/TN = 0.06, and NH/NV = 0.09. The lower left first incisor had 54 long striations (265.67 µm), primarily vertical (70.37%), with mesiodistal (18.51%) and horizontal (9.26%) orientations (Figure 5d). Striations were wide, averaging 19 µm.

4. Discussion

4.1. Differential diagnosis

Taphonomic processes may create a similar appearance, known as pseudopathology, particularly erosions that can lead to misdiagnosis of osteolytic lesions patterns. Additionally, the bone's fragility is more noticeable in the axial skeleton, which includes postmortem fractures, particularly in the spinal vertebrae, making it challenging to fully characterize the lesion pattern. Another limitation was the inability to apply radiological techniques, which could have provided information on the internal extent of the lytic lesions in the radius, tibia, and metatarsal of the individual from Qubbet el-Hawa. Nevertheless, the labiated borders of certain lytic lesions indicate a multifocal pathological pattern rather than taphonomic processes.

In the clinic, lytic lesions similar to those usually found have a differential diagnosis with subacute and pyogenic osteomielitis, fungal infections (such as aspergillus and candida osteomyelitis), Langerhans cell histiocytosis (LCH), neo-

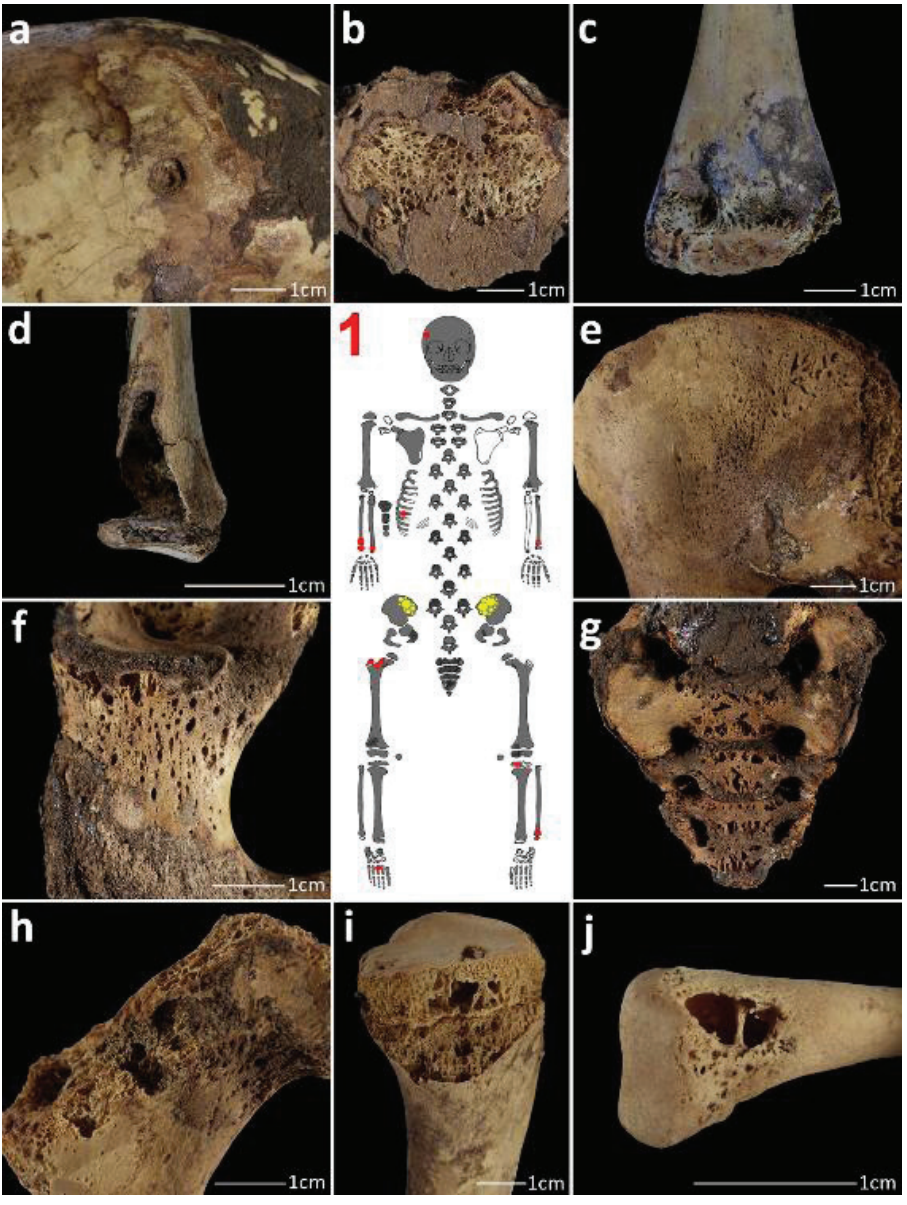

Figure 2. Bone lesion pattern of the 10.5 to 14-year-old individual: 1. Skeletal preservation: red dots = lytic lesions; raster = porotic areas and frame porosities; yellow points = proliferative lesions. a. Lytic lesion on the right parietal. b. Loss of trabecular structure on the internal surface of the manubrium. c. Porosity in the coronoid fossa. d. Lytic lesion and trabecular bone loss in the left radius. e. New bone formation on the gluteal surface of the right ilium. f. Porosity in the tubero-acetabular sulcus of the right ischium. g. Macroporosity in the vertebrae of the sacrum. h. Multiple erosions in the neck of the right femur. i. Lytic lesion on the medial border of the proximal epiphysis of the tibia. j. Lytic lesion at the proximal end of the fourth right metatarsal.

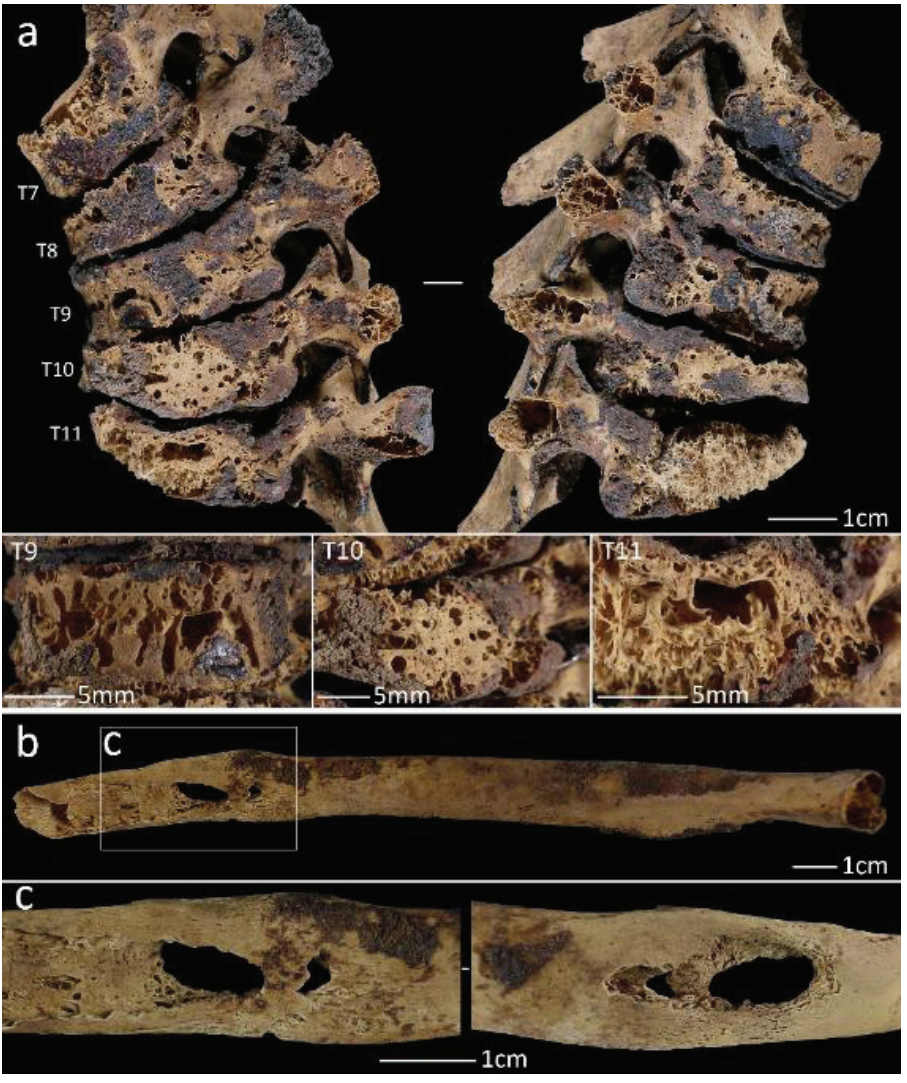

Figure 3. Pathological lesions in the thorax. a. Lateral views of the lower dorsal sector (T7–T11) with detailed images of the vertebral bodies showing macroporosity (T9), porosity (T10), and loss of trabecular structure (T11). b. Lytic lesion at the sternal end of the right sixth rib. c. Detailed images of the visceral (left) and external (right) surfaces of the same rib, showing the labiated margins of the lesion.

plasms (such a Ewing sarcoma, aneurysmal bone cyst, neuroblastoma, and giant cell tumour), as well as tuberculosis osteomyelitis (Rasool, 2001; Morris et al. 2002; Teo and Peh, 2004; Kanoun et al. 2007; Costelloe and Madewell, 2013; Hirji and Saifuddin, 2014; Katragkou et al. 2017; Alasaad et al., 2024). However, analysis of

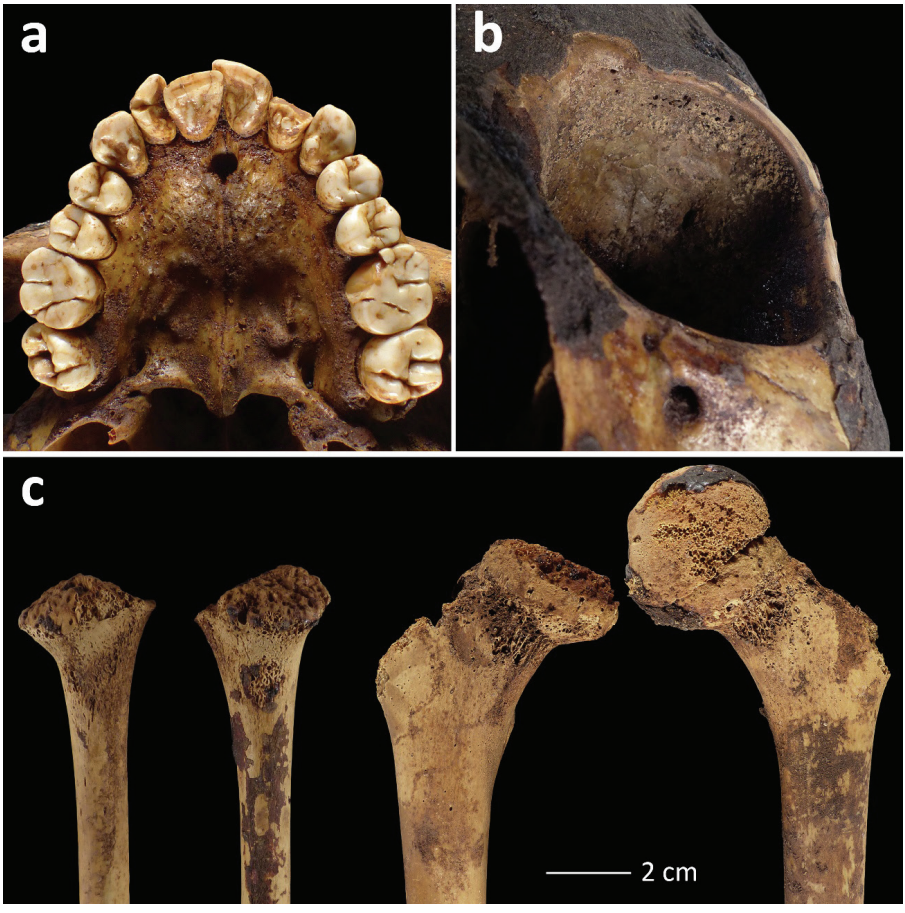

Figure 4. a. View of the teeth in situ of the maxilla; b. Cribra orbitalia on the roof of the left orbit; c. Bilateral porosities on the humeri (cribra humeralis) and femurs (cribra femoralis).

the dry bones reveals smoothed edges of certain lesions in the cranium, rib, and metatarsal, with restricted margins. This finding eliminates the possibility of neuroblastoma (Morris et al., 2002) and LCH, as the latter does not typically involve multiple bones (Huang et al., 2013). This phenomenon is also observed in the remaining appendicular skeleton of the individual, comprising the radius, ulna, tibia, and fibula. Notwithstanding the extent of the lesions in the long bones, the absence of periosteal reaction and the size of the erosions do not affect the normal morphology of the bone. Consequently, the following conditions can be excluded: Ewing Sarcoma (Ozaki et al., 2015); aneurysmal bone cyst (Freiberg et al., 1994); and giant cell tumour (Puri et al., 2007). As is well documented, fungal

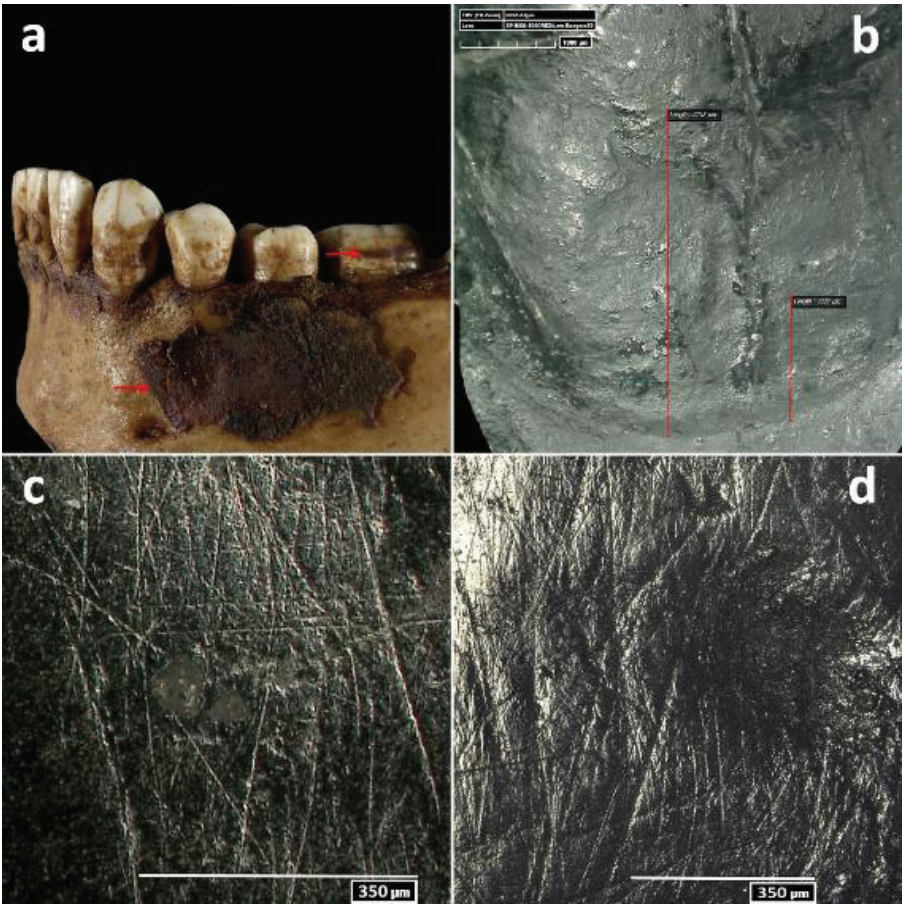

Figure 5. a. Lateral view of the mandible showing enamel hypoplasia of lower left canine, with remnants of mummified soft tissue (red arrows); b. Metric traits of enamel hypoplasia obtained with the 3D digital microscope (KH-8700 3D; 50× magnification); c. Striations on the buccal surface of the lower second molar (Zeiss Axioscope A1; magnification: 140×), d. Striations on the buccal surface of the lower left central incisor (Zeiss Axioscope A1; magnification: 100×).

infections can affect vertebrae, ribs and epiphyses of long bones, with the potential for the development of abscesses and bone destruction (Katragkou et al., 2017). However, it is improbable that such infections would manifest as generalized osteopenia of the axial skeleton, as evidenced in the QH adolescent.

The multifocal pattern can exclude subacute type osteomyelitis, such as Brodie's abscess, which typically presents with metaphyseal localization in long bones (tibia and femur) and a lytic morphology similar to the current erosions (Kanoun et al., 2007; Takeuchi et al., 2017; Sari et al., 2019). Furthermore, the

absence of spinal lesions (abscesses) in the individual suggests that pyogenic osteomyelitis is unlikely (Mylona et al., 2009), supporting hematogenous dissemination of tuberculosis as the most probable diagnosis.

4.2. Tuberculosis lesion pattern

The presence of hematopoietic marrow in non-adults facilitates the spread of the foci and lesion pattern observed in the individual's cranium, thorax, and metatarsal bone (Alfer, 1892; Huang et al., 2001; Rasool, 2001; Fonseca-Santos, 2005). In adolescents with secondary tuberculosis due to hematogenous dissemination, characteristic findings include lesions located in the epiphyses of the long bones and generalized osteopenia, which is more pronounced in the axial skeleton but also detectable in the appendicular skeleton (Rasool, 2001; Cruz and Starke, 2007; Wainwright, 2014). This may explain the presence of different lesions in the cranium (Kumar et al., 2002). The multifocal pattern and cavities (sizes and morphology) in the long bones have been observed on ribs (Huang et al., 2001) and tibia (Kao et al., 2010). In addition, cystic cavities with metaphyseal expansion in the epiphyses of long bones — such as those located in the femoral neck, radius, and most clearly in the tibia of the present case — can be explained by pressure necrosis of granulation tissue and the direct action of bacilli (Morris et al., 2002). Furthermore, lesions observed in adolescent individuals, such as QH, have been documented in clinical literature (Alfer, 1892; Haygood and Williamson, 1994; Dhammi et al. 2003; Teo and Peh, 2004; Hosalkar et al. 2009). In the present case, that observed locations suggest hematogenous tuberculosis dissemination, although some of the identified lesion sites and their morphology differ to some extent from those documented in the paleopathological literature. Therefore, it is important to refer to clinical cases that may support the diagnosis of tuberculosis for specific skeletal lesions (Table 1).

As shown in Table 1, the chronic lesion pattern observed exhibits characteristics that are consistent with those typically seen in tuberculosis, albeit with slight variations comparable to those observed in dry bone. The lesions align with those documented in palaeopathological and clinical literature, although some localisations are exclusive to the latter. In the cranium, the lesion has a labiate margin but does not present a periosteal reaction around the orifice as seen in other cases (Dawson and Robson, 2012), neither with the same extension as some cases (Ortner, 2003; Pálfi, 2012). Nor endocranial lesions (Hershkovitz et al., 2002; Lewis, 2004; Abegg et al., 2020; Spekker et al., 2024), although some adolescent individuals have also shown an absence of endocranial involvement (Gooderham et al., 2020). The same applies to the lytic lesion of the fourth metatarsal, which, although a common location in children during the first decade of life (Cruz and

Table 1. Description of the bone lesions of the QH individual and their association with tuberculosis in clinical cases and in the palaeopathological literatura.

Location	Type of lesion (clinical analytical assessment)	Description of lesion in the QH individual	TB lesion characteristics (clinical studies)	Similar lesions in children reported in Paleopathology
Cranium (Fig. 2a)	Focal erosion (common)	The orifice in question is characterized by labiate edges in the right parietal region. This condition affected both tables.	This is a common occurrence in adolescents and is frequently observed in the parietal region. In some cases, new bone formation may be observed in the vicinity of the orifice (Teo and Peh, 2004; Buikstra, 2019).	Dawson and Robson (2012)
Radius (Fig. 2d) and ulna	Infiltrative (common)	The distal end of the diaphysis (metaphyseal and epiphyseal area) had an osteolytic lesion. The edges of the bone were labiate, and there was trabecular destruction.	Bone cysts with diaphyseal expansion (infiltrative) have been observed in long bones (Rasool, 2001; Teo and Peh, 2004). This location has been reported in clinical sources (Hakimi et al., 2008; Agarwal, 2020)	Dabernat and Crubézy (2011)
Ilium (Fig. 2e)	New bone formation (common)	A proliferative lesion was observed on the posterior aspect of the lateral surface.	This location is less common than the iliac fossa, but it could correspond to abscesses in other muscles in the vicinity (Elshafie et al., 2013), including the gluteus (Toda et al., 1998; Ludwig and Lazarus, 2007).	No documented cases
Low spine (Fig. 3a)	Macroporotic and trabecular bone loss (common)	The presence of porosities interspersed with large holes (macroporosities) precluded the possibility of considering them lytic lesions.	Hypervascularisation and osteopaenia of the vertebral bodies have been documented (Teo and Peh, 2004).	Mays et al. (2002); Klaus et al. (2010); Pálfi (2012); Mariotti et al. (2015); Masiu et al. (2023); Spekker et al. (2024)
Long bone (Fig. 2c)	Pits (common)	Pits were present in the cortical bone of the metaphyseal and epiphyseal areas of the long bones.	Generalised osteopaenia affecting long bones is characterised by alterations in the trabecular and cortical bone structure (Haygood and Williamson, 1994; Teo and Peh, 2004).	Gooderham et al. (2020); Masiu et al. (2023); Larentis et al. (2023)

Location	Type of lesion (clinical analytical assessment)	Description of lesion in the QH individual	TB lesion characteristics (clinical studies)	Similar lesions in children reported in Paleopathology
Sternum (Fig. 2b), ischium (Fig. 2f), and sacrum (Fig. 2g)	Pits and trabecular bone loss (common)	The cortical bone (spine and ischium) exhibited extensive porosity, while the trabecular structure of the sternum was lost.	The process of demineralisation is associated with the localisation pattern of the bone marrow (Rasool, 2001).	Formicola et al. (1987); Gooderham et al. (2020); Sparacello et al. (2017); Spekker et al. (2024)
Rib (Fig. 3b)	Focal erosion (common)	The lesion exhibited labiate margins and a minor periosteal reaction at the edges.	Hematogenous foci were most prevalent in the area near the osteocartilaginous border. A lytic lesion with fusiform enlargement and smooth borders was observed, except where trabeculae were exposed (Huang et al., 2001; Fonseca-Santos, 2005).	Mays et al. (2002); Matos et al. (2011); Pálfi (2012); Dangvard et al. (2019); Libor et al. (2023)
Femoral neck (Fig. 2h)	Focal erosion (uncommon)	The bone tissue had been eroded in the neck and metaphyseal area of the greater trochanter. There was no evidence of tubular expansion.	Infection may originate in the head, neck, acetabulum, or greater trochanter (Lynch et al., 1982; Mohideen and Rasool, 2013; Shenoy et al., 2013; Mahomed et al., 2023). Small erosions are a common occurrence (McNeur and Pritchard, 1955).	No documented cases
Tibia (Fig. 2i) and fibula	Focal erosion (common)	A unilateral lesion was identified in the metaphyseal area and tibial plateau.	Destructive areas in the tibial plateau are particularly prevalent in non-adults (Kao et al., 2010; Agarwal et al., 2016). This is attributed to the entrapment of tubercle bacilli in the small arterioles of the metaphysis (Morris et al., 2002).	Mays et al. (2002); Dabernat and Crubézy (2011); Dangvard et al. (2019)
Metatarsal (Fig. 2j)	Infiltrative (common)	A cystic cavity with labiate borders was present, devoid of bone formation or osteitis.	The cystic cavity expands through the diaphysis with labiate outer edges, although it is surrounded by sclerosis, this is referred to as spina ventosa (Dhammi et al., 2003; Kumar et al., 2003).	No documented cases

Starke, 2010), lacks the periosteal reaction and thickening that produce the characteristic imaging appearance of *spina ventosa* (Kumar et al., 2003), typically observed in chronic infections occurring before the age of five (Goldblatt and Cremin, 1978; Rasool, 2001). This pattern suggests a later onset of infection, possibly after early childhood. The lesions indicate a chronic process, although the lack of further development may be related to the adolescent's death. Nevertheless, tuberculosis is primarily a lytic disease, and periosteal reaction is not present in all cases (Morris et al., 2002).

The individual exhibits a slight thinning of the vertebral bodies in the lower spine, although this cannot be considered pathognomonic due to the absence of the characteristic lesion of Pott's disease. Such lesions are, however, less frequently observed in adolescents than in children during the first decade of life (Cruz and Stake, 2010; Ortiz et al., 2025). Despite the absence of pathognomonic features of tuberculosis, the vertebral bodies display macroporosity consistent with hypervascularisation associated with the disease (Baker, 1999; Teo and Peh, 2004), particularly during the early stages of spinal tuberculosis (Baker, 1999; Mariotti et al., 2015). Similar patterns have also been reported in adolescents of comparable age to the Qubbet el-Hawa individual (Pálfi, 2012; Mariotti et al., 2015; Masiu et al., 2023; Spekker et al., 2024).

The adolescent from Qubbet el-Hawa exhibits pathological conditions associated with episodes of physiological stress (cribra and enamel hypoplasia). The individual presents porous lesions on the humerus, femur, and orbital roof, defined as *cribrous syndrome* (Miquel-Feucht et al., 1999), although the concomitance of these lesions remains a matter of debate. Likewise, a correlation between such porous lesions and enamel hypoplasia has been reported (Kozak and Krenz-Niedbala, 2002; Obertová and Thurzo, 2008), although establishing a common aetiology for these conditions in archaeological remains is challenging, making it difficult to determine whether they are linked to the disease affecting this individual. Nevertheless, recent studies have identified the presence of similar porous lesions in individuals with tuberculosis, particularly *cribra orbitalia* (Kyselicová et al., 2015; O'Donnell et al., 2020; Gomes et al., 2022), suggesting that these may represent a manifestation of the disease (Blondiaux et al., 2015). Pulmonary tuberculosis can interfere with erythropoiesis and iron metabolism, leading to hypoxia and anaemia, which may in turn result in *cribra orbitalia* (Gomes et al., 2022). Moreover, such lesions are common among non-adults from the necropolis of Qubbet el-Hawa (De la Torre and Jiménez-Serrano, 2023) and, as in the present case, may indicate episodes of nutritional or metabolic deficiency during childhood, which could have rendered the individual more susceptible to infectious diseases of this kind.

Moreover, other authors have argued that advanced osteopenia, such as

that observed in this individual, may be caused by prolonged immobility (Santos and Roberts, 2001; Sparacello et al., 2016), as well as by reduced size of the long bones (Mansukoski and Sparacello, 2018). Moreover, extended periods of immobility may exacerbate both conditions (Gooderham et al., 2020). This could account for the discrepancies between the dental age estimation and the lower age estimation based on the long bones. However, demineralisation and bone mass loss can also result directly from tuberculosis itself (Teo and Peh, 2004; Sparacello et al., 2016), and therefore cannot be ruled out as a manifestation of the disease. Despite this, the QH adolescent was likely immobile, severely debilitated, and dependent on care — either to move or to feed him — due to the advanced state of the lesions. Such loss of mobility may have further aggravated both growth impairment and osteopenia. In addition, tuberculous osteomyelitis involving the growth plates, as evidenced in the radius, ulna, femur, tibia, and fibula, can cause disturbances in the longitudinal growth of the bones (Aufderheide and Rodríguez-Martín, 1998; Hiddema et al., 2012).

4.3. Dental microwear considerations

The dental microwear pattern provides insight into the dietary habits of this individual. The most suitable tooth to determine dental microwear pattern is the lower first molar. However, resin residue from the mummification process and tissue mummification on the buccal enamel has not been removed (Figure 4a), preventing the visualization of dental microwear features on the lower first molar. Therefore, the lower second molar, with low striation density, was the most suitable for analysis, although its short functional period may have influenced the results.

Nevertheless, a low density of microwear features in the occlusal surfaces was recorded in a population of Predynastic Egyptians from Hierakonpolis (Gamza and Irish, 2010), indicating that this individual may follow the same pattern already documented at Hierakonpolis. The predominant orientation of the striations is vertical, with the length of the striations standing out. Scarce, long, and vertical striations have been associated with diets that include large meat components or even secondary products of animal, origin such as dairy (Organ et al. 2005; Romero et al. 2013). The toughness of meat requires a shearing movement of the mandible, which can result in the formation of longer and vertical striations (Pérez-Pérez et al., 1994). However, the presence of striations with mesiodistal (26.15%) and horizontal (6.15%) orientations may indicate the consumption of certain vegetal items in the diet. The results of the different indexes calculating the relationship between vertical and horizontal striations support a high carnivorous component in the diet.

Conversely, the presence of scarce, long, wide, and vertical striations on the

lower incisors suggests an animal-based diet and possible exogenous grit in food (Ungar and Spencer, 1999; Hernando et al., 2024). In addition to the microwear features, the first and second molars of this adolescent show exposed dentine in all cuspids, which indicates the presence of abrasive or fibrous items in the diet. The presence of environmental sand cannot be ruled out, potentially explaining both striation width and significant occlusal wear in the QH adolescent.

Malnutrition, whether preceding or following disease onset, is a significant factor in the progression and severity of tuberculosis, as well as in the mortality of infected individuals (Brigden et al., 2015; Sinha et al., 2021). Tuberculosis can also induce malnutrition through impaired protein absorption (Schwenk and Macallan, 2000); however, the individual appears to have maintained a diet high in animal protein. A protein-high diet, particularly one abundant in meat, may have influenced the progression and severity of tuberculosis, as well as mortality (Sinha et al., 2021). Protein supports the immune system in combating skeletal spread (Wilbur et al., 2008), and vitamin A and zinc from meat show modest benefits in patients with tuberculosis (Karyadi et al., 2002), although causality is debated (Mehta et al., 2011; Jaganath and Mupere, 2012). This adolescent, of medium-high social status, may have survived early-stage tuberculosis due to a beneficial diet.

5. Conclusions

The multifocal pattern, morphology, and location of the bone lesions are highly consistent with tuberculosis with hematogenous spread. Despite this, the present case displays variations in the pattern of lesions when compared with those most frequently documented in non-adults within the palaeopathological literature. This discrepancy is likely because published cases tend to focus on individuals exhibiting pathognomonic features, particularly when spinal osteomyelitis, Pott's disease, dactylitis, or *spina ventosa* are clearly expressed. In contrast, the Qubbet el-Hawa adolescent highlights the heterogeneity of the tuberculous lesion pattern in children, as also noted in clinical reports. In such cases, comparison with clinical evidence has been essential for recognising the morphological diversity of the lesions and their distribution pattern, as well as for identifying less common localisations, thereby strengthening the diagnosis of tuberculosis.

Although infectious diseases, including tuberculosis, were probably widespread in Ancient Egypt, the limited number of documented skeletal cases may reflect both the high lethality of these conditions and the relatively low proportion of tuberculosis infections that produce bone lesions. The QH adolescent, with privileged access to quality food, may have survived longer, developing chronic lesions. Furthermore, the excellent state of preservation allows us to understand the lesion pattern, which may aid future diagnoses in dry bone.

Funding

This research was supported by the Ministerio de Ciencia e Innovación (Spanish Government) [Project i+d+I HAR2016-75533-P] of the University of Jaén, Fundación Palarq, and Fundación Gaselec. A. Rubio Salvador was funded by a Postdoctoral Juan de la Cierva grant [JDC2022-049955-I] by the Ministerio de Ciencia e Innovación of IPHES-CERCA, and M. Lozano was supported by the Spanish Government MICINN [PID2021-122355NB-C32]. Additional financial support was provided by the CERCA Programme/Generalitat de Catalunya, AGAUR agency, and the 2021 SGR 2017 Research Group.

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