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RESEARCH

The medieval burial assemblage from Koudiet er Rammadiya, Northern Tunisia. An interdisciplinary bioarchaeological investigation

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Abstract
The osteological analysis of human skeletal assemblages offers crucial osteobiographical insights into ancient populations, yet remains largely unexplored in past Tunisia. This paper presents the first archaeological investigation of Tunisian medieval burials, unearthed during excavations between 2016–2017 and 2021–2022. This interdisciplinary study, combining archaeology, bioarchaeology, and paleopathology, examines skeletons from Koudiet er Rammadiya, a site in the Wadi Serrat region. The main aim is to investigate the funerary practices, health, and lifestyle of individuals from medieval North-western Tunisia, shedding light on this underexplored population. The focus is on the site's final phases of use and occupation, exploring funerary practices and rituals from the early Islamic period. The skeletal assemblage dates to two main periods: the seventh century CE and the fifteenth century CE. Osteological analysis revealed a minimum number of individuals (MNI) of 10, including three young females and two foetuses. A preliminary palaeopathological assessment identified a congenital condition in two individuals. An exploratory stable isotope analysis highlighted dietary practices focused on a predominantly terrestrial diet and a possible shared local origin for all the buried individuals.

Keywords North Africa · Middle Ages · Funerary context · Paleopathology · Biomolecular analyses

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Introduction

From the conclusion of the Late Antique period, marked by the capture of Carthage in 439 CE, to the onset of the Arab-Islamic period (6th-7th c. CE), the Tell region and El Kef (North-western Tunisia; Fig. 1A) have been impacted by the spread of tribal groups. The heterogeneous population of this territory reflects the economic evolution and social structures of an area known for its predominantly semi-nomadic rural settlement. Between the 7th and the 13th c. CE, the region became a battleground for numerous tribal conflicts that contributed to the Arabisation of the area (Boukhchim and Marzouki 2024). In the 11th c. CE, this instability led to a complex tribal structure involving Berber tribes and segments of Arab tribes (Araar 2014). From the mid-8th to the 14th c. CE, the region appears to have experienced a movement towards sedentarisation, as evidenced by the establishment of fortified villages and agricultural exploitations. The Berber village, known as Sidi Abdelkader, on the left bank of the Wadi Serrat, seems to be one of the villages founded during this period (Fig. 1B).

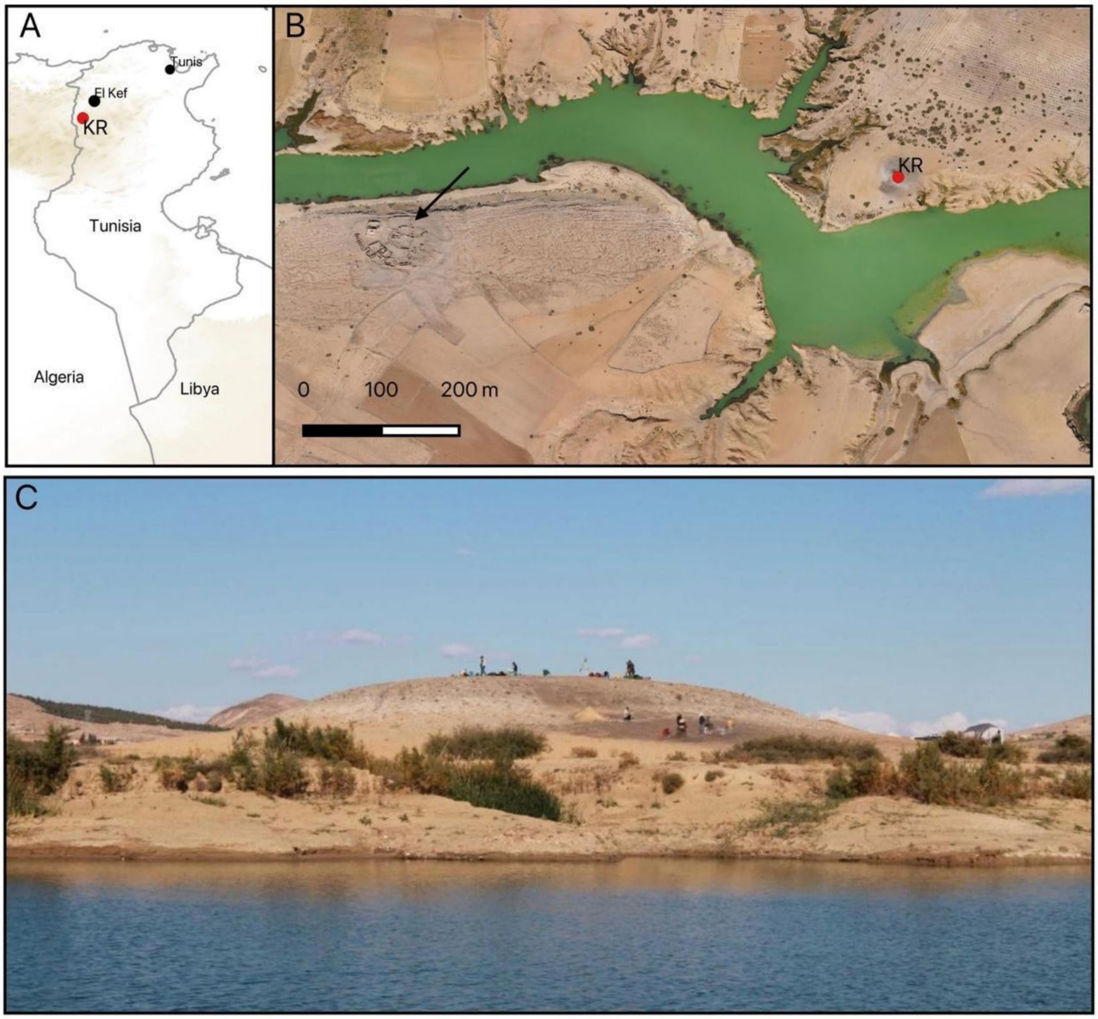

Fig. 1 **A** Localization of Koudiet er Rammadiya (KR); **B**: drone orthomosaic of the stretch of Wadi Serrat where KR is located. The black arrow indicates the village of Sidi Abdelkader; **C**: view of KR during excavation from the South

Given the few historical sources and the absence of archaeological data from Medieval Tunisia, this study stands as a unique contribution to understand past populations from North-western Tunisia. It involves the archaeological excavation of the medieval Muslim funerary area atop the Capsian *rammadiya* of Koudiet er Rammadiya in the el Kef region. This excavation provides unprecedented insights into the funerary practices, demographic insights, and cultural dynamics of medieval North-western Tunisia.

This study aims to investigate the temporal and spatial dynamics of the cemetery on the hill during the medieval period. The research will focus on understanding patterns of site use and their possible relationship to the prominent position of the hill in the landscape. In addition, the study aims to examine burial practices across the site, exploring the possible expansion of burials from the hilltop to its slopes over time. This research explores the socio-cultural significance of the archaeological site of Koudiet er Rammadiya as a medieval burial context through the analysis of human skeletal remains. The research contextualises the biological profiles of individuals, including sex, age at death and stature, while also examining palaeopathological indicators and biomechanical activity markers to assess health and lifestyle conditions. Dietary patterns were analysed using stable isotope ratios of carbon (δ^{13}C ‰), nitrogen (δ^{15}N ‰) and sulphur (δ^{34}S ‰), providing insights into subsistence strategies. In addition, strontium isotope ratios (^{87}Sr/^{86}Sr) were used to determine past geographic origins and mobility patterns. Finally, this study aims to provide important osteobiographical insights into ancient populations through the osteological analysis of past individuals, thereby filling a significant research gap in the study of medieval Tunisia.

Regional setting

The Wadi Serrat, a tributary of the Wadi Mellegue in the High Tell of North-western Tunisia near the Algerian border, lies within a mountainous region averaging 700 m in altitude and covering approximately 15,000 sq km. Known as the "Tunisian water reservoir," this area forms the country's primary hydrographic nexus (Zielhofer and Faust 2008; Ben Ghazi 2021). The Wadi Serrat basin spans 2188 sq km and sits around 700 m asl, with a semiarid continental climate experiencing harsh winters with occasional snowfall. Temperatures vary significantly between winter and summer. Predominant winds can elevate temperatures to 40–45 °C. Rainfall averages over 500 mm, reaching 700 mm in the Djebel Dyr Mountains (Faust et al. 2004; Zielhofer and Faust 2008).

Geologically, the region lies between the central and Northern Atlas Mountains, marked by folded structures and rift basins, notably the Kalaa el Khasba and Rouhia depressions (Karoui-Yaakoub et al. 2016). Since the Early Pleistocene, it has functioned as an endorheic sedimentary basin, with a shallow lake active during the Middle Pleistocene, resulting in a sedimentary succession over 15 m thick. Fluvial-lacustrine sediments from the Late Pleistocene overlay an erosive disconformity, with a Middle Pleistocene base rich in vertebrate fauna and Acheulean tools, and Holocene gastropods in the upper layers (Martínez-Navarro et al. 2014; Karoui-Yaakoub et al. 2016; Burjachs et al. 2023).

The site and the archaeological investigations

The site of Koudiet er Rammadiya is located in correspondence with a meander of the Wadi Serrat on its right bank (Fig. 1B and C), approximately 1 km North of Mahjouba. This area of the Wadi Serrat has been recently transformed into a reservoir by constructing a dam about 6 km West of Mahjouba.

It falls under the category of *rammadiya* or *escargotière*. The terms denote archaeological contexts typically associated with the Capsian and the Neolithic of Capsian Tradition (NCT), two prehistoric North African cultures, mainly attested in Algeria and Tunisia between 10,000 to 7000 cal BP (e.g., Aouadi and Harbi-Riahi 2020). The sites are characterised by abundant terrestrial snail shells, faunal remains, thick layers of ash, burnt stone structures, sometimes containing human burials. The term *escargotière*, from the French *escargot* (snail), was initially used for these sites, believed to be related to snail management locales (Camps 1997). The Arabic term *rammadiya* (plural: *rammadiyet*), meaning ash, refers to visible ash layers, a key feature in such contexts. In the Maghreb area, it is widely considered synonymous with *escargotière*. Significantly, the term *rammadiya* is included in the names of the locality, as documented by the toponymy of the area, and here retained for its widespread use in the scientific literature (Gobert 1937).

Koudiet er Rammadiya features a roughly circular, anthropogenic mound, about 6 m high and 60 m in diameter, formed by human activity in prehistoric and historic times. This greyish hillock, visible above the alluvial plain (Fig. 1), has been affected by natural erosion and more recent agricultural activities on its slopes and summit.

It was identified in the late 2000s by Ridha Boussofara from the National Heritage Institute (INP) within the framework of the project of the national archaeological map of Tunisia. The site showed potential due to the abundance of archaeological material and snail shells eroded from the mound's surface, along with ashy sediments. Preliminary investigations began in 2016, involving a surface survey and test trench (Sounding A), which revealed human bones. In 2017, INP, the University of Kairouan, and Sapienza University of Rome collaborated to conduct four test excavations across the mound (Fig. 2), uncovering significant archaeological material and human remains. These trenches were excavated using predefined cuts due to the largely undifferentiated nature of the sediments across very thick units, as is common practice in investigating such types of contexts (e.g. Mulazzani 2013; Lubell 2016; Aouadi and Harbi-Riahi 2020).

Extensive excavation was further carried out on the top of the mound (including Sounding B), covering 35 sqm (Main Sector, Fig. 2). A detailed study of the archaeological material is ongoing. However, it is evident how the upper layers, which contain abundant prehistoric artefacts (e.g. lithics, bone tools, beads), were affected by the deposition of later inhumations and use, as also testified by the presence of pottery, metal, glass or mosaic tiles. In this overall context, five burials were identified and investigated.

The bioarchaeological investigation: materials and methods

Chronological framework

Radiocarbon dating was conducted on five individuals, considering both the remains from the uppermost layers and those retrieved from deeper stratigraphic levels, to ensure accurate chronological attribution and assess deposition phases at the site. The measurements were conducted at CEDAD (Dipartimento di Matematica e Fisica "Ennio De Giorgi", Università del Salento, Italy) and at Dipartimento di Scienze e Tecnologie Ambientali, Biologiche e Farmaceutiche, Università degli Studi della Campania Luigi Vanvitelli (Italy) and calibrated following standard procedure (Bronk Ramsey 2021; Reimer et al. 2020).

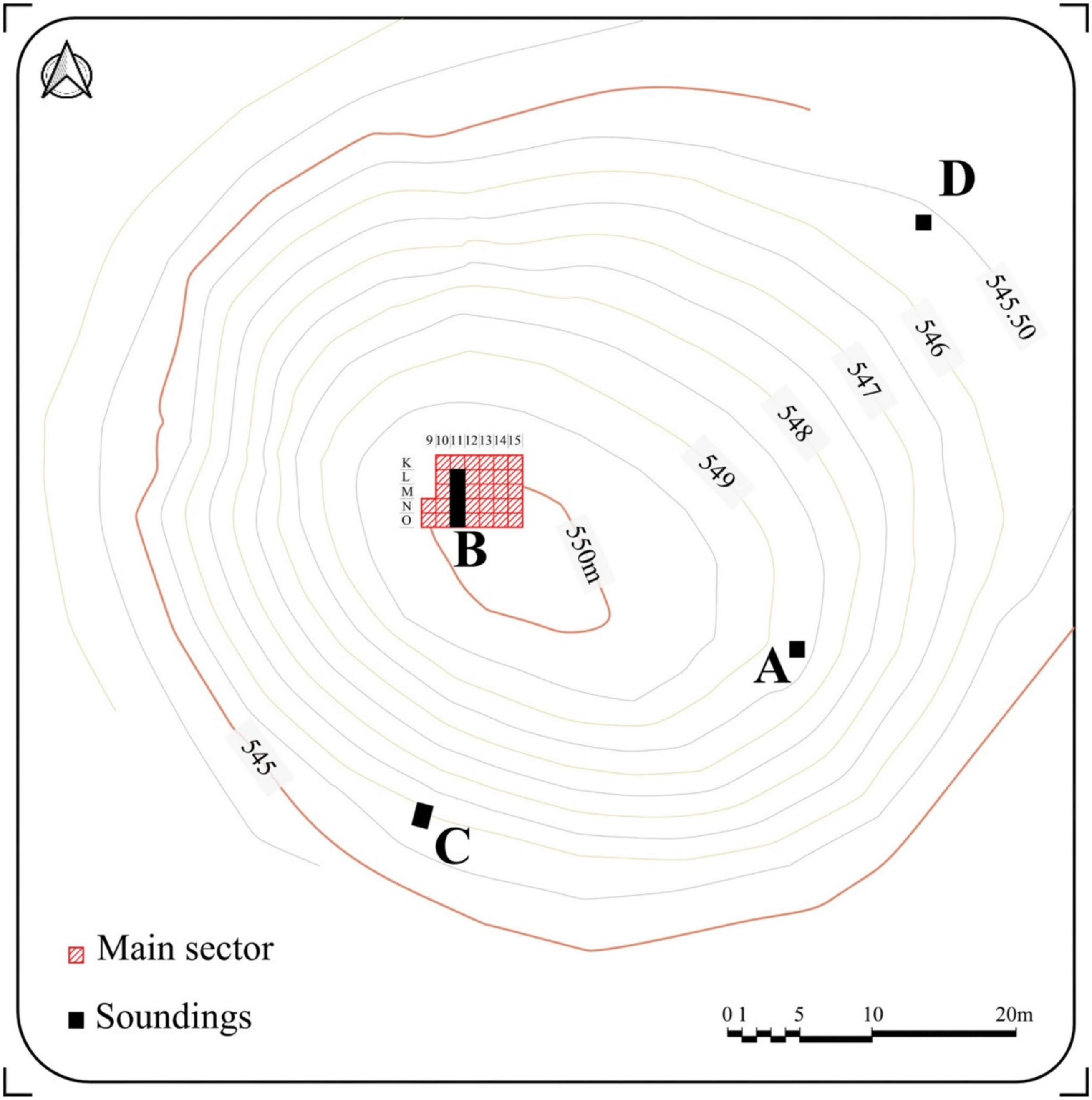

Fig. 2 Map of the site with soundings and the main sector (elevation asl is indicated in the rectangles)

The human remains and their depositional features

Some human bones do not appear in anatomical connection, particularly those found on the surface and the more superficial layers of soundings A and B. These scattered remains, were in extremely poor conditions, particularly the surface ones. The cortical portion of the bone was preserved, but the spongious bone, when visible, was highly degraded. The minimum number of individuals (MNI) investigation was performed following White et al. (2011).

Five burials with anatomically connected human remains (Fig. 3) were identified in the main sector. Their features are summarised below.

H1 (US 3f) The individual was positioned in a right lateral decubitus, with the skull elevated above the post-cranial skeleton, oriented SW-NE and facing E. The boundaries of the pit are not clearly defined. A series of stones demarcates the presumed cut on the surface and at the bottom of the pit, enclosing the deposition space of the skeleton, particularly

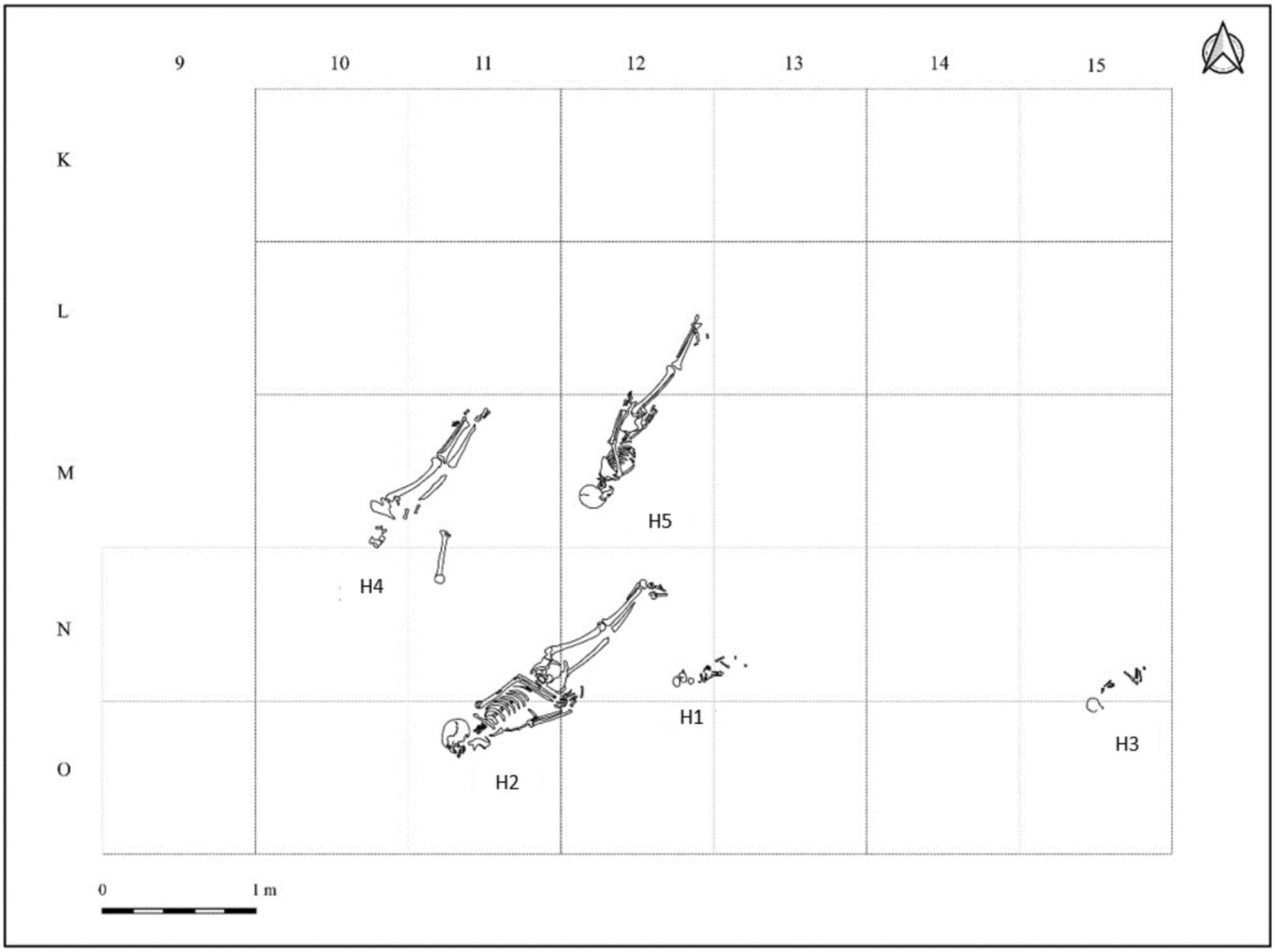

Fig. 3 Map of the burials from the main sector

around the lower limbs. The burial site has been disturbed by root activity and malacofauna. The anatomical alignment of the right side of the skull and mandible, along with the entire post-cranial skeleton, indicates deposition in a filled space. Conversely, the left side of the skull appears to have decomposed in a semi-empty space or may have been disturbed by post-depositional human activity. The skeleton is in good condition, with 95% of its elements preserved.

H2 (US 6b) The individual is oriented SW-NE. The skull faces SW and is inclined at approximately 45° in the ground; the spine is oriented at 240° SW (Fig. 4B-C). Pit boundaries were not identified. Taphonomic processes have led to the dislocation of the mandible, as a root intrudes into the space between two maxillary teeth. The teeth are in excellent condition, with the enamel perfectly preserved. The two central incisors and the left lateral incisor of the upper jaw were found dislodged from their sockets and within the soil surrounding the maxilla. The mandible is well-preserved, with all teeth intact within their alveoli. The post-cranium appears to have been deposited in a smaller space or wrapped in a shroud, as the right clavicle is positioned vertically. The fill is characterised by very friable sediment and fragments of malacofauna. The burial has not been disturbed by anthropogenic interventions since the deposition of the deceased. The burial seems to align with a stone structure (US 5a), approximately 190 cm long with a NE-SW orientation, consisting of stones embedded almost vertically in the ground, as well as H4. The skeleton is in good condition, with 95% of the elements preserved.

H3 (US 6a) The individual is oriented SW-NE. The skull faces SE (Fig. 4A). The decomposition occurred in a filled space, with the body lying on the right side and knees bent. The burial was in a primary position. The right arm is under the ribcage, while the left arm is bent over the pelvis. The left side of the skull is not anatomically connected to the right side. As in other cases, pit boundaries were not identified. The skeleton is 90% preserved, and the state of preservation of the bones is good. At the base of the burial, a

Fig. 4 Some of the burials unearthed during the excavation, including: **A** H3; **B** a general view of H2 and (**C**) a detail of the upper part of the skeleton; **D** H5

medium-sized stone near the right side of the skull emerges, oriented NW–SE and immersed at a 45° angle in the deposit. The skull partially covers it.

H4 (US 6c) The individual is oriented SW-NE, with the skull to the SW. The preserved part of the skeleton, in anatomical connection, appears aligned with the structure US 5a, as also noted for H2. The burial is preserved from the second lumbar vertebra (L2) to the feet. Commingled remains, including the clavicle, sternum, and some hand bones, were found near the feet. The individual was lying on their right side. The lower limbs are extended, one above the other. The hands (several carpal, metacarpal, and phalanx bones) were on the pelvis. Decomposition occurred in a filled space. The burial was affected by anthropogenic post-depositional disturbance (possibly a reopening of the pit), mainly affecting the thoracic girdle. Commingled remains were found in US 4III and US 5: disarticulated bones of the upper post-cranial segment, including three cervical vertebrae, five thoracic vertebrae, one lumbar vertebra, two rib fragments, the right radius, left ulna, a distal phalanx of the hand, and the fifth metacarpal on the right. These bones likely belong to H4. The minimum number of individuals (MNI) is one. The growth status of the bones further confirms that H4 and the bones in US 4III and US 5 belong to the same individual. The difference in elevation between H4 and the scattered bones suggests that during the reopening phases of the burial, the disturbed soil and, therefore, the bones accumulated in a disorderly and chaotic manner near the primary burial. Soil was sampled from within the sacrum.

H5 (US 9a) The individual is oriented SW-NE, facing E. The skull faces SE (Fig. 4D). Decomposition occurred in a filled space. H5 was lying on the right side, with arms extended along the body. Later disturbance can be detected in the region of the lower limbs, especially the left one. The right arm is under the ribcage, while the left arm is over the ribcage with the hand over the pelvis. Pit boundaries are not identified. The skeleton is 90% preserved, and the state of preservation of the bones is good.

The osteological assessment

Adults Sex determination is based on the observation of sexual dimorphism recognisable from the examination of the cranium and the pelvis (Buikstra and Ubelaker 1994). The methods used are among the most commonly found in the literature and refer to the observation of morphological variables in the skeleton, assessing diagnostic characteristics in the cranium and the pelvic bones, as reported by Acsadi and Nemeskéri (1970), and compared with Ferembach et al. (1979), and Buikstra and Ubelaker (1994). Additionally, the method proposed by Phenice (1969) was applied, allowing sex determination through observing morphological variables in the pubis. In the estimation of age at death, differentiation between "young adult" and "mature adult" was considered since the fusion of the epiphyses continues into the early years of the third decade of life (Buikstra and Ubelaker 1994). A combination of macroscopic methods was utilised in age estimation: the degree of cranial suture fusion (Meindl and Lovejoy 1985), the degree of pubic symphysis remodelling (Brooks and Suchey 1990), the observation of modifications to the sternal articular surface of the fourth rib (Işcan 1991), and the degree of remodelling of the auricular surface of the ilium (Lovejoy et al. 1985). Where possible, dental wear patterns were recorded according to Lovejoy (1985). The age at death was estimated by calculating the average ages obtained by the methods discussed. Despite the widespread use of these criteria, it is crucial not to overlook a significant aspect: age estimation investigates degenerative changes in bones and teeth, processes that occur at different rates depending on contexts and populations, themselves influenced by genetic, hormonal, environmental, nutritional, and social factors (Mays 2015). The robustness of the bones and possible biomechanical activities were investigated following Mariotti et al. (2007), Mays (2008), and Karakostis et al. (2021) and using White et al. (2011) to interpret muscular involvement. The stature estimation was carried out using the methods outlined by Olivier (1963). Finally, we included the observation of the discontinuous morphological traits, also known as epigenetic traits (see White et al. 2011, p. 476, Table 21.1, and referring to Mann et al. 2016).

Sub-adults The study of the age at death of foetuses, children and adolescents is based on various factors, including the length of the diaphysis of long bones, the appearance of secondary fusion centres (the epiphyses), and the degree of fusion with the primary centres, such as the analysis of maturation stage and dental development. The methods used for this purpose included dental growth (White et al. 2011, pg. 386, adapted from Ubelaker 1999 and integrated with AlQahtani and Liversidge 2010), long bone growth, and clavicle growth (Cunningham et al. 2016 and cited literature). To estimate the age at death of the foetuses, standards for the length of long bones by Scheuer and Black (2004, and cited literature therein) were considered. These methods provide a precise age range, as it is less influenced by environmental factors compared to adults.

Finally, all the individuals were classified into age classes, as it follows: i) foetuses: before birth; ii) infants: birth – 3 years old; iii) child: 4 – 12 years old; iv) adolescent: 12 – 17 years old; v) young adult (YA): 18 – 35 years old; vi) middle adult (MA): 35 – 50 years old; vii) old adult (OA): > 50 years old (following Buikstra and Ubelaker 1994).

The palaeopathological investigation

Due to the similarity in lesion patterns across pathological conditions and the diverse appearance of lesions, differential diagnosis becomes one of the most challenging tasks when evaluating diseases from dry bones (e.g., Roberts and Manchester 2007; Aufderheide and Rodriguez-Martin 2011; Appleby et al. 2015; Buikstra et al. 2017; Mays 2018; Buikstra 2019). In this context, we describe the lesion patterns and the literature review of the recorded pathological condition.

This provided a detailed overview of palaeopathological conditions recording the presence or the absence of the following pathologies: i) non-specific infections (i.e., periostitis, Roberts 2019), ii) degenerative joint disease and spinal osteoarthritis (Zampetti et al. 2016), iii) health-stress indicators (e.i., Linear Enamel Hypoplasia, Reid and Dean 2006; Kinaston et al. 2019), iv) developmental anomalies (Lewis 2019), v) dento-alverolar pathologies (i.e., possible presence of caries, tartar, periodontal diseases, and *ante-mortem* tooth loss; Hillson 2005).

Isotopic analyses

Stable carbon, nitrogen and sulphur isotopes

Considering that the study of the faunal record is still ongoing we could not sample animal bone to define a local baseline, however we measured the isotope ratio of one modern sample of sheep, which grew locally, to have a relative indication of the local environment. In plants, carbon fractionates according to their photosynthetic pathways and in different ecosystems, hence $\delta^{13}C$ values can be used to discriminate between C3 (~ −28 ‰), C4 (~ −14 ‰) and CAM (~ −11 ‰) plants and their consumers (O'Leary 1988), as well as between terrestrial (~ −7 ‰) and marine (~ 0 ‰) or freshwater (~ −15 ‰) environment (Peterson and Fry 1987). Similarly, $\delta^{15}N$ values are affected by climatic and environmental conditions and can be used as a trophic level indicator or to discriminate between terrestrial and marine environments (Van Klinken et al. 2002). Sulphur can be used to assess marine resources consumption (Peterson and Fry 1987; Nehlich and Richards 2009; Nehlich 2015), and in coastal area it serves as a mobility proxy (Bataille et al. 2021).

Collagen extraction for isotopic analysis followed Longin's (1971) method. Cortical bone (0.5 g) was cleaned by mechanical abrasion and demineralised in 0.5 M aq. HCl at 4 °C for several days. The samples were then rinsed to neutral pH. All samples were gelatinised in pH 3 water at 70 °C for 48 h. The collagen solution was filtered off with 5–8 µm Ezee filters, then frozen, and freeze dried. Each of the collagen extracts was weighed (ca. 0.8 mg) in triplicate into tin capsules, and stable carbon and nitrogen isotope ratios were measured using an automated elemental analyser coupled in continuous-flow mode to an isotope-ratio-monitoring mass-spectrometer. Analyses were carried out at SUERC. The International Atomic Energy Agency (IAEA) reference materials USGS40 (L-glutamic acid, δ13CV-PDB = −26.4 ± 0.0‰, δ15NAIR = −4.5 ± 0.1‰) and USGS41a (L-glutamic acid, δ13CV-PDB = 36.6 ± 0.1‰, δ15NAIR = 47.6 ± 0.2‰) were used to normalise δ13C and δ15N values. Normalisation was checked using the marine collagen USGS88 (δ13CV-PDB = −16.1 ± 0.1‰ and δ15NAIR = 15.0 ± 0.1‰) and the porcine collagen USGS89 (δ13CV-PDB = −18.1 ± 0.1‰ and δ15NAIR = 6.3 ± 0.1‰), which gave the values: USGS88, δ13CV-PDB = −16.3 ± 0.1‰ and δ15NAIR = 15.2 ± 0.1‰ and USGS89, δ13CV-PDB = −18.2 ± 0.1‰ and δ15NAIR = 6.4 ± 0.2‰. Stable isotope concentrations are measured as the ratio of the heavier isotope to the lighter isotope relative to an internationally defined scale, Vienna Pee Dee Belemnite (VPDB) for carbon and Ambient Inhalable Reservoir (AIR) for nitrogen (Hoefs and Hoefs 2009) and Vienna Canyon Diablo Troilite (VCDT). We considered reliable for further analysis only samples with a collagen yield of < 1% (Ambrose 1990; van Klinken et al. 2002). Preservation quality was assessed using %C (13–47%), %N (4.8–17%) and %S (0.15–0.35%) and C/N (2.9–3.6), C/S (300–900) and N/S (100–300) (Ambrose 1990; Nehlich and Richards 2009).

Stable isotope concentrations are measured as the ratio of the heavier isotope to the lighter isotope relative to an internationally defined scale. Isotope results are reported as δ values ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) in parts per 1000 or "permil" (‰).

Strontium isotope ratio

Based on its chemical characteristics, Sr behaves as Ca in the living organism, substituting that element in hydroxyapatite from hard tissues such as bones and teeth. The Sr isotopic ratio measured as $^{87}Sr/^{86}Sr$ varies across the landscape according to the age and original rubidium (Rb) content (e.g., higher $^{87}Sr/^{86}Sr$ result from older and Rb-rich rocks and sediments). Due to its high atomic mass, the strontium mass-dependent fractionation is negligible. Therefore, it is taken up by organisms with the local isotopic signature. When measured in human skeletal remains (teeth and bones), strontium can be used to investigate questions relating to human origins and migration and to reconstruct the dietary habits of humans and animals (Bentley 2006). The weathering of the bedrock minerals releases Sr, which enters the different environmental matrices without significant isotopic fractionation. The strontium isotope ratio ($^{87}Sr/^{86}Sr$) contained in food and drinking water are incorporated, through their intake, in the skeletal tissues (bone and tooth apatite) of consumers and reflect the characterisation of the places of residence of individuals at the time of tissue formation or remodelling. The similar $^{87}Sr/^{86}Sr$ ratios of enamel, bone, and local geology suggest an indigenous condition, whereas different isotopic values prompt human mobility from a geologically distinct homeland. The two main limitations in the use of strontium isotopes are diagenesis of skeletal tissues linked to the burial environment and the possibility of reconstructing mobility patterns of ancient human populations only when there is a displacement of residence among territories with different isotopic strontium ratios (i.e., different geological formations). These limitations may be successfully addressed by careful selection of the tissue, hence by analysing dental enamel rather than bone, which is less subject to post-mortem alteration, and by using multiple proxies to differentiate among possible geological backgrounds of origin.

For this study, seven human samples were analysed for strontium isotope ratios (87Sr/86S). We further analysed rock, sediment, soil, botanical remains, and water to define the local baseline (Bentley 2006). Sample collection, preparation, and analysis were performed following relevant regulations for treating ancient human remains.

All samples were prepared using ultrapure reagents and Milli-Q water. Bone samples were mechanically cleaned, and any authigenic carbonates were removed with acetic acid–ammonium acetate buffer at pH 5 in an ultrasonic bath. Cortical bones were reduced to ash in a furnace at 800 °C for 10 h and dissolved with 0.5 M HNO_3. Soils and plant leaves were cleaned to remove any dust, dried in the open air, and pestled in agate mortar, then leached with CH_3COONH_4 at neutral pH to obtain the bioavailable Sr. Water sample was filtered through 0.45 µm polyamide syringe filters and dried on a hotplate and the residue taken up in 3 M HNO_3.

The Sr separation procedure followed the method of Pin and colleagues (1994). The strontium isotope composition was measured at the Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR- Rome) using a Finnigan-MAT 262 RPQ multi-collector mass spectrometer equipped with nine Faraday detectors. The samples were analysed in static mode on W-filament with $TaCl_5$ as an activator with analysing intensities ≥ 1 V for ^{88}Sr. Repeated NBS 987 Sr standard analyses yielded $^{87}Sr/^{86}Sr$ values 0.710249 ± 0.000009 (2 s, n = 20).

Results

Radiocarbon chronology

Two radiocarbon dates were obtained from two individuals whose bones were not in anatomical connection: specifically, one adult (from the surface) and one infant (from the upper layer of Sounding A). Their location, on the edge of the hillock and within the uppermost part of the sequence or the surface, and the chronological attributions suggest a later (final?) use of the area around 1270–1400 CE (Table 1). Three formal burials (H1, H2, H4) from the Main Sector have been also directly dated and traced back to historical phases between ca. 660 and 1035 CE (Table 1).

The biological profile

The scattered bones from the superficial layers of soundings A and B are attributable to a total of five individuals, including four sub-adults: one not determined, one approximately 0–6 months old, two children aged around 5 and 10 years, respectively, and a probate adult male (represented by the midshaft of the femur). Five formal burials have been identified, attributable to five individuals, including two foetuses (35–38 weeks) and three adults of female sex (Table 2).

H1 (US 3f) The long bones preserved (clavicles, right humerus, radius, ulna, and right tibia) were measured and compared with the standards for age at the death of foetuses in Scheuer and Black (2004). The individual was in the last month of pregnancy (between the 35th and the 38th weeks). The skeleton was in a good state of preservation.

H2 (US 6b) The cranium and pelvic bone morphology determine H2 to be female. It is noticed that the preauricular groove is well-marked. The degree of dental wear, the morphology of the pubic symphysis and the morphology of the auricular surface of the ileum indicate an age range of 18 – 29 years old at death (YA = Young Adult individual). The individual's stature was estimated based on the left humerus (31.1 cm, corresponding to a height of approximately 162.5 cm) and both tibiae (each 36.7 cm, indicating

Table 1 Radiocarbon chronology of the contexts here discussed. All the dates are calibrated using OxCal v4.4.4 (Bronk Ramsey 2021) and atmospheric data from Reimer et al. (2020)

Area	Layer	Material	Lab. Code	uncal BP	cal CE (95,4%)
Surface grid	Surface	human bone collagen	LTL17416A	625 ± 40	1289–1403 CE
Sounding A	Layer 3	human bone collagen	LTL17415A	675 ± 40	1271–1395 CE
Main sector	US 3f H1	human bone collagen	iCON22_4	1149 ± 72	685–1025 CE
Main sector	US 6b H2	human bone collagen	iCON22_5	1108 ± 64	710–1038 CE
Main sector	US 6c H4	human bone collagen	iCON22_7	1198 ± 89	661–1014 CE

Table 2 Taphonomic information, biological profiles, palaeopathological results, and stature estimation from the five burials in anatomical connections

Burial – skeletal code	Sex	Age at death	Pathological conditions	Stature
H1 (US 3f)	IND	Foetus 35–38 weeks	No	-
H2 (US 6b)	F	YA	reactive alveolar bone and periodontal disease, enamel hypoplasia, spinal osteoarthritis, spondylolysis	164.5 cm
H3 (US 6a)	IND	Foetus 35–38 weeks	No	
H4 (US 6c)	F?	Adolescent—YA	No	
H5 (US 9a)	F	YA	dental pathologies, enamel hypoplasia, spondylolysis	156.5 cm

**IND* indeterminable, *F* female, *YA* Young Adult. Stature: the average calculated by measuring the length of the bones a height of around 166.5 cm; average stature in Table 2). The skull shows several epigenetic traits. Various Wormian bones are at the lambda along the parieto-mastoid suture, and the suture of the mastoid is also preserved. The sternum exhibits a rather pronounced hint of the stern foramen. Both humeri display supratrochlear foramen, a condition that could be related to intense occupational activity, as indicated by the robustness of the bones.

H3 (US 6a) All the preserved long bones were measured to estimate the individual's age at death. The individual was between the last month of pregnancy (between the 35th and 38th weeks) and the first weeks after birth.

H4 (US 6c) The pelvic bone morphology determines H4 to be female. As also noted in H2, the preauricular groove is well-marked. The status of epiphysis fusion, the morphology of the pubic symphysis and the morphology of the auricular surface of the ileum indicate an age range of 18 – 24 years old at death (YA = Young Adult individual).

H5 (US 9a) The pelvic bone morphology determines H5 to be female. The degree of dental wear, the auricular surface associated with the state of the pubic symphysis and the sternal rib changes show Young Adult individual (YA). The stature of individual H5 (US 9a; average stature in Table 2) was estimated using the left humerus (28.8 cm), the left radius (20.4 cm), and the right radius (20.5 cm). The left femur measured 39.8 cm, while the right femur was slightly shorter at 38.8 cm. Additionally, the left tibia measured 33.3 cm, with the right tibia measuring 33.5 cm. Also, the individual shows stress or epigenetic traits, such as the septal aperture of the olecranon of the left humerus, and stress features, as Poirier's facet on the left femur, enthesopathy of the supinator muscles on both ulnae, as well as squatting facet on both tibiae.

The palaeopathological profile

Among the ten adult individuals examined, two exhibit pathological conditions, including periodontal disease, spinal osteoarthritis, indicators of metabolic stress, and separate neural arches on L3, L4, and L5 in H2, and on L5 in H5. In contrast, neither the foetal remains nor the bones within the scattered assemblage show any evidence of pathological conditions (Table 2).

H2 (US 6b) No signs of dental caries are present. The skeleton presents the thoracic vertebrae with large osteophytes on the articular facets, especially those on the right side. The lumbar vertebrae show slight spinal osteoarthritis along the edges of all the vertebral bodies. L3, L4, and L5 show the separation of a major portion of the neural arch from the body (Fig. 5).

The post-cranium and the temporomandibular joint show no signs of DJD. This is likely related to the young age of the individual. Moreover, both the mandible and maxilla exhibit reactive alveolar bone and periodontal

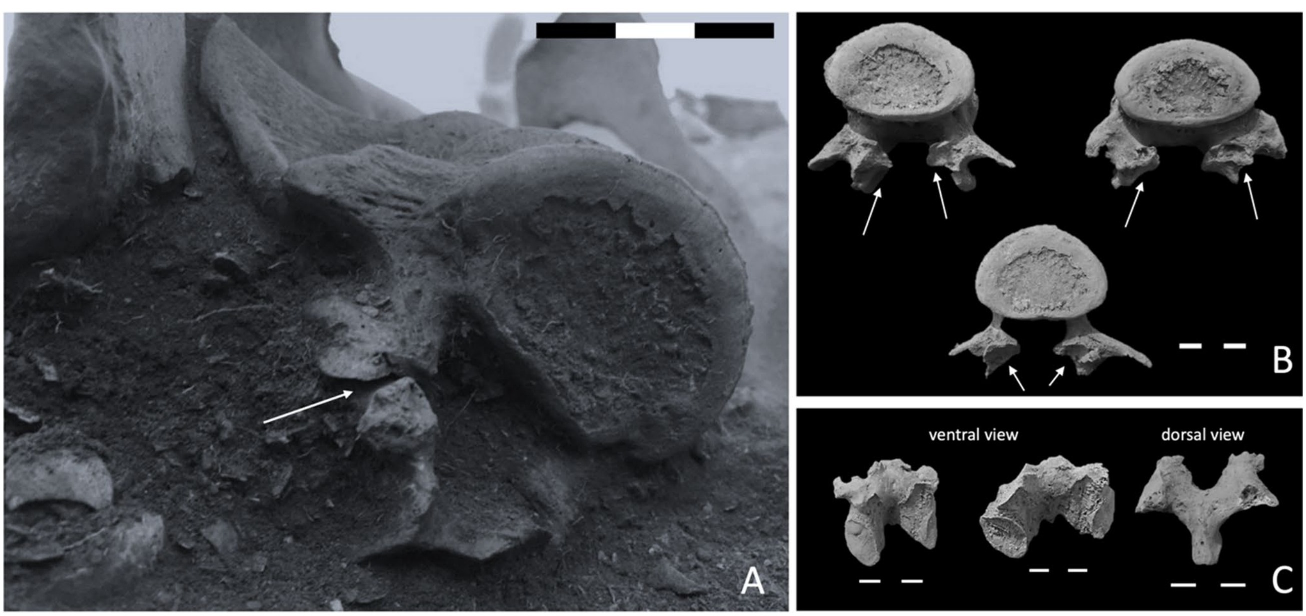

Fig. 5 Separate neural arch of L3, L4, and L5 in H2 (US 6b). The arrows indicate the non-union of the neural arch with the vertebral body. **a** during the field excavation; **b** L3, L4, and L5 bodies; **c** neural arches

disease. The bone is retracted by a few millimetres with exposure of the root teeth. The teeth show lines associated with enamel hypoplasia (less severe hypoplasia). The teeth on the right side of the dental arch show slight wear (while such wear is not observed on the left side). The lower right canine displays a facet of extra-masticatory wear.

The insertions of the occipital and trapezius muscles on the occipital bone are highly developed. These muscular insertions are involved in the *rectus capitis posterior minor* and *major*. When the first contracts bilaterally, it extends the head on the neck. This action has an essential postural role, stabilising the head while standing and during various body movements. When the second contracts, it causes an ipsilateral rotation of the head and extension. Both first metacarpals exhibit flattening of the proximal epiphysis, suggesting a power-grasping tendency in the hands, meaning that the individual was likely involved in strenuous manual activities. The insertion of the costoclavicular ligament on the right clavicle is extremely marked. Muscle insertions of the humeri (especially deltoid and brachioradialis) are well pronounced. Both crests of the supinator muscle at the proximal epiphysis of the ulna are highly developed. Periostitis is observed on both tibiae.

H4 (US 6c) The skeleton shows no signs of DJD, likely due to the individual's young age. No other pathologies have been diagnosed in this individual.

H5 (US 9a) The skeleton shows several dental pathologies linked to metabolic stresses and poor oral hygiene. Enamel hypoplasia was found on the maxillary teeth (i.e., right and left incisors, canine, and second molar) and on the mandibular teeth (i.e., right second molar and left incisors, canine, and second molar). The maxilla exhibits reactive alveolar bone and periodontal disease associated with dental calculus on the molars. H5 also shows separate neural arch of L5 (Fig. 6).

Isotopic analyses

Table 3 presents the good quality results obtained for carbon, nitrogen and sulphur stable isotopes. The percentage of collagen yield confirmed that all the three selected samples were of good quality. Carbon values (mean −18.9‰ ± 0.5) reflect a diet mostly, but not solely, reliant on C3 species (i.e. wheat and barley). In fact, carbon values of the humans are less depleted, than the only (modern) animal sample, which might indicate a greater contribution of C4 plant resources to the human diet. C4 plants in Africa are not uncommon

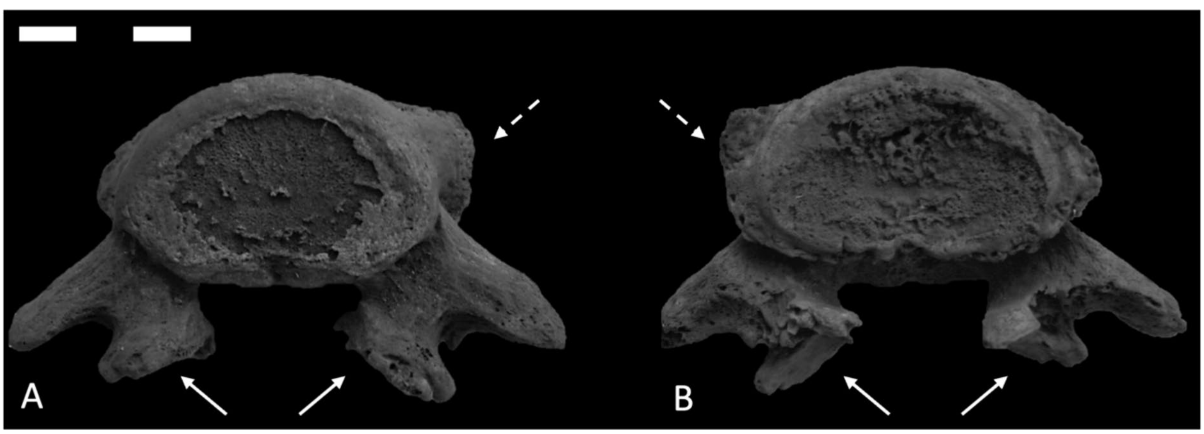

Fig. 6 Separate neural arch of L5 in H5 (US 9a). **a** L5 superior view; **b** inferior view. The arrows indicate the non-union of the neural arch with the vertebral body. The dotted arrows indicate the osteophyte on the body of the vertebra. This can be associated with the non-union of the processes

Table 3 Stable carbon, nitrogen and sulphur isotope ratio of bone collagen of humans excavated at KR and the modern ovicaprid. Collagen yield (%), C:N, N:S and C:S are reported for quality control. Legend: ind. = indeterminate; F = female; YA = Young Adult

ID sample	species	Sample type	Sex	Age at death	% collagen	$\delta^{13}C$	$\delta^{15}N$	$\delta^{34}S$	C:N	C:S	N:S
H1	Human	skull	ind	35–38 weeks	4.7	−18.7	15.5	6.3	3.3	505	152
H2	Human	rib	F	YA	11.6	−18.6	12.3	4.8	3.3	486	148
H4	Human	metatarsal	F	YA	6.8	−19.5	10.3	5.8	3.3	467	143
KR21	Modern sheep	mandible			17.6	−21.5	8.0	5.3	3.4	591	176

and might include several species within the genus *Panicum* and *Setaria*. In contrast, nitrogen values (mean 12.7‰ ± 2.6) appear to be relatively high, suggesting a dietary contribution of animal protein or the consumption of aquatic resources. The value obtained from the foetus (H1) should be considered as reflective of the values of the mother (Fuller et al. 2004). Figure 7 shows carbon and nitrogen values for the three humans and the modern animal sample, together with published measurements (Keenleyside et al. 2009; Barton et al. 2021) from roughly contemporaneous sites in Northern Tunisia. The isotope data from Koudiet er Rammadiya are relatively more dispersed than elsewhere, possibly showing a more varied diet and/or exploited environment. The nitrogen values of the three humans are slightly more enriched than the only animal sample, which suggests a relative contribution of animal proteins. Sulphur values (mean 5‰ ± 0.8) confirm the terrestrial diet, with a possible contribution of freshwater resources. However, the small human sample size and the need for animal data associated with the burials to establish a baseline preclude further speculation on dietary practices.

Table 4 A $^{87}Sr/^{86}Sr$ ratios measured for plant, soil leachate, surface water, sediments, and local rock

ID sample	Sample type	$^{87}Sr/^{8}6Sr$	± 2se
GEO/6	fluvial conglomerate	0.708942	± 0.000018
GEO/7	clay	0.708326	± 0.000009
GEO/8	limestone	0.708510	± 0.000019
GEO/9	plant	0.708067	± 0.000013
GEO/14	sandy/clay	0.711701	± 0.000009
GEO/15	palustrine deposit	0.708029	± 0.000007
GEO/22	well water	0.708021	± 0.000009
GEO/20	modern animal bone (sheep)	0.708737	± 0.000028

Strontium isotope values from environmental samples exhibit a range between 0.70802– 0.70894 when excluding the sample Geo/14, sandy clay that shows a significantly higher value (0.7117) (Table 4; Fig. 8). The relatively homogeneous isotope ratios suggest the predominance of sedimentary geological formations, while the higher value of sandy/clay sample could be inherited from the weathering of Rb-rich rocks. The analysed human remains (enamel

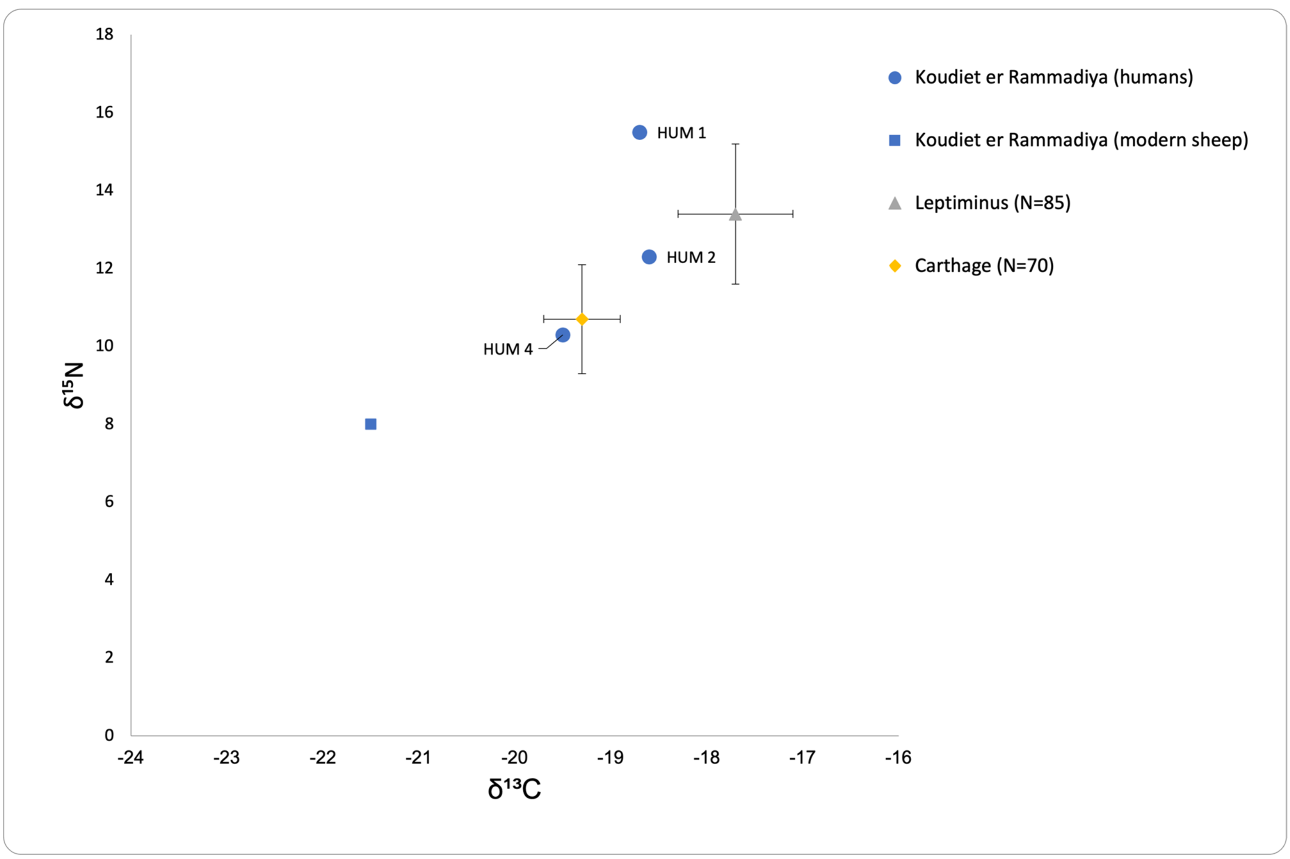

Fig. 7 Diagram reporting stable carbon ($\delta^{13}C$‰-VPDB) and nitrogen ($\delta.^{15}N$‰-AIR) isotope ratio of bone collagen for humans and animals at Koudiet er Rammadiya. Comparative data refer to the Roman and Late Roman sites of Leptiminus (Keenleyside et al. 2009) and Vandalic Carthage (Barton et al. 2021)

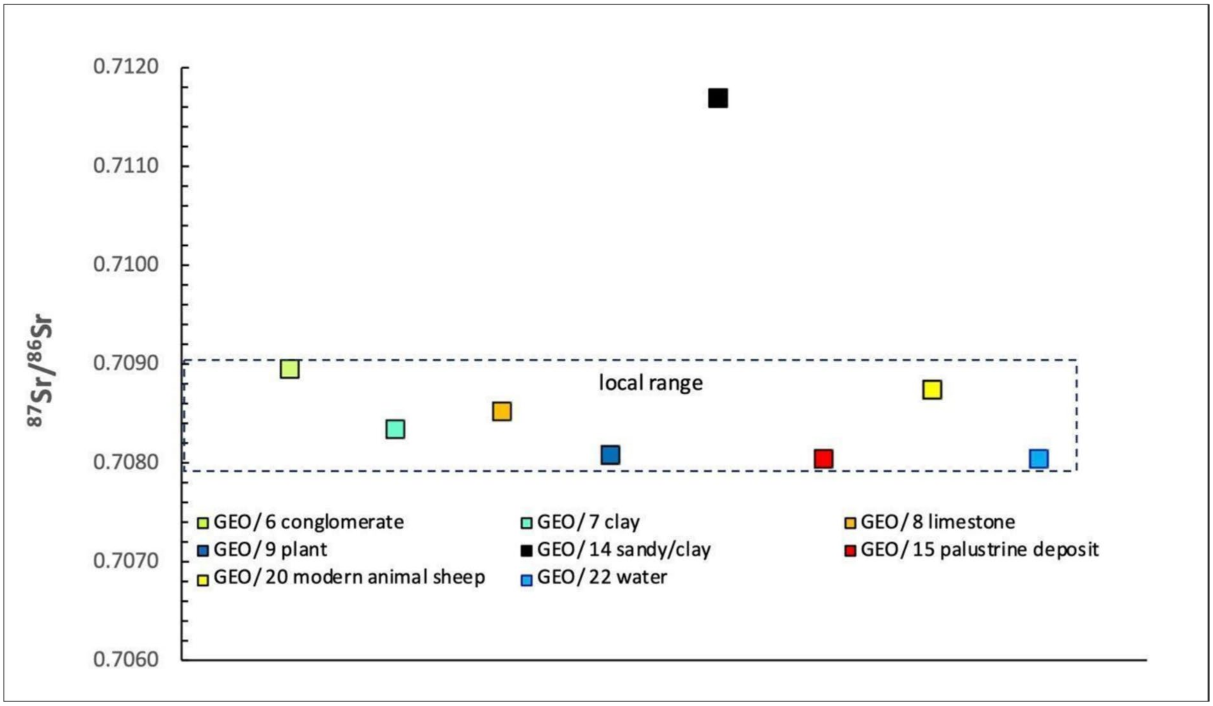

Fig. 8 Jitterplot showing the ^{87}Sr/8.^{6}Sr values of soil leachable fractions, plants, surface water, sediments and a modern animal. The local baseline is defined by excluding sample GEO/14

Table 5 Intra-site samples: bioavailable $^{87}Sr/^{86}Sr$ of human bones, dental enamel and soil related to the burials

ID sample	Sample type	$^{87}Sr/^{86}Sr$	±2se
H1_1	lower incisor	0.708173	±0.000010
H1_2	lower molar	0.708159	±0.000007
H1_3	soil from thorax	0.708193	±0.000009
H2_1	upper central right incisor	0.708079	±0.000008
H2_2	left rib	0.708040	±0.000009
H2_3	soil from sacrum	0.708088	±0.000009
H2_4	soil from iliac bone	0.708127	±0.000010
H2_5	soil from skull	0.708093	±0.000011
H3_1	upper incisor	0.708189	±0.000009
H3_2	upper molar	0.708209	±0.000010
H3_3	soil from right parietal	0.708159	±0.000012
H4_1	first right metatarsal	0.708201	±0.000012
H4_2	soil from sacrum	0.708150	±0.000009

and bone) and the soil removed from hard human tissues show an isotopic signal ranging from 0.70804–0.70821 and 0.70808–0.70819, respectively (Table 5; Fig. 9). The isotopic signature of strontium from human enamel, bone, and the bioavailable strontium from the local background doesn't differ significantly, suggesting a local origin for the individuals analysed.

Discussion

The two chronological spans, the 7th and then the 15th c. CE, suggest a discontinuous use of the hillock's summit, likely due to its prominent and visible position within the landscape, such as from the Berber village of Sidi Abdelkader.

Such locations were often chosen for their symbolic and practical significance in mortuary practices. The extended duration of use could indicate a stable or evolving community that consistently returned to this significant site over several centuries. This prolonged use may reflect a tradition maintained over generations, emphasising continuity in cultural practices related to burial and commemoration. Given the extent of the excavation, the archaeological evidence indicates that the hill, or *rammadiya*, served as a medieval cemetery, both in its central and peripheral areas. More specifically, the peripheral parts of the mound, where Sounding A was located, yielded more recent dates, approximately between the 13th and 15th c. CE. This might indicate a final phase of use of the site as an area for disposing of the dead. Therefore, it could be argued that the hill was likely used throughout the medieval period, with burials commencing at the top and gradually moving downhill as the upper areas became fully occupied. It is reasonable to infer that the local population of Sidi Abdelkader transported their dead across

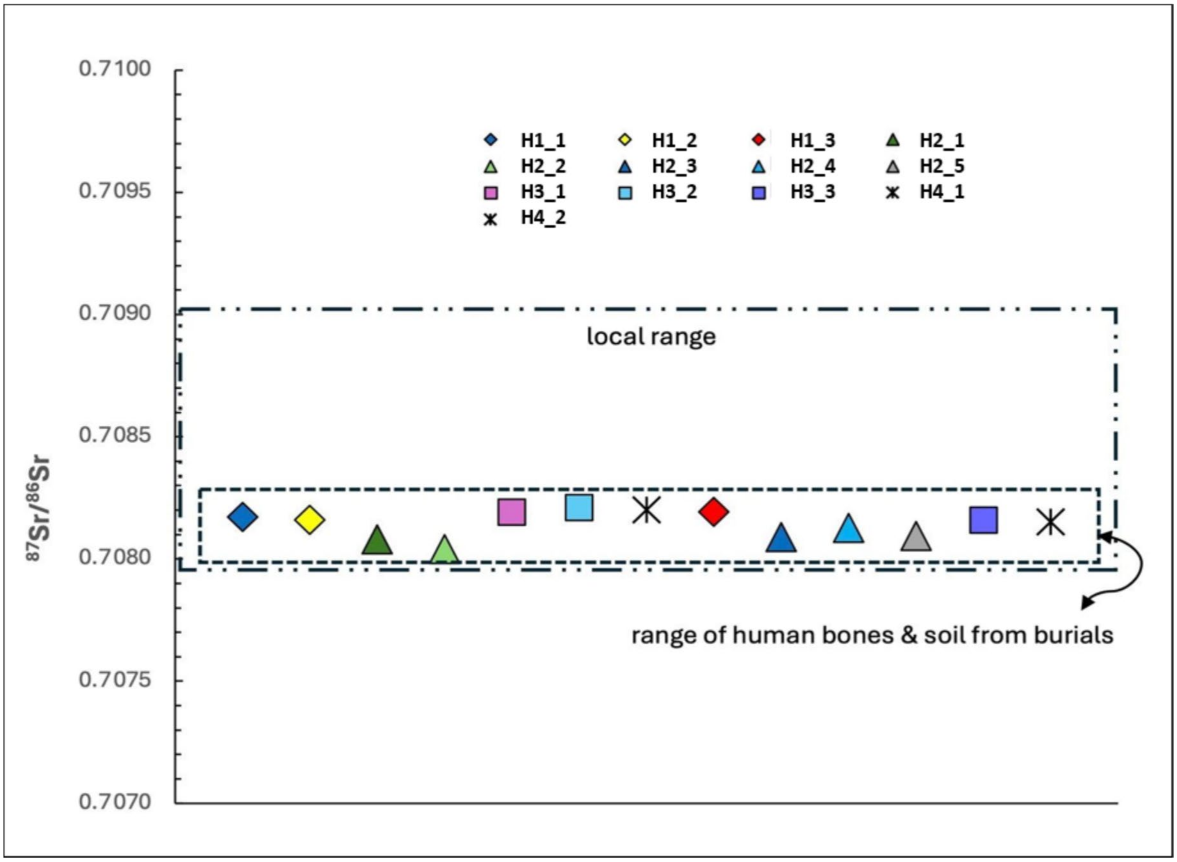

Fig. 9 Jitterplot showing the ^{87}Sr/8.^{6}Sr values of human tissues and soil leachable fractions from analysed bones. The local baseline is reported in the stroke-to-point line rectangle. Legend: diamond H1; triangle H2; square H3; star H4

the *wadi*. This continuity may shed light on the significance of the hill as a dedicated funerary site for the local community. The lack of historical sources concerning Medieval funerary practices in Mahjouba and the surrounding area underscores the critical importance of insights from excavating medieval graves in Tunisia. However, this task is challenging within a Muslim context due to religious laws that prohibit the disturbance of graves. Exceptions can be made for scientific or social purposes (Insoll 2002; Atighetchi 2007). With a few exceptions from the Mediterranean area (e.g., Egyptian and Spanish contexts), a further problem is integrating osteological data into the scientific mainstream literature (Inskip 2014 and cited literature therein).

The five burials from Koudiet er Rammadiya are crucial for understanding funerary rituals among rural Muslim populations, as they represent the first excavated Muslim burials in Tunisia. During the Late Antique—Middle Ages, the populations inhabiting the region of El Kef, Kalat Snan, and the areas surrounding Mahjouba, near the Algerian border, experienced significant geopolitical events, including tribal conflicts, famine, and disease (Hassen 2001; Araar 2014). The Koudiet er Rammadiya region is rural (Boukhchim and Marzouki 2024). Local groups engaged in farming, foraging, and herding, with funerary rites consisting of simple shallow pits in an open cemetery without boundary walls. In Islam, the grave is simple, with the body placed directly into the ground without construction or ornamentation (Tritton 1938; Jonker 1996; Meri 2018; Gleize 2022). Adhering to Islamic burial norms (King 2004; Gordon 2022), the positions of the inhumations at Koudiet er Rammadiya, oriented SW-NE and facing East, indicate that these burials can be associated with Muslims. Furthermore, ensoulment is a crucial aspect of Islamic bioethics, marking the final stage when the foetus attains personhood and becomes a Muslim. This stage is notably linked to the pregnant woman's ability to feel foetal movements (Halcrow et al. 2017). Therefore, the presence of foetal remains in the last months of pregnancy or close to childbirth at Koudiet er Rammadiya is significant, suggesting adherence to the concept of ensoulment and Muslim personhood. As Inskip (2014) highlighted for other contexts in the Mediterranean, a common feature of Muslim funerary areas at Koudiet er Rammadiya is the presence of separate burial areas for women and children, commonly observed in cemeteries (Insoll 2002). Finally, according to ancient Muslim customs, if a baby perishes during pregnancy or premature childbirth while the mother survives, the infant must be removed and buried separately (Perez et al. 2007).

Following Islamic norms, the roles of men and women are intended to complement each other. While Islam does not technically restrict either sex from any role, men typically handle strenuous activities and provide for the household (Lindsay 2005). Women are generally responsible for household maintenance and raising children (Waines 2003). However, in a rural context, such as Koudiet er Rammadiya, despite their young age at death, female individuals are likely to have engaged in heavy activities, as indicated by the biomechanical stress on bones. Additionally, the extra-masticatory facets on teeth (i.e., H2) may indicate activities like making nets for fishing, weaving reeds or similar materials, and processing fibres for threading items like beads (Walsh 2022). Finally, despite the common local origin of all individuals according to strontium (Sr) data, the diverse signs of extra-masticatory wear may indicate varied diets and practices. Stable carbon, nitrogen, and sulphur isotope (CNS) data reveal dispersed values, especially when compared with other coeval Tunisian contexts, possibly reflecting different dietary traditions, possibly associated with the consumption of aquatic resources. Overall, the isotope data obtained represent a novelty for this area and period, contributing significantly to a better understanding of Medieval Tunisia. The presence of periodontal disease, associated with dental calculus, indicates poor oral hygiene, which may also be linked to systemic health stress and dietary-related factors (Forshaw 2022). Enamel hypoplasia in adults (i.e., H2 and H5) indicates survival through childhood hardships (Reid and Dean 2006).

Challenging survival in childhood is also confirmed by the small sample of foetuses, which, conversely, reflects the poor health conditions of their mothers. In general, archaeological populations exhibit a high level of female mortality, primarily during the reproductive period (i.e., from puberty to menopause), mainly due to complications related to childbirth (Halcrow et al. 2017 and cited literature). By the tenth century, Muslim beliefs and practices concerning pregnancy and childbirth were well-established and thoroughly developed (Arjona 1983; Perez et al. 2007). Knowledge about potential complications during labour was extensive and widely disseminated within the community. Additionally, it should be considered that the two distinct periods of use of the hillock during the medieval period correspond to crises such as starvation, disease, and tribal wars (Hassen 2001; Araar 2014). Small foetal and infant remains suggest alterations in food availability in previous generations; this evidence could account for population changes observed many years after historically documented famines or plagues (Halcrow et al. 2017). So, the maternal health of the adult individuals found at Koudiet er Rammadiya may have been affected not only by political but also by cultural practices related to pregnancy. Furthermore, both adult individuals (H2 and H5) exhibit enamel hypoplasia, suggesting that they endured stress during childhood (Lewis 2018).

Lastly, these two adult individuals show separate neural arches on lumbar vertebras (i.e., on L3, L4, and L5 in H2, and on L5 in H5). This condition can be associated with a congenital defect of the spine called spondylolysis (i.e., separate neural arch in Mann et al. 2016; Lewis 2019). In this case, the defect separates the main part of the vertebra from the inferior facets, potentially allowing the vertebral body to slide forward, a condition known as spondylolisthesis (Stewart 1931). Otherwise, this pathological disorder can also be related to a fatigue fracture-related phenomenon (Merbs 1996; Bruno et al. 2017). Although genetics play a fundamental role in predisposition, environmental factors such as repetitive activities on a still immature spine (i.e., adolescents), microtrauma, repetitive loading in hyperextension, trunk torsion/rotation, and axial forces lead to reactions of mechanical stress and subsequent spondylolysis of the vertebral isthmus (i.e., subsequent non-union of the spinous process to the vertebral body), which in most cases results in spondylolisthesis. It can be stated that, in accordance with the Istanbul Protocol (Appleby et al. 2015), this condition may have been caused by a genetic condition; however, it is non-specific, and trauma should still be considered. Finally, in light of the reconstruction of the health status of these two individuals, it is noteworthy that this condition can lead to pain, as well as potential neurogenic claudication, motor deficits in specific nerve root distributions, and, more generally, mechanical low back pain, which is typically associated with posture and daily activities (Sengupta and Herkowitz 2005).

Finally, epigenetic traits were observed. In traditional Arab-Muslim societies, partner selection follows specific customs, including parental oversight and homogamy (for Tunisia, see Romdhane et al. 2019; for Algeria, see Saoudi et al. 2015). Although limited by the small skeletal sample size in this study, the occurrence of Wormian bones, the supratrochlear foramen, and evidence of spondylolysis (observed in both adult individuals) may indicate a group of individuals sharing a common genetic background. Given this context, it may be speculative yet plausible to consider these individuals as members of an extended family group, potentially originating from the Berber village of Sidi Abdelkader across the *wadi*. Local tradition suggests the possibility of relatedness, while epigenetic traits and palaeopathological markers (e.g., spondylosis) may offer preliminary indications of such connections, genetic analyses would be required to substantiate these hypotheses.

Conclusions

The long-life span of the funerary area at Koudiet er Rammadiya suggests a reoccupation or re-utilisation of the site after a considerable interval during the Middle Ages. The peripheral areas might represent a shift in the community's burial practices or a response to different social or cultural conditions. The placement of burials in the mound's periphery during this later phase could indicate changes in the community's structure, population pressure, or evolving cultural or ritualistic practices.

The osteological, palaeopathological, and isotopic results presented here constitute the sole contribution, so far, for reconstructing past populations that lived during the medieval period in North-western Tunisia. These data provide a foundational framework that must be integrated with new information from future excavation campaigns and research in this area. Such integration will be essential for constructing a more comprehensive picture of the region's historical and cultural context.

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Authors' contributions MDM contributed expertise in osteology, fieldwork, and data management, as well as in writing and editing. IM focused on human osteology and paleopathology, participated in fieldwork, and contributed to writing and editing. FT provided support in human osteology and fieldwork, along with writing and editing. KT was responsible for fieldwork, data management, and mapping. NB's role included fieldwork, along with writing and editing contributions. MAT specialized in isotopic analysis, in addition to writing and editing. RR supported fieldwork, writing, and editing tasks. EC contributed through fieldwork, data management, and writing and editing. FC's contributions involved data management, writing, and editing. SDL designed the research and led fieldwork in 2017 and 2021–2022 while also handling writing, editing, and supervision. Finally, NA directed fieldwork in 2021–2022, with writing, editing, and supervision responsibilities. All authors read and approved the final manuscript.

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Data Availability No datasets were generated or analysed during the current study.

Code availability The codes related to the C14 lab results are included in Table 1.

Declarations

Conflicts of interest/Competing interests The authors declare no competing interests.

Ethics approval This study does not involve any modern human or animal subject.

Consent to participate Not applicable.

Consent for publication Not applicable.

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