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A multi-analytical approach to fetal/neonatal birth trauma and possible metabolic stress in a Neolithic alpine mobility context (3932–3653 cal BCE)

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ABSTRACT

Fetal or neonatal skeletal trauma is uncommon even in modern clinical settings and is hardly identifiable in the archaeological record, where preservation constraints and the absence of soft tissues limit diagnostic confidence. We report a fetal/neonatal individual (RAB ID1; c. 40 lunar weeks) recovered from the Ripari Alti rock shelter (north-eastern Italian Alps; c. 1100 m a.s.l.). AMS radiocarbon dating of a tibial fragment places the remains within 3932–3653 cal BCE (2σ), dating to the Late Neolithic. The assemblage comprises six elements dispersed within a restricted excavated volume and attributable to a single individual based on osteological coherence, contralateral pairing of tibiae, and the absence of duplicated elements. Macroscopic examination, digital microscopy and SEM document: (i) bilateral tibial diaphyseal porosity with metaphyseal lace-like cortical reduction; (ii) mandibular porosity with lamellar bone deposition; (iii) and a mid-diaphyseal right humeral fracture with smooth, curved surfaces and an oblique-to-spiral trajectory, showing homogeneous cortical colour across the fracture plane. The porous and lamellar changes is most consistent with systemic metabolic stress, interpreted as possible micronutrient deficiency, while acknowledging diagnostic overlap with other conditions and incomplete skeletal representation. Fracture morphology and microstructural features support a perimortem origin and, by comparison with clinical literature, are most plausibly compatible with birth-related forces during a difficult delivery and attempted extraction manoeuvres. This case provides unique osteological insight into fetal/neonatal risk, maternal–fetal health, and obstetric decision-making within Neolithic alpine mobility systems.

1. Introduction

1.1. Clinical background of birth-related trauma

Perinatal birth-related trauma is defined as physical injury sustained by the neonate during labour or the expulsive phase of delivery and encompasses a broad spectrum of clinical manifestations, ranging from minor soft-tissue injuries to more severe skeletal and neurological damage (Warke et al., 2012; Linder et al., 2013; Rubin, 2013). In modern healthcare settings, such injuries are considered infrequent events, largely due to improvements in obstetric practice and the early identification of risk factors (Smith et al., 2013; Surel et al., 2025). Epidemiological estimates indicate that the overall incidence of birth-related trauma in neonates generally does not exceed 30 cases per 1,000 live births, depending on the definitions adopted and the populations examined (i.e., Alexander et al., 2006; Onuoha et al., 2020; Aurilio et al., 2025). Within this category, neonatal skeletal injuries account for a minority of cases when compared with soft-tissue trauma or neurological injuries, yet they remain of clinical and diagnostic relevance (Basha et al., 2013; Carvalho et al., 2024).

Among birth-related fractures, clavicular fractures are by far the most frequently reported, with an estimated incidence ranging from 0.2% to 4.5% of live births, particularly in association with fetal macrosomia, shoulder dystocia, and operative deliveries (Politi et al., 2010; Choi et al., 2016; Gandhi et al., 2019; Galimberti et al., 2024). In contrast, fractures of the long bones are significantly less common and represent only a small proportion of neonatal skeletal trauma, (Abedzadeh-Kalahroudi et al., 2014: Högberg et al., 2020). Within this

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context, humeral fractures are considered rare lesions, with reported incidences markedly lower than those of clavicular and femoral fractures (Dunkow et al., 2005; Basha et al., 2013; Von Heideken et al., 2020). Specifically, epidemiological studies indicate that while neonatal diaphyseal fractures of the femur occur at an incidence of approximately 2 per 1,000 live births, humeral shaft fractures are markedly rarer, ranging between 0.05 and 0.1 cases per 1,000 births (Sherr-Lurie et al., 2011; Basha et al., 2013; von Heideken et al., 2020; Carvalho et al., 2024). Clinical literature consistently indicates that such fractures are most frequently associated with complicated deliveries, particularly shoulder dystocia, abnormal presentations (such as breech delivery), and obstetric emergencies requiring manual or instrumental extraction manoeuvres (Leung et al., 2011; Dolivet et al., 2018; Rehm et al., 2020). From a biomechanical perspective, neonatal humeral fractures are generally interpreted as the result of torsional or traction forces applied to the upper limb during attempts to disengage the shoulders or facilitate fetal expulsion, especially under conditions of fetopelvic disproportion or fetal macrosomia (Rahul et al., 2017; Hamilçıkan et al., 2018; Surel et al., 2025). Although such manoeuvres are performed with life-saving intent, they carry a documented risk of skeletal and neurological injury to the neonate (Alexander et al., 2006; Warke et al., 2012; Ariyawatkul et al., 2017; Carvalho et al., 2024). Obstetric conditions that predispose to fetal trauma are also frequently associated with maternal complications, including lacerations of the birth canal, postpartum haemorrhage, and an increased need for surgical intervention or invasive manoeuvres, underscoring the bidirectional nature of risk in complicated deliveries (Huls and Detlefs, 2018; MacArthur et al., 2019).

Taken together, these data demonstrate that perinatal skeletal trauma—and humeral fractures in particular—represent exceptional yet well-documented events even in highly medicalised modern clinical contexts. It is precisely this rarity that lends particular significance to the identification of analogous lesions in the archaeological record, where the absence of soft tissues and clinical documentation necessitates a rigorous, multidisciplinary analytical approach to distinguish between perimortem trauma, taphonomic alteration, and injury mechanisms potentially related to childbirth.

1.2. Birth-related trauma in historical and archaeological contexts

For much of human history, childbirth has represented one of the highest-risk biological events, with potentially severe consequences for both the mother and the neonate (i.e., Arriaza et al., 1988; Slaus, 2000; Sayer and Dickinson, 2013; Haeusler et al., 2021). Prior to the advent of modern obstetrics, complications arising during labour and the expulsive phase constituted a major cause of maternal and perinatal mortality, as documented by historical sources, demographic data, and—albeit more indirectly—by the bioarchaeological record. Historical populations consistently exhibit high rates of neonatal and infant mortality, often exceeding 20–30% within the first years of life, with a substantial proportion of deaths concentrated in the perinatal period (i.e. Storey, 1986; Woods 1994). Although specific causes of death cannot always be identified with precision, childbirth-related complications—including prolonged labour, abnormal fetal presentations, and dystocia—are widely regarded as key contributing factors in many pre-industrial societies (Chamberlain, 2006).

Within the archaeological record, a limited number of osteological findings have been interpreted as indirect evidence of perinatal trauma, including cases of neonatal fractures and fetal remains found in association with adult female skeletons (i.e., Sjovold et al., 1974; Hawkes and Wells, 1975; Wells, 1978; Owsley and Bradtmiller, 1983; Pounder et al., 1983; Persson and Persson, 1984; Högberg et al., 1987; Malgosa et al., 2004; Rascón Pérez et al., 2007; Cruz and Codinha, 2010; Willis and Oxenham, 2013; Lieverse et al., 2015; Zhou et al., 2020; Ejsmond et al., 2021; Murphy, 2021). From a paleopathological standpoint, fetal and neonatal skeletal lesions attributable to childbirth are uncommon, both because of the inherent fragility of immature bone tissue and because of the intrinsic limitations of the archaeological record (Halcrow and Tayles, 2008). Among the traumatic conditions that may be recognisable osteologically are fractures of the long bones, which in modern clinical contexts are well documented as possible outcomes of traction forces or extraction manoeuvres applied during difficult deliveries (Basha et al., 2013).

The identification and interpretation of such injuries in archaeological contexts must therefore rely on a multi-level analytical framework. This includes the assessment of fetal osteological characteristics—such as an estimated gestational age consistent with term or near-term birth, the presence of fractures localised to long bones (e.g., humerus, femur) or the clavicle, the absence of bone remodelling indicative of healing, and fracture morphology compatible with perimortem trauma — as well as detailed taphonomic and post-depositional evaluation (i.e., exclusion of fractures caused by sedimentary compression, excavation damage, or post-recovery manipulation). Finally, interpretative coherence must be ensured by evaluating the compatibility of the observed fracture patterns with the biomechanical constraints of childbirth, while carefully considering alternative explanations.

1.3. Metabolic and nutritional disorders in paleopathology

Over the past decades, the bioarchaeology of non-adult populations has received increasing scholarly attention, leading to a more nuanced understanding of growth, health, and disease during infancy and childhood in past societies (Perry, 2005; Lewis, 2007; Mays, 2017). Within this field, a substantial body of research has focused on the identification and interpretation of pathological conditions affecting immature skeletal remains, with particular emphasis on metabolic and nutritional disorders (Grauer, 2011; Waldron, 2012; Rotschild et al., 2023). Among these, micronutrient deficiency diseases have emerged as a key area of investigation, owing to their high prevalence, systemic impact, and strong links to environmental, dietary, and social factors (Larentis et al., 2023; Schattmann et al., 2016; Brickley et al., 2018; Brickley et al., 2020).

Within the spectrum of micronutrient deficiencies, rickets and scurvy have been the most extensively studied in paleopathological research. These conditions are caused, respectively, by deficiencies of vitamin D and vitamin C and are known to produce characteristic, albeit partly overlapping, skeletal responses (Carpenter, 1988; Wharton and Bishop, 2003). Importantly, the skeletal manifestations of these deficiencies may co-occur within the same individual, giving rise to what is defined as a co-occurrence disease, a condition in which multiple pathological processes act simultaneously on the growing skeleton (Schattmann et al., 2016; Brickley et al., 2018; Brickley et al., 2020). Such co-occurrence has been reported most frequently in non-adult individuals between approximately three months and five years of age, a developmental window characterised by rapid growth and heightened physiological vulnerability (Ortner, 2003; Ortner and Mays, 1998; Schattmann et al., 2016; Buikstra, 2019).

Rickets is a multifactorial disease (Misra et al., 2008) that may result from inadequate cutaneous synthesis of vitamin D due to limited exposure to ultraviolet B (UVB) radiation, which impairs the conversion of 7-dehydrocholesterol to pre-vitamin D (Granger and Eck, 2018; Holick, 2006). In addition to environmental constraints, rickets may also arise from congenital conditions (Canepa, 1996), diets deficient in calcium and phosphorus (Vieth and Fraser, 2002), or dietary regimes rich in phytates, which inhibit vitamin D metabolism and calcium absorption (Chaplin and Jablonski, 2009; Mays and Brickley, 2018). The resulting impairment of mineralisation affects growing cartilage and osteoid tissue, leading to insufficiently mineralised bone, particularly at the metaphyses of long bones (Sahay and Sahay, 2012; Holick, 2006). Macroscopically, this process often manifests as diffuse porosity, cortical thinning, and, in more advanced cases, bending or deformation of long bones under muscular load (Lewis, 2007; Larentis et al., 2020, 2023).

Scurvy, by contrast, is caused by a deficiency of vitamin C (ascorbic acid), an essential micronutrient required for the hydroxylation reactions involved in collagen synthesis. In the absence of adequate vitamin C, collagen production is disrupted, resulting in weakened connective tissues, impaired osteoid formation, and defective bone remodelling (Moore and Koon, 2017). At the skeletal level, existing osteons may be resorbed without being adequately replaced, leading to porous cortical surfaces and abnormal bone responses (Ortner et al., 2001). Clinically and osteologically, scurvy is associated with subperiosteal haemorrhages, gingival bleeding, and compromised immune function, often accompanied by anaemia and increased susceptibility to infection (Schwetje et al., 2020). Several of these features—particularly cortical porosity and metaphyseal surface alteration—may overlap with those observed in rickets, complicating differential diagnosis (Brickley and Ives, 2006; Larentis et al., 2023).

In response to these diagnostic challenges, paleopathological research has progressively refined a set of skeletal criteria aimed at distinguishing between rickets, scurvy, and their co-occurrence in non-adult individuals (Ortner, 2003; Schattmann et al., 2016; Buikstra, 2019). These criteria emphasise the distribution, morphology, and anatomical localisation of bone changes, which typically include

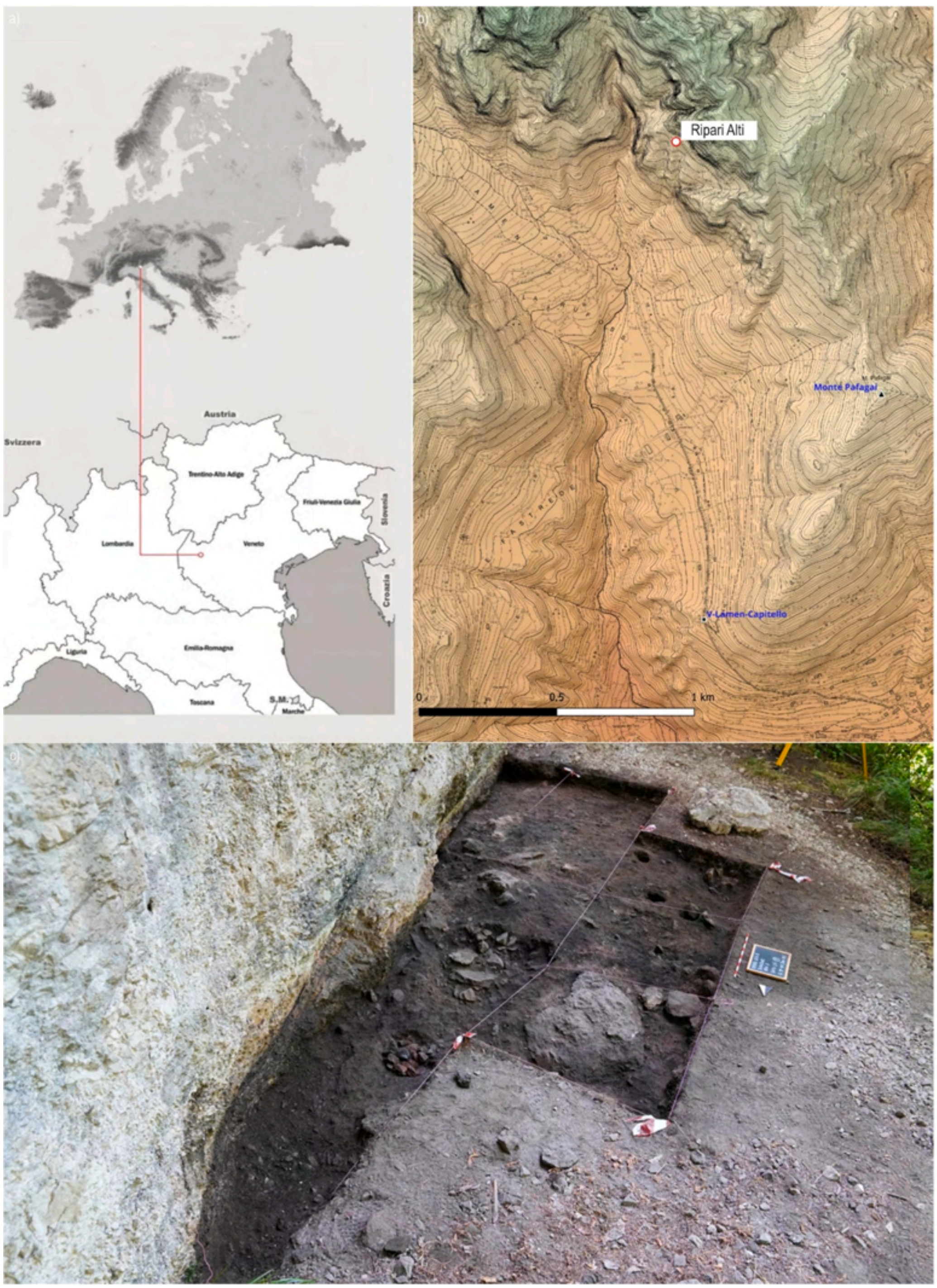

Fig. 1. Location and archaeological context of the Ripari Alti rock shelter system. (a) Geographic setting of the Ripari Alti in the Feltre area, Belluno province, Veneto Region, north-eastern Italy. (b) Riparo Alto B, situated at approximately 1100 m a.s.l. overlooking the Lamen Valley (c. 46.079006° N, 11.876221° E). (c) Riparo Alto B during excavation activities.

increased porosity associated with enhanced vascularisation and cortical thinning, changes that generally remain confined to the external cortical surface and rarely penetrate deeply into the bone tissue. When evaluated within a comprehensive analytical framework, these markers provide a robust basis for exploring metabolic stress and nutritional imbalance in past populations.

2. Materials and methods

2.1. Archaeological context

The osteological remains analysed in this study derive from a rock shelter belonging to the so-called Ripari Alti (literally "High Rock shelters"), a group of natural shelters located at approximately 1100 m a.s.l. in the Lamen Valley (Feltre, Veneto Region, northeastern Italy)

Fig. 2. Human skeletal remains recovered from the Riparo Alto B (RAB) site. (a) Right hemimandible in mediolateral view, anterior portion to the right. (b) Right humerus in posterior view, proximal epiphysis to the right. (c) Right radius in posterior view, proximal epiphysis to the right. Taphonomic alterations (dashed outlines) and pathological changes (solid outlines) are indicated by Roman numerals. Scale bars = 1 cm.

(Fig. 1).

These sites represent some of the highest-altitude Late Neolithic contexts documented in the Dolomitic area and provide clear evidence of prehistoric groups' interest in and exploitation of mountain environments and resources (Bianchin Citton, 2000).

In 2021, a test trench was opened in the deepest shelter, designated Riparo Alto A (RAA S1). Two additional trenches were subsequently opened in a large adjacent shelter located to the south, designated Riparo Alto B (RAB S1 and RAB S2) (Carrer and Cavulli, 2023a). Following the results of these investigations, further excavation campaigns were conducted in RAB S2. During the 2022 field season, the osteological remains of the present study were recovered.

Material culture and radiocarbon dating place the occupation of the site within the Italian Late Neolithic, corresponding to the Isera III/Fiavè 1 cultural horizon, dated to approximately 3800–3600 cal BCE (Carrer and Cavulli, 2023a); considering the presence of VBQ ceramics, it is

Fig. 3. Human skeletal remains recovered from the Riparo Alto B (RAB) site. (a) Left rib in ventral view, head to the left. (b) Right tibia in lateral view, proximal epiphysis to the left. (c) Left tibia in lateral view, proximal epiphysis to the right. Taphonomic alterations (dashed outlines) and pathological changes (solid outlines) are indicated by Roman numerals. Scale bars = 1 cm.

more plausible to propose a more stringent comparison with Isera III (Pedrotti et al., 2022).

The archaeological context where the bones are coming from is the upper part of the deposit (unit 2) and the radius from the sediment accumulated against the rock wall (unit 26). The bones have been found scattered on a surface c. 2 m^2 large and there is no evidence of any sort of funeral structure.

2.2. Osteological material

The osteological assemblage consists of seven bone fragments belonging to six bones identified as human based on preliminary morphological assessment (Figs. 2, 3; Table 1). The osteological remains analysed in this study were recovered from two distinct stratigraphic units (SU 2 and SU 26) and within grid squares named 100/503, 100/504, and 101/502, a spatial pattern that indicates a limited dispersal of skeletal elements within an estimated area of c. 0.5x2 m along the rock wall (Fig. 1c; Table 1). Such a distribution suggests that the bones were not recovered in primary anatomical connection but were instead scattered across an occupation level, or alternatively underwent post-depositional reworking, resulting in their gradual incorporation into the sedimentary matrix of one or more palaeosurfaces over time.

This pattern is consistent with archaeological scenarios in which human remains, following soft-tissue decomposition, lose anatomical coherence and are subsequently redistributed by a combination of natural and anthropogenic processes, including sedimentation dynamics, minor slope movement, trampling, or surface reworking (Duday, 2009; Nilsson Stutz, 2003; Knüsel and Robb, 2016). The relatively constrained spatial dispersion observed here argues against extensive secondary burial, instead supporting localised post-depositional displacement within a restricted area of the site (Guy et al., 1997).

Despite the fragmented and dispersed nature of the assemblage, osteological analysis allows the estimation of a minimum number of individuals (MNI) equal to 1. This assessment is based on the absence of duplicated homologous skeletal elements, the presence of clearly contralateral bones (notably the left and right tibiae), and the consistent degree of skeletal maturation observed across all elements. Age-at-death estimations obtained through multiple independent osteometric methods converge on a similar developmental stage, further supporting attribution to a single perinatal individual (see Material and methods section and Table 2).

Variability in cortical surface preservation among the bones is interpreted as the result of microenvironmental differences in depositional conditions, rather than evidence of multiple individuals (Rasmussen et al., 2019). Differential diagenetic alteration affecting cortical bone quality is a well-documented phenomenon in archaeological contexts, particularly where skeletal elements are dispersed and exposed to heterogeneous sedimentary, geochemical, and hydrological conditions (Hedges, 2002; Nielsen-Marsh and Hedges, 2000; Collins et al., 2002). In this case, differences in cortical preservation do not correlate with anatomical duplication or divergent developmental stages and therefore do not contradict the single-individual hypothesis.

Taken together, the spatial distribution of the remains, the osteological coherence of the assemblage, the convergence of age-at-death estimates, and the fact that these represent the only human remains recovered from the excavated area—whose stratigraphic infilling was completely exhausted—allow the conclusion, with a high degree of confidence, that the recovered bones belong to a single perinatal individual, with an estimated age at death of approximately 40 lunar weeks from conception, named RAB ID1. The loss of anatomical connection and subsequent dispersal of the skeletal elements likely occurred after decomposition, during an undetermined phase of site use or sedimentary reorganisation, resulting in their gradual incorporation into the palaeosurface deposits. Such processes are well attested in prehistoric open-air and rock shelter contexts and do not preclude the interpretation of the assemblage as deriving from a single biological individual.

The remains were recovered from a mixed assemblage that also included non-human faunal bones; consequently, the specimens bear non-sequential IDs.

Table 1
Inventory of the analysed osteological remains. SU = Stratigraphic Unit.

ID no.	Site	Year	SU	Location	No. of fragments
187	RAB	2022	2	100/504	1
188	RAB	2022	2	100/504	1
193	RAB	2022	2	100/503	1
225	RAB	2022	2	100/504	1
227	RAB	2022	2	100/503	2
507	RAB	2022	26	101/502	1

Table 2
Anatomical identification of the bone fragments, together with their weights and maximum lengths. The maximum length reported herein represents the actual physical measurement of the surviving bone fragment; it does not constitute a reconstructed estimate intended for anthropometric calculations, unless there is a superscript numeric reference pointing to a complete measurement, which is useful for age estimation according to Fazekas and Kósa (1978). In the case of the hemimandible, the following measurements were recorded: (1) Oblique length: distance from the mental tuberculum to the posterior border of the condyle; (2) Body length: distance from the mental tuberculum to the mandibular angle; (3) Width: distance from the posterior border of the condyle to the tip of the coronoid process.

ID no.	Bone	Side	Weight (g)	Max length (mm)	min width (mm)	Other measures (mm)
187	Tibia	Left	2.55	67.16	15.81	/
188	Tibia	Right	1.69	64.12	10.06	/
193	Hemimandible	Right	1.36	49.66[1]	9.12	34.65[2]; 18.14[3]
225	Humerus	Right	1.52	49.87	13.44	/
227	Rib	Right	0.53	60.04	4.29	/
507	Radius	Left	0.72	54.08	8.36	/

2.3. Methods of anthropological analysis

All bone fragments were cleaned using demineralised water and a soft synthetic-bristle toothbrush. After drying at 20°C for 24 h, each bone was weighed using a laboratory balance (GRAM Lite FS; maximum capacity 120 g; resolution 0.0001 g). For the purposes of this study, weights were rounded down to the second decimal place. The remains were then photographed using a Canon R10 mirrorless camera equipped with an 18–150 mm STM lens and measured with a Mitutoyo digital caliper (model 500–181-30; range 0–150 mm; resolution 0.01 mm).

Age at death was estimated using osteometric criteria based on mandibular dimensions and measurements of the available postcranial long bones (Fazekas and Kósa, 1978; Jeanty, 1983; Scheuer et al., 1980). Macroscopic observations were carried out with the naked eye and aided by a magnifying lens.

One sample of human bone (ID 188, RAB 2022, SU 2, unit 100/504) corresponding to a fragment of right tibial diaphysis of 0.99 g, was submitted for radiocarbon dating at the ^{14}CHRONO – Centre for Climate, the Environment, and Chronology of the Queen's University in Belfast, United Kingdom. The 14C/12C ratio in the graphite was measured with the AMS type MICADAS, mini carbon dating system, at the ^{14}CHRONO (Lab-code: UBA-56870) and converted into a radiocarbon age (expressed in years BP), after correction for isotope fractionation, using the δ13C AMS measurement. Calibration of this radiocarbon age (BP) and all dates cited in the text into calendar years (BCE) was performed using the software OxCal 4.4 (Bronk Ramsey, 2009) and the atmospheric calibration curve IntCal20 (Reimer et al., 2020).

Bone anomalies interpreted as possible pathological alterations were assessed through comparison with both clinical and paleopathological literature (Ortner and Ericksen, 1997; Ortner and Mays, 1998; Ortner et al., 1999, 2001; Ortner, 2003; Brickley and Ives, 2006; Mays et al., 2006; Mays, 2008; Geber and Murphy, 2012; Schattmann et al., 2016; Brickley et al., 2018, 2020; Snoddy et al., 2018). Given the profound difficulties of establishing an unequivocal differential diagnosis from such highly fragmented material—particularly in the absence of a complete skeleton required to build a robust diagnostic framework—this study adopts a probabilistic approach. Consequently, we have relied on a well-established paleopathological taxonomy that categorizes lesions as "possible" or "probable" indicators of a specific condition, or alternatively, classifies them as overlapping traits shared among multiple micronutrient deficiencies (Schattmann et al., 2016; Larentis et al., 2023 Vlok et al., 2023, 2024). This classification acknowledges that defining a unique, macroscopic etiology for these features is often impossible when dealing with incomplete remains, thereby shifting the interpretive focus toward a more generalized signature of metabolic stress. Diagnostic features considered included abnormal porosity, new bone formation in both cranial and postcranial elements, lytic lesions, alterations of the growth plates, and fractures. Finally, features potentially related to the pathological condition of the individual were documented at the microscopic level using a Hirox RH-2000 digital microscope, allowing detailed surface analysis at high magnification. To investigate a fracture identified on specimen ID 225 (RAB, 2022, SU 2, location 100/504) at ultra-high magnification, the fragment was further examined using a Phenom XL compact scanning electron microscope (SEM). This analysis was performed to characterise fracture surface morphology and microstructural features relevant to the assessment of fracture timing and formation processes.

All osteological analyses were conducted in accordance with the guidelines issued by the Italian Central Institute for Archaeology (Istituto Centrale per l'Archeologia, ICA) and the Italian Central Institute for Catalogues and Documentation (Istituto Centrale per il Catalogo e la Documentazione, ICCD) (MiC, 2022). All analytical procedures were formally authorised by the Italian Ministry of Culture (Ministero della Cultura, MiC).

3. Results

Macroscopic anthropological analysis allowed the anatomical identification of the remains as belonging to both the cranial and postcranial skeleton, with elements attributable to both the right and left sides of the body (Table 2).

All osteometric measurements, when evaluated according to the adopted methodological criter ia, allowed the estimation of the individual's age at death at approximately 40 lunar weeks, thus classifying the remains as belonging to a fetal/neonatal individual.

The fragment of tibial diaphysis, yielded a radiocarbon date (UBA-56870 ID 188) of 4983 ± 34 BP, calibrated to: 3793–3706/3671–3659 BCE (1σ) or 3932–3877/3804–3653 (2σ) (Fig. 4).

The right tibia fragment identified as ID 188 shows limited cortical surface readability, as diagenetic processes have altered the external bone surface (Fig. 2 e). This condition, however, does not affect the remaining skeletal elements, which—although not representing a complete skeleton—preserve sufficiently well-defined cortical surfaces to allow reliable observation of bone morphology and remodelling features.

The hemimandible ID 193 exhibits abnormal bone porosity characterised by the presence of newly formed lamellar bone apposed to the original cortical surface. This alteration is visible on the surface of the mandibular ramus and extends to the posterior portion of the mandibular foramen (Fig. 2a IV, V; Fig. 5a, b). The affected areas display an irregular but well-defined surface texture, with clear distinction between the underlying cortical bone and the superimposed lamellar tissue.

A small groove is present on the proximal portion of a ID 227 right rib fragment, located on the infero-ventral aspect of the rib shaft (Fig. 3IV; Fig. 5c, d). The groove is delimited by a remodelled floor and sharp, well-defined margins, clearly distinguishable from the surrounding bone surface. The adjacent cortical bone shows no evidence of fragmentation or surface abrasion.

A fracture affecting the distal third of the right humerus ID 225 was identified (Fig. 2b II, III; Fig. 5e–g). The fracture is characterised by smooth and curved fracture surfaces, with an oblique to spiral fracture line. The edges of the fracture are sharp and exhibit distinct beveling, characterized by oblique planes sloping from the external to the internal cortex. Conversely, along the posterior aspect of the diaphysis, viewed from a superior-lateral perspective, the fracture margin becomes more irregular, displaying a characteristic zigzag pattern (Fig. 5e–g). No discontinuity in colour or texture is observed between the external

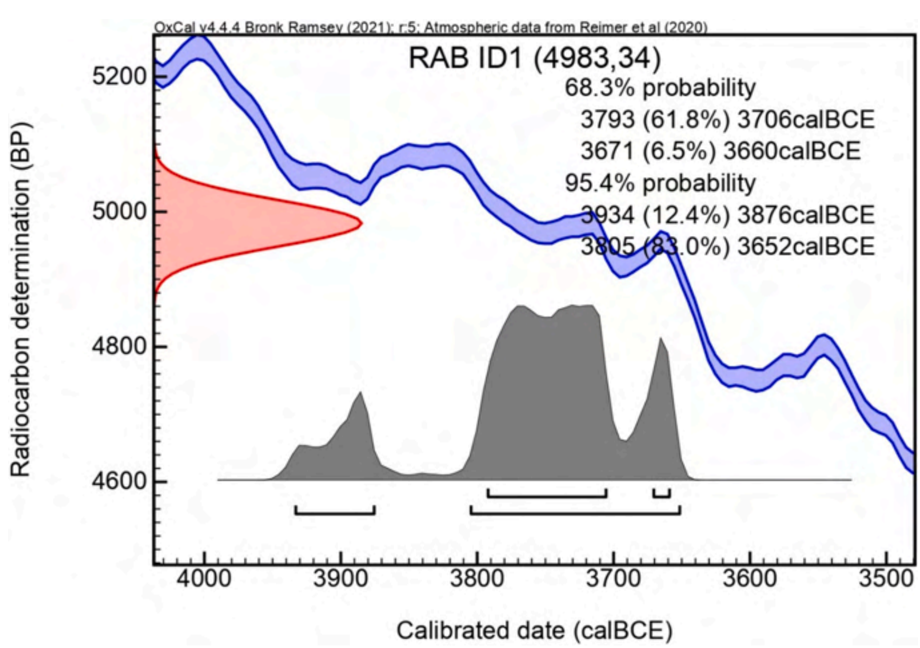

Fig. 4. OxCal plot showing the uncalibrated and calibrated radiocarbon date of ID 188, RAB 2022, SU 2, unit 100/504.

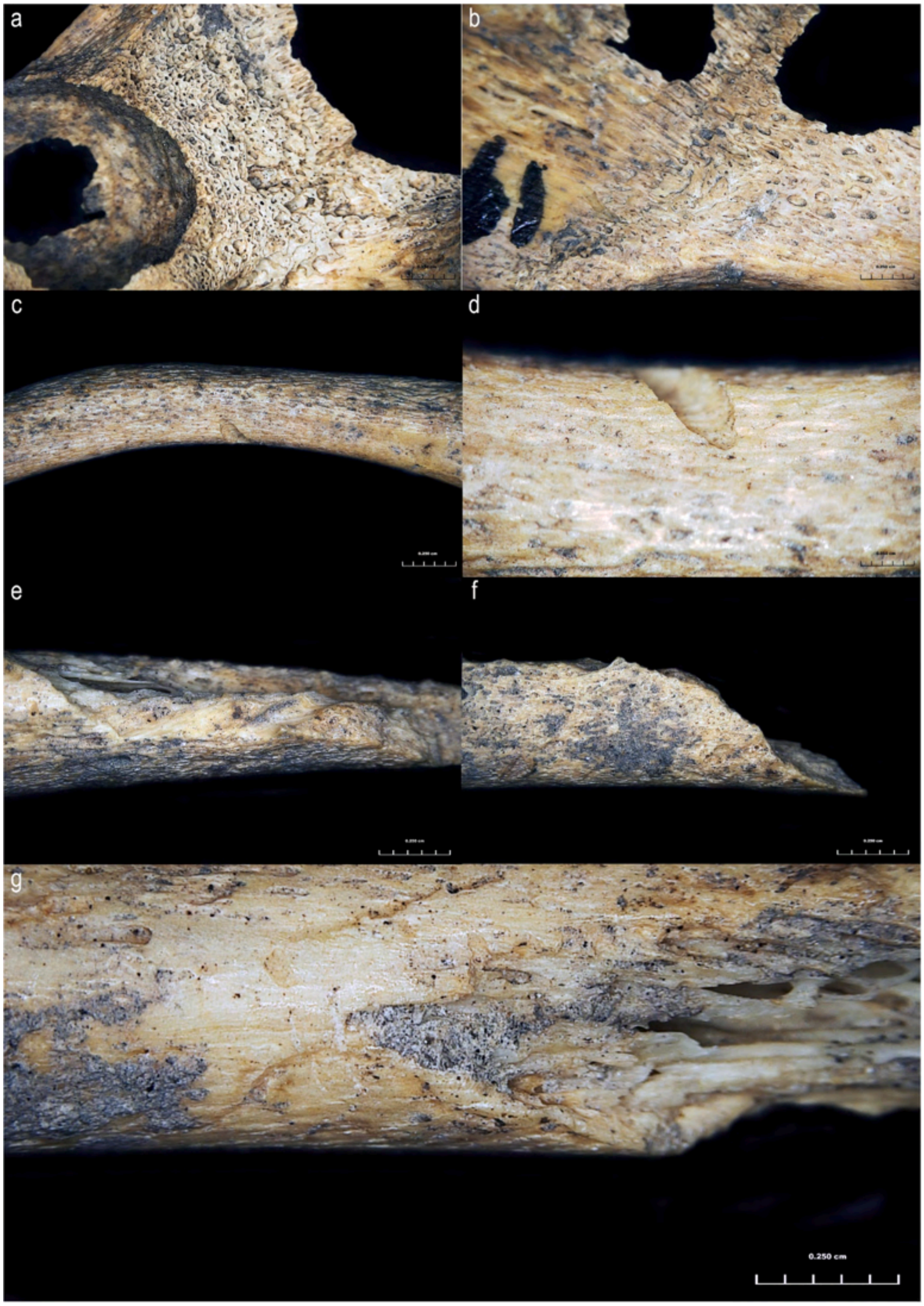

Fig. 5. Detail photographs of the pathological features identified on the analysed skeletal elements. (a–b) Right hemimandible showing abnormal cortical porosity and areas of lamellar bone deposition on the mandibular ramus and around the posterior portion of the mandibular foramen. (c–d) Left rib exhibiting a focal cortical alteration with a small groove on the infero-ventral surface of the shaft. (e–g) Right humerus showing a mid-diaphyseal oblique-to-spiral fracture; images illustrate the smooth and curved fracture surfaces and the absence of colour discontinuity between the external cortex and the fracture plane, consistent with perimortem breakage.

cortical surface and the cortical bone exposed along the fracture plane, which appear macroscopically homogeneous (Fig. 5g).

A lace-like cortical reduction is observable at the distal metaphysis of the right radius (ID 507), where the cortical bone appears thinned and irregularly perforated (Fig. 2c III; Fig. 6a), and a porous remodelled bone tissue is present at the radial tuberosity (Fig. 2c IV).

As previously noted, the right tibia (ID 188) displays marked diagenetic alteration, which partially obscures the external cortical surface. However, comparison with the lateral surface of the contralateral tibia (ID 187) allows the identification of a mild, bilaterally symmetrical cortical porosity relative to the sagittal plane, localised at the mid-diaphyseal region (Fig. 5b, d). Further examination of the right tibia, which preserves well-defined proximal and distal metaphyseal regions, reveals a lace-like cortical reduction comparable in appearance

Fig. 6. High-magnification detail photographs of the pathological features identified on the analysed skeletal remains. (a) Lace-like cortical reduction of the distal radius. (b) Porosity on the medial aspect of the right tibia. (c) Porosity on the medial aspect of the left tibia. (d) Lace-like cortical reduction of the proximal left tibia. (e) Lace-like cortical reduction of the distal left tibia. (f) Lace-like cortical reduction of the distal right tibia.

and distribution to that observed at the distal metaphysis of the radius.

Scanning electron microscopy of the fracture surface (Fig. 7) reveals a complex microtopography characterised by multiple delamination planes running parallel and sub-parallel to the cortical surface (Fig. 7a–d). At higher magnifications, the exposed cortical microstructure appears compact and homogeneous, with no visible infilling or surface weathering. The fracture plane shows a uniform coloration and texture across its extent, with no discernible contrast between internal and external cortical surfaces (Fig. 5e–g; Fig. 7).

High-magnification observation of the humeral fracture surface reveals a complex microtopography characterised by multiple delamination planes running parallel and sub-parallel to the external cortical surface (Fig. 7a, b). These planes define thin, superimposed lamellae that locally detach from one another, producing a stepped appearance across both the apical and distal portions of the fracture surface.

Numerous small cortical scales and flakes are present along the fracture margins and within the fracture plane (Fig. 7c). These elements vary in size and thickness and show an irregular distribution. Some flakes remain partially attached to the underlying cortical substrate, whereas others appear completely detached (Fig. 7d). The margins of the flakes are sharp and angular, and their surfaces do not display evidence of abrasion, rounding, or sedimentary coating (Fig. 7a–e).

Overall, the fracture surface appears predominantly smooth and curved, with a continuous fracture trajectory observable at higher magnification (Fig. 7). In several areas, small microfractures with a regular concave, conchoidal morphology are present within the cortical bone tissue (Fig. 7e).

As a morphological comparison with the humeral fracture, we also examined under SEM the post-mortem fracture affecting the rib shaft (Fig. 8).

In this case the fracture surface is perpendicular to both the outer and inner cortical tables (Fig. 8a, d), and the plane of force propagation disregards the anatomical microstructure of the bone, transecting the Haversian canals longitudinally (Fig. 8b, c). No portion of the fracture surface shows features attributable to bone flaking, a stepped appearance, or conchoidal fracturing; on the contrary, the surface is planar and uniformly rough (Fig. 8a, c).

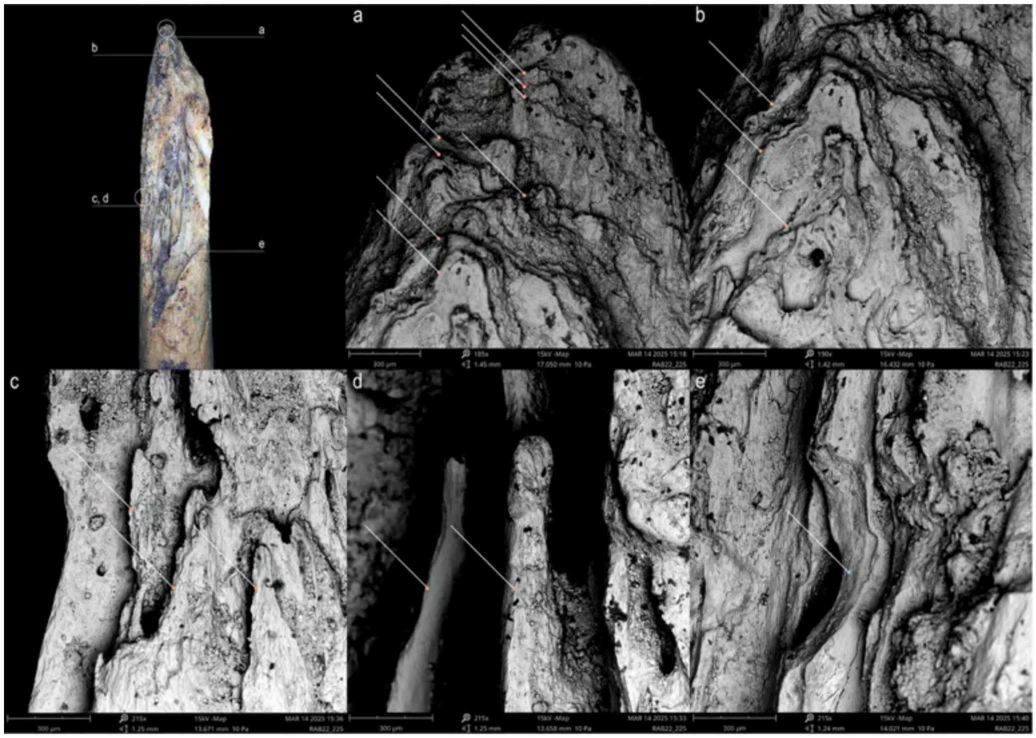

Fig. 7. High-magnification detail photograph of the humeral fracture, with circles and letters indicating the areas selected for SEM image acquisition. Orange dots highlight the areas that best display the stepped morphology and bone flaking, marking the edges along which the steps descend, while the concavity of the conchoidal fracture is indicated in light blue. (a) Stepped appearance of the apical portion of the fracture surface. (b) Similar stepped morphology characterising the entire distal portion of the fracture. (c) Cortical scales and flakes observed on the lateral portion of the fracture in anteroposterior view. (d) Cortical scales and flakes of the same area viewed in mediolateral orientation. (e) Conchoidal microfracture of the cortical bone tissue, consistent with breakage of fresh (green) bone.

4. Discussions

Beginning our analysis with the macroscopic features potentially linked to pathological conditions, it should be noted that the porous, remodelled bone tissue observed at the radial tuberosity (Fig. 2c IV) does not represent a pathological process; rather, it reflects the normal physiological appearance of the external cortical surface during subadult skeletal development at a site of muscle insertion. This feature, along with the small lesion identified on the ventral surface of the rib, is presented specifically to contrast possible post-mortem taphonomic alterations and normal developmental variants with genuine pathological lesions (Fig. 5c, d). A definitive pathological origin can likely be ruled out for the groove observed on the rib; given the ambiguous nature of this feature, it has been classified as indeterminate in origin. Indeed, the lesion exhibits sharp, well-defined margins, well-preserved compact bone tissue, and a depth that appears to penetrate beyond the expected cortical thickness of a subadult rib. While these macromorphological features could theoretically argue against a taphonomic modification in favor of a non-pathological anatomical variant, any conclusive assessment based on these criteria alone would represent an over-interpretation of the available evidence.

The pattern of skeletal alterations documented in the present assemblage (Table 3) is characterised by a combination of slightly increased cortical porosity, lace-like metaphyseal cortical reduction and lamellar bone deposition, affecting multiple skeletal elements of a fetal/neonatal individual (Figs. 5 and 6). Although the skeletal representation is highly incomplete, the distribution, morphology, and anatomical localisation of the observed changes allows us to propose a cautious comparison with paleopathological descriptions of micronutrient deficiency diseases (Ortner and Ericksen, 1997; Ortner and Mays, 1998; Ortner, 2003; Brickley and Ives, 2006; Lewis, 2007; Mays et al., 2006; Mays, 2008; Geber and Murphy, 2012; Schattmann et al., 2016; Brickley et al., 2018; Buikstra, 2019; Brickley et al., 2020).

Increased cortical porosity and reduced cortical density, documented bilaterally at the mid-diaphysis of the tibiae (IDs 187 and 188), represent non-specific but recurrent features in metabolic stress conditions, including micronutrient deficiencies (Ortner, 2003; Brickley and Ives, 2008; Weston, 2009; Brown and Ortner, 2011; Schattmann et al., 2016; Rittemard et al., 2019). Of particular relevance is the presence of lace-like cortical porosity localised to the metaphyseal regions of the tibia (proximal and distal) and radius (distal), a pattern widely described in association with impaired collagen synthesis and vascular fragility in growing bone (Lewis, 2007; Schattmann et al., 2016; Snoddy et al., 2018). Similar metaphyseal surface alterations, described as porous, finely trabeculated, or lace-like, have been reported in non-adult individuals affected by possible vitamin C deficiency and interpreted as the osseous correlate of subperiosteal haemorrhages and abnormal bone formation (e.g. Brickley and Ives, 2008; Larentis, 2023).

Additionally, a slight support for a metabolic aetiology is provided by the bilateral involvement of tibiae and by the presence of lamellar bone deposition associated with increased porosity on the mandibular ramus and around the posterior portion of the mandibular foramen (Brickley and Morgan, 2023). Craniofacial involvement, particularly affecting the mandible, is a well-documented feature in cases of infantile scurvy, where defective collagen production leads to vascular instability and reactive new bone formation in areas of muscular attachment and vascular supply (Patel et al., 2022; Lešić et al., 2024). In this regard, it must be emphasized that the poor skeletal representation of the subject precludes the evaluation of critical cranial areas essential for a robust differential diagnosis, such as the sphenoid, the pars basilaris, and the squamous portions of the neurocranium (i.e. Schattmann et al., 2016; Larentis et al., 2023).

A differential diagnosis must nevertheless be considered, despite the challenges of analyzing a highly incomplete skeleton, as several of the observed features are not pathognomonic and may overlap with other pathological conditions. Rickets (vitamin D deficiency) can produce

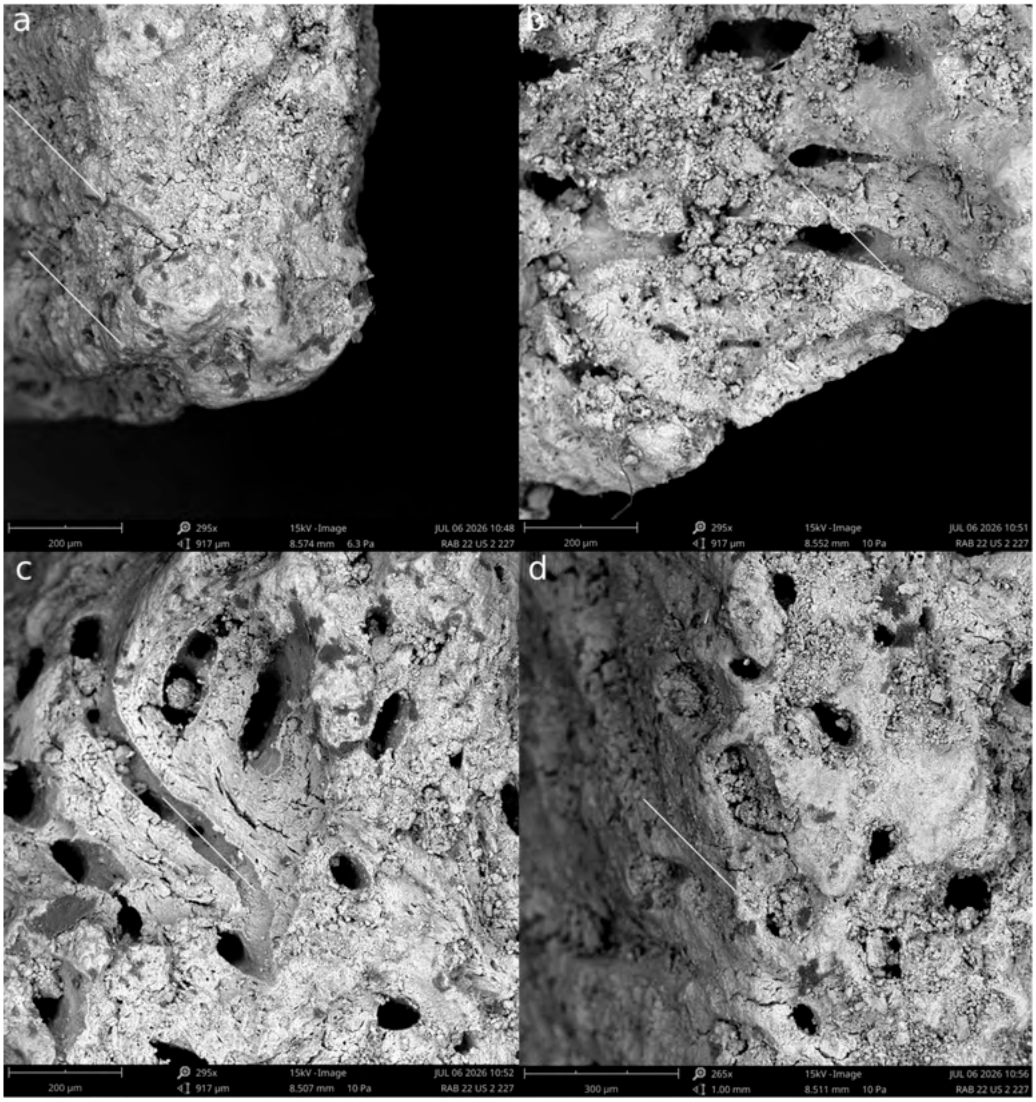

Fig. 8. High-magnification detail of the post-mortem rib fracture. (a) The orange dots mark the fracture margin, which meets the cortical bone at 90° and shows no bone flaking. (b, c) The orange dot indicates the margin of a Haversian canal cut longitudinally by the fracture. (d) The fracture margin, again perpendicular (90°) to the rib cortex, likewise showing neither stepped morphology nor bone flaking.

Table 3
Summary of the observed bone changes. When multiple locations are present on a single bone, each finding is reported in a separate row.

ID no.	Bone	Side	Location	Bone change
187	Tibia	Left	Diaphysis, outer cortex, lateral surface	Increased porosity or reduced cortical density
188	Tibia	Right	Diaphysis, outer cortex, lateral surface	Increased porosity or reduced cortical density
188	Tibia	Right	Proximal metaphyseal area, outer cortex	Lace-like increased porosity
188	Tibia	Right	Distal metaphyseal area, outer cortex	Lace-like increased porosity
193	Hemimandible	Right	Ramus, outer cortex	Increased porosity and lamellar bone deposition
193	Hemimandible	Right	Posterior portion of the mandibular foramen	Increased porosity and lamellar bone deposition
225	Humerus	Right	Diaphysis	Oblique fracture
507	Radius	Left	Distal metaphyseal area, outer cortex	Lace-like increased porosity

metaphyseal alterations and cortical porosity; however, it is typically associated with metaphyseal flaring, growth plate widening, and long bone deformities, none of which are documented in the present assemblage (Ives, 2018; Larentis et al., 2020; Pitre et al., 2023; Zinn et al., 2025). Anaemia-related conditions may also result in porous cranial and postcranial bone surfaces, but they preferentially affect flat bones and cranial vault structures and do not usually produce the metaphyseal lace-like pattern observed here (Anderson et al., 2025; Petiti et al., 2025).

Taken together, the combination of bilateral long bone cortical porosity, metaphyseal lace-like cortical reduction, and possible craniofacial involvement with lamellar bone deposition, suggest the constellation of features described in the paleopathological literature as compatible with micronutrient deficiency in non-adult individuals (Ortner and Ericksen, 1997; Brickley and Ives, 2008; Snoddy et al., 2018; Larentis et al., 2020; 2023 and already cited literature). However, the incomplete skeletal representation of RAB ID1, the fetal/neonatal age of the individual, and the possibility of co-occurring pathological conditions necessitate interpretative caution. Several skeletal responses observed in micronutrient deficiencies are shared across different metabolic and systemic stressors, and the absence of some diagnostic skeletal districts limits the strength of a definitive diagnosis.

The skeletal manifestations observed in our sample—specifically the mild subperiosteal new bone formation on the tibiae, alongside metaphyseal porosity and the apposition of porous bone on the coronoid process of the mandible—have traditionally been attributed to possible micronutrient deficiencies (e.g., Schattmann et al., 2016). Recent paleopathological re-evaluations underscore that these markers frequently present as "overlapping features," lacking the diagnostic specificity required to isolate a single nutritional deficiency (Vlok et al., 2023, 2024).

While such lesions may be suggestive of the vascular fragility and subperiosteal hemorrhaging characteristic of scurvy (vitamin C deficiency), they are also known to manifest in cases of rickets (vitamin D deficiency) or as a result of other systemic nutritional stressors. Consequently, rather than attributing these traits to a singular, specific avitaminosis, they are better interpreted as a suite of indicators reflecting a broader state of metabolic compromise. Viewed through this lens, these lesions constitute a generalized "metabolic signature" of physiological stress rather than a pathognomonic marker for a single disease.

A final consideration concerns the possible presence of a metabolic pathology in a fetal/neonatal individual, a circumstance that necessarily requires evaluation within a maternal–fetal biological framework (Gowland and Halcrow, 2020). At this developmental stage, the individual could not have been weaned, and nutritional intake was entirely mediated through the mother, either via placental transfer during gestation or, in the very late perinatal period, through colostrum and breast milk. Consequently, interpreting the lesions as being linked to a general vitamin deficiency stress, any micronutrient deficiencies affecting a fetal/neonatal individual could be interpreted as reflecting maternal nutritional status, rather than independent postnatal dietary insufficiency (Mudiyanselage et al., 2024; Rahayu et al., 2024).

Fetal skeletal development is highly dependent on the maternal supply of micronutrients, including vitamin C, vitamin D, iron, and other essential compounds required for collagen synthesis, bone mineralisation, and vascular integrity (Fowden and Moore, 2012; Díaz et al., 2014). During pregnancy, deficiencies in these micronutrients may compromise fetal growth and skeletal development, resulting in osseous changes that mirror those observed in the maternal organism, particularly when maternal reserves are limited or chronically depleted (Roberts and Manchester, 2010; Snoddy et al., 2018).

Paleopathological studies have repeatedly emphasised that skeletal manifestations of scurvy observed in fetal/neonatal perinatal subjects are best understood as indicators of maternal deficiency, especially in contexts where an infant's nutrition would strictly depend on maternal milk or immediate neonatal care, without the introduction of complementary foods (Lewis, 2007; Snoddy et al., 2018; Larentis et al., 2023).

In this perspective, the skeletal alterations documented in RAB ID1—interpreted as consistent with a probable micronutrient deficiency—are most plausibly understood as the osteological expression of a shared maternal–fetal metabolic condition. While the maternal skeleton is not available for direct comparison, the biological dependence of the fetus on maternal nutritional status allows the inference that, if RAB ID1 experienced micronutrient deficiency, the mother was likewise affected by a similar condition during pregnancy. Such an interpretation is further supported by archaeological and historical evidence indicating that nutritional stress during gestation was common in prehistoric populations, particularly in marginal or seasonally constrained environments (Kyriacou et al., 2014; Hochberg and Hochberg, 2019).

In this context, the results obtained from the radiocarbon dating of the individual become particularly relevant. The chronological interval between 3900 and 3600 cal BCE falls within a transitional phase between the late Recent Neolithic and the early Copper Age in north-eastern Italy, broadly encompassing the advanced stages of the Square-Mouthed Pottery (VBQ III) cultural tradition and the emergence of Late Neolithic/early Copper Age horizons conventionally referred to as Isera III/Fiavè 1 (ca. 3800–3600 cal BCE) (Perini, 1975; Pedrotti 2001). At present, RAB ID1 represents the only human individual securely attributable to a late phase of the Square-Mouthed Pottery (VBQ) cultural tradition during the Late Neolithic. In northern Italy, the only other individual with a broadly comparable radiocarbon date derives from the scattered human remains recovered in Grotta della Pollera, identified as Tomb 7 (Sparacello et al., 2019). That assemblage consists of an incomplete infant skeleton associated with a late Chassean cultural context. Owing to the extreme fragmentation of the remains, which precluded detailed paleopathological investigation, and to the different cultural attribution, no direct comparison is proposed here.

When extending the perspective to the early Copper Age, the available dataset increases significantly. In this framework, reference to the South Tyrolean territory is required, and in particular to the necropolis of Barbiano in the Isarco Valley (Dal Rì et al., 2002). Based on a radiometric measurement (ETH-17526) of 4810 ± 70 BP, corresponding to 3712–3375 cal BC, the site is placed within the transitional phase between the Late Neolithic and the Copper Age (95.4% probability) (Dal Rì et al., 2002; Tecchiati, 2013). At present, the cultural threshold identifying the Bolzano Basin as a boundary between cremation practices to the north and inhumation practices to the south, towards Trentino, remains a matter of debate (Tecchiati, 2013; Mottes and Nicolis, 2019).

From the earliest phases of occupation at Riparo Marchi (Trento), human skeletal remains in secondary position have been recovered, likely displaced to a marginal area of the shelter following a change in the function of the site. Radiocarbon dating of human bone (DSH8327_G: 4624 ± 47 BP) yields a calibrated range of 3625–3126 cal BC (Mottes, 2014; Mottes and Nicolis, 2019), placing the site among those providing the earliest funerary evidence of the Copper Age in the south-Alpine and central-eastern pre-Alpine regions.

When considered in light of the later Copper Age tradition of using rock shelters for funerary purposes—a well-documented practice in Trentino and the Brescian area (see synthesis in Roncoroni, 2013)—the Lamen find may indicate an early phase of the shelter's use as a burial place. New osteological data are currently emerging from the analysis of materials recovered during the most recent excavation campaign, and their detailed study and interpretation will be crucial in clarifying this aspect.

The nature and function of human occupation at the Ripari Alti during prehistory remain incompletely understood. These natural rock shelters, distributed along a slope at 1050 m a.s.l., are well suited to serve as intermediate stopping places during movements between the valley floor and higher alpine zones. Their location suggests episodic but structured use, potentially linked to seasonal mobility rather than permanent settlement. In the regional archaeological literature, Neolithic presence at such elevations has been interpreted as evidence for the progressive expansion of agro-pastoral activities into mid- and high-altitude environments, beginning during the Neolithic period (Leonardi, 2004).

Despite this general framework, it remains unclear why Neolithic and early Eneolithic groups inhabiting the Feltrine area repeatedly and over several centuries utilised a context that appears geographically isolated and logistically demanding (Carrer and Cavulli, 2023b). The osteological evidence presented here, particularly the indicators consistent with micronutrient deficiency, offers an additional line of enquiry that may contribute to the broader interpretation of site use and subsistence strategies.

The skeletal alterations observed in RAB ID1, interpreted as compatible with a probable micronutrient deficiency, suggest that the diet of both the fetal/neonatal individual and the mother may have been nutritionally unbalanced, at least with respect to specific micronutrients. Given the fetal/neonatal age of the individual and the biological dependence of fetal nutrition on maternal intake, these data are best understood as reflecting maternal dietary stress rather than an individual pathological condition. A genetic impairment affecting micronutrient absorption in both mother and child is considered unlikely in the absence of supporting evidence and given the systemic nature of the observed skeletal changes.

In prehistoric contexts of northern Italy, particularly in alpine and pre-alpine regions, subsistence strategies during the Neolithic were predominantly based on cereal agriculture and animal husbandry, supplemented to varying degrees by hunting and the gathering of wild plant resources (Pessina and Tiné, 2008). While such mixed economies were generally sufficient in terms of caloric intake, they could nevertheless result in seasonal or chronic micronutrient deficiencies, especially in environments characterised by altitude, climatic constraints, and limited access to fresh plant foods (Roberts and Manchester, 2010).

Vitamin C is of particular relevance in this context, as it must be obtained entirely through the diet and is primarily supplied by fresh fruits, leafy vegetables, and certain wild plant resources. In temperate and alpine environments, the availability of such foods is highly seasonal, and reliance on stored plant products, cereals, and animal-derived foods may significantly reduce vitamin C intake, particularly during winter and early spring (Brickley and Ives, 2008; Snoddy et al., 2018). Ethnographic and archaeological studies have repeatedly shown that populations inhabiting marginal or high-altitude landscapes are especially vulnerable to such nutritional imbalances, even in the absence of overt food scarcity (Larson et al., 2019).

Within this framework, the evidence of probable micronutrient deficiency observed in RAB ID1 may reflect broader subsistence and mobility constraints experienced by Neolithic groups exploiting alpine environments. The use of *Ripari Alti* as part of a seasonal movement system—potentially linked to pastoral practices or resource procurement—may have coincided with periods of increased nutritional stress, particularly for pregnant individuals.

In the present case, the fracture identified on the distal third of the diaphysis of the right humerus displays morphological characteristics compatible with a perimortem oblique fracture, as defined in the osteoarchaeological and paleopathological literature (Villa and Mahieu, 1991; Pechníková et al., 2011; Ribeiro et al., 2020). In bioarchaeology and anthropology, perimortem trauma is generally defined as an injury inflicted while the bone still retains its organic components, causing it to biomechanically behave as green or fresh bone (Symes et al., 2012).

SEM analysis of the fracture surface (Fig. 7) provided critical micromorphological evidence to assess the *peri*-mortem nature of the trauma (Christensen et al., 2018, 2021; Goguen et al. 2023). The observed surfaces exhibited distinct smooth fracture mirrors, which typically occur when the propagating crack is physically slowed down by the compliant organic matrix, producing relatively homogeneous and smooth microscopic regions prior to ultimate failure (Fig. 7a–c). This viscoelastic behavior is further supported by the presence of conchoidal fracture patterns—a diagnostic feature that requires highly elastic, fresh bone tissue to manifest (Fig. 7e). Additionally, numerous microscopic adherent bone flakes were observed partially attached to the fracture plane, held in place by the residual tensile strength of the collagen network (Fig. 7a–d). These micro-features stand in stark contrast to the taphonomic criteria established in the literature for dry bone fractures (Dirkmaat and Cabo, 2016; Kemp, 2016; Anastopoulou et al., 2025). In dry bone, the taphonomic degradation of the organic component results in a total absence of collagen pull-out, leading to sharp, rigid, and immediate cleavage planes. Furthermore, dry bone failures characteristically display a rough, chalky, and granular texture under SEM, driven by the chaotic detachment of hydroxyapatite crystals no longer bound by collagen. This is frequently accompanied by distinct micro-flaking and brittle exfoliation along the margins, without any evidence of plastic deformation. Consequently, the presence of fracture mirrors, conchoidal propagation, and adherent micro-flakes firmly identifies the lesion as a fresh bone fracture. To corroborate our diagnosis and to rule out taphonomic or diagenetic factors specific to the depositional context, we applied the same SEM protocol to the rib fracture, which had been morphologically interpreted as post-mortem (Fig. 8a–d). Its features differ clearly from those of the humeral fracture and fall squarely within the descriptive and interpretive framework of post-mortem (dry-bone) fracturing, thereby providing an intra-site diagnostic criterion.

The morphology of bone fracture patterns is directly dictated by the nature and direction of the applied mechanical forces (Tommasini et al., 2005); failure occurs when the kinetic energy of the trauma exceeds the bone's capacity for viscoelastic absorption (Emin and İsmail, 2025). Structurally, bone tissue is weakest under tension and strongest under compression (Nyman et al., 2008). Consequently, bending forces subject the convex surface of a long bone to tensile stress, leading to elongation and resulting in a classic transverse fracture (Melvin, 1993). Conversely, torsional loading induces shear stress along the shaft, culminating in a spiral fracture (VanCourt et al., 2000). In paleopathological and forensic analyses, macroscopic edge morphology remains a critical diagnostic criterion: perimortem fractures are characteristically defined by sharp margins and acute/obtuse angles, whereas post-mortem fractures of dry bone typically exhibit right-angled edges (Haglund, 2005; Byers, 2008). Furthermore, the presence of jagged, irregular surfaces at the broken ends serves to differentiate perimortem trauma from post-mortem taphonomic damage (Byers, 2008). Advanced diagnostic indicators of fresh bone failure include the formation of oblique fracture planes relative to the longitudinal and transverse axes (Villa and Mahieu, 1991; Kim et al., 2011). At the textural level, fresh bone fractures typically display a smooth, homogenous surface, whereas dry bone failure yields a rough, irregular, and stepped texture (Gupta and Zioupos, 2008; Kemp, 2016. The macroscopic and microscopic features in our sample—smooth and curved fracture surfaces, an oblique to spiral fracture line are consistent with biomechanical failure occurring while the bone retained its organic properties (Skinner et al., 2024).

Evaluating the precise timing of skeletal trauma in relation to the moment of death presents a critical methodological challenge in paleopathology (Lovell, 1997; Cattaneo and Cappella, 2017; Ribeiro et al., 2020). Because bone tissue retains its organic collagen matrix and viscoelastic properties for a post-mortem interval dependent on specific burial taphonomy, injuries sustained shortly after death can macroscopically mimic genuine perimortem trauma (Kemp, 2016). Furthermore, gross skeletal analysis alone cannot definitively establish whether a neonatal individual was stillborn, succumbed during delivery, or survived for a brief postnatal period (Hughes et al., 2024). Nevertheless, the specific biomechanical profile of the humeral lesion documented here supports an obstetric or mechanical origin over a post-mortem taphonomic phenomenon. While post-mortem sediment pressure, skeletal settling, or accidental impacts, such as trampling, typically generate compressive or bending forces—resulting in transverse, longitudinal, or comminuted fracture trajectories—they are generally incapable of propagating high-torque rotational forces along the longitudinal axis of a constrained limb (Cappella et al., 2014; Kemp, 2016; Sorg, 2019; L'Abbé et al., 2021). The distinct spiral morphology of this fracture requires a torsional loading mechanism (Miyasaka et al., 1991; VanCourt et al., 2000; Theobald et al., 2012).

Within a clinical and biomechanical framework, fractures of this type are documented as potential outcomes of manual extraction manoeuvres during complicated deliveries, particularly in cases involving shoulder dystocia, abnormal fetal presentation, or obstructed labour. In modern obstetric contexts, humeral diaphyseal fractures are recognised complications of emergency interventions aimed at resolving life-threatening situations for both mother and child. The close correspondence between the fracture morphology observed here and those described in clinical literature provides a comparative basis for interpreting the lesion as birth-related trauma.

While this represents an uncommon condition (McDonald et al., 2024), this fracture of the humerus may occur when a rotational force is propagated along the longitudinal axis of the diaphysis, producing a helical, corkscrew-shaped fracture trajectory. In the present case, the specimen exhibits a distinctive spiral fracture localized at the distal third of the humeral diaphysis. In clinical and orthopedic literature, this specific traumatic lesion represents the classic morphological profile of a Holstein-Lewis fracture (Ekholm et al., 2008, Updegrove et al., 2017; Singh et al., 2021).

As already stated, from a biomechanical perspective, the failure of the distal humeral diaphysis occurs when the application of external forces exceeds the bone's viscoelastic resistance threshold (Emin and İsmail, 2025). In this case, the primary mechanical driver is torsional loading. When the limb is constrained—for instance, if the hand or forearm becomes fixed—and the body undergoes forced rotation along the longitudinal axis of the limb, kinetic energy propagates through the humerus, generating significant shear stress (Hamilçıkan et al., 2018). This torsional loading is frequently coupled with bending forces, which create tensile stress on the convex surface of the bone and compressive stress on the concave side (Saunier and Chapurlat, 2018). Given that bone tissue is biologically weaker under tension than compression, the fracture initiates on the tensile side and propagates distally, yielding the characteristic oblique or spiral morphology observed (Khalid et al., 2025).

In neonates and full-term fetuses, the biomechanics of humeral spiral fractures possess unique characteristics dictated both by the intrinsic properties of developing bone and the specific dynamics of the causal event, which is almost exclusively obstetric in nature (Altai et al., 2019; Delbreil et al., 2019). Fetal/neonatal bone is characterized by a high organic-to-mineral ratio, resulting in extreme elasticity and ductility. Consequently, to achieve a complete oblique or spiral fracture of the distal third, the applied force must be continuous, high-torque, and highly directional; otherwise, the compliant neonatal bone would undergo plastic deformation (i.e., a greenstick or bow fracture) rather than a complete failure (Currey and Butler, 1975; Wetzel et al., 2026). In such young individuals, this fracture pattern rarely results from direct impact or pure compression (Altai et al., 2019; Delbreil et al., 2019; Wetzel et al., 2026). Instead, it typically develops during difficult delivery maneuvers, such as those associated with breech presentation—where the fetal arms may remain extended or reflected above the head—or shoulder dystocia, where the anterior shoulder becomes impacted behind the maternal pubic symphysis (Carlan et al., 1991; Gherman et al., 1998; Yenigül et al., 2020; Bothou et al., 2021; Habek et al., 2022; Carvalho et al., 2024; Yaliwal et al., 2024). In these clinical scenarios, the combination of a constrained limb and the forceful rotational or traction maneuvers required for disengagement provides the exact torsional and bending requirements necessary to produce a spiral fracture of the humeral shaft.

When evaluated in conjunction with the neonatal developmental stage of the individual and the specific anatomical location of the failure, clinical and obstetrical literature heavily contextualizes this pattern as a classic mechanical complication of severe dystocia during difficult deliveries. Consequently, while alternative postnatal or immediate postmortem etiologies cannot be definitively ruled out, the combination of torsional biomechanics, neonatal age, and robust clinical parallels allows us to parsimoniously propose a birth-related obstetric event as the most plausible explanation for the observed trauma.

The importance of this finding lies in its exceptional chronological and cultural context. To date, no published archaeological case from the Italian Neolithic has provided direct osteological evidence compatible with the outcome of an obstetric manoeuvre performed during childbirth. While maternal–fetal deaths and perinatal remains are occasionally documented in prehistoric contexts, most interpretations rely on spatial association, burial position, or demographic patterns rather than on unequivocal skeletal indicators of obstetric intervention. In this respect, the present case represents, to our knowledge, the first osteologically documented evidence suggesting emergency birth assistance in the Italian Neolithic. Such evidence has important implications for our understanding of prehistoric reproductive care. The presence of a fracture consistent with an attempted manual extraction implies not only awareness of the biomechanical challenges of childbirth, but also the existence of practical knowledge aimed at preserving the lives of both mother and child. Although it is impossible to reconstruct the precise nature of the manoeuvre performed, the lesion itself indicates that an active intervention took place rather than passive acceptance of an adverse outcome. This suggests that Neolithic communities possessed experiential knowledge of childbirth and may have developed culturally transmitted strategies to manage obstetric emergencies, even in the absence of formalised medical systems.

The archaeological context further strengthens this interpretation. The high-altitude rock shelter setting of Ripari Alti suggests that the remains were deposited within a landscape characterised by seasonal mobility between lowland and upland zones. Such movements are best understood as involving groups embedded within broader community networks, rather than isolated individuals such as solitary herders. The presence of a fetal/neonatal individual in this context, together with evidence of attempted obstetric intervention, implies that pregnant women were moving with their communities and that childbirth—and its associated risks—occurred within socially cohesive groups capable of providing assistance. This scenario aligns with broader interpretations of Neolithic alpine land use as involving collective, rather than individualised, exploitation of mountain environments.

From a broader evolutionary and bioarchaeological perspective, this case contributes to ongoing discussions concerning the relationship between Neolithic lifeways and obstetric risk. Multiple studies have suggested that the transition to agricultural economies was accompanied by increased challenges in childbirth, potentially linked to changes in female pelvic morphology, nutritional stress, and increased fetal size (Wells, 1978; Rosenberg and Trevathan, 2002; Thomas et al., 2004). Elevated mortality among women of reproductive age in Neolithic populations is consistent with the interpretation of childbirth as a high-risk event, even if direct skeletal evidence has scarcely been identified (Willis and Oxenham, 2013). Within this framework, the identification of a perimortem fetal fracture compatible with birth-related trauma assumes particular significance (Leung et al., 2011). Such lesions provide a unique and direct osteological window onto the biomechanics of childbirth, the limits of human parturition, and the adaptive strategies developed by prehistoric communities to cope with a biologically critical yet culturally mediated event. Most published archaeological examples of problematic childbirth rely on circumstantial indicators and exclusion of alternative explanations rather than on clear diagnostic markers. Consequently, each well-documented case substantially enhances our ability to explore obstetric practices and perinatal risk in past populations. Although the present interpretation must remain cautious, given the inherent limitations of the archaeological record and the absence of soft tissue or maternal remains, the convergence of fracture morphology, biomechanical plausibility, and contextual evidence allows the conclusion that this lesion most plausibly represents the osteological outcome of a failed obstetric manoeuvre. As such, it constitutes a unique contribution to the study of childbirth, care practices, and reproductive risk in Neolithic Italy and, more broadly, in prehistoric societies.

5. Conclusions

This study documents a fetal/neonatal individual dated to 3932–3653 cal BCE from a high-altitude alpine rock shelter context, expanding the empirical basis for investigating childbirth-related risk in prehistoric Europe. The skeletal assemblage is consistent with a single fetal/neonatal individual and preserves a distinctive combination of bone changes suggestive of systemic metabolic stress, while acknowledging diagnostic overlap with other conditions and the limitations imposed by incomplete skeletal representation. Crucially, the right humeral mid-shaft fracture exhibits morphological and microstructural characteristics compatible with perimortem oblique-to-spiral failure, effectively excluding typical taphonomic breakage patterns. Considering clinical analogues, the fracture most plausibly reflects birth-related trauma associated with a difficult delivery and attempted obstetric intervention. Together, these findings offer a rare osteological window onto maternal–fetal health and the management of obstetric emergencies in the Neolithic, and they highlight the value of multi-analytical approaches for disentangling perimortem trauma from post-depositional damage in fragile fetal/neonatal remains.

CRediT authorship contribution statement

Omar Larentis: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Francesco Carrer:** Visualization, Project administration. **Fabio Cavulli:** Writing – review & editing, Visualization, Project administration, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

Abedzadeh-Kalahroudi, M., Talebian, A., Jahangiri, M., Mesdaghinia, E., Mohammadzadeh, M., 2014. Incidence of neonatal birth injuries and related factors in Kashan, Iran. Arch. Trauma Res. 4 (1), e22831. https://doi.org/10.5812/atr.22831.

Alexander, J.M., Leveno, K.J., Hauth, J., Landon, M.B., Thom, E., Spong, C.Y., Varner, M. V., Moawad, A.H., Caritis, S.N., Harper, M., Wapner, R.J., Sorokin, Y., Miodovnik, M., O'Sullivan, M.J., Sibai, B.M., Langer, O., Gabbe, S.G., 2006. Fetal injury associated with cesarean delivery. Obstet. Gynecol. 108 (4), 885–890. https://doi.org/10.1097/01.AOG.0000237116.72011.f3.

Anastopoulou, I., Buikstra, J.E., Tamayo, L., Chryssoulaki, S., Moraitis, K., Karakostis, F. A., 2025. Trauma or taphonomy? A forensic reassessment of perimortem cranial trauma in burials from the Phaleron cemetery (Archaic Athens, Greece). J. Archaeol. Sci. 181, 106331. https://doi.org/10.1016/j.jas.2025.106331.

Altai, Z., Viceconti, M., Li, X., Offiah, A., 2019. Investigating rolling as mechanism for humeral fractures in non-ambulant infants: a preliminary finite element study. Clin. Radiol. 75 (1), 78.e9–78.e16. https://doi.org/10.1016/j.crad.2019.08.026.

Anderson, A.S., Blackwell, A., Sutherland, M.L., Kraft, T., Sutherland, J., Beheim, B., Cummings, D., Ghafoor, S., Hooper, P.L., Rodriguez, D.E., Irimia, A., Gatz, M., Mack, W., Rowan, C., Miyamoto, M., Buetow, K., Finch, C., Wann, L.S., Allam, A., Thompson, R.C., Thomas, G., Kaplan, H., Stieglitz, J., Trumble, B., Gurven, M.D., 2025. Childhood skeletal lesions common in prehistory are present in living forager-farmers and predict adult markers of immune function. Sci. Adv. 11 (29), eadw3697. https://doi.org/10.1126/sciadv.adw3697.

Ariyawatkul, T., Worawuthangkul, K., Chotigavanichaya, C., Kaewpornsawan, K., Chalayon, O., Eamsobhana, P., 2017. Potential risk factors for birth fractures: a case-control study. Int. Orthopaed. 41 (11), 2361–2364. https://doi.org/10.1007/s00264-017-3600-5.

Arriaza, B., Allison, M., Gerszten, E., 1988. Maternal mortality in pre-Columbian Indians of Arica, Chile. Am. J. Phys. Anthropol. 77, 35–41. https://doi.org/10.1002/ajpa.1330770107.

Aurilio, M.T., Fava, L., Chisari, M., Bolcato, M., 2025. Birth-related long bone fractures in otherwise healthy newborns and medical professional liability: literature review and case presentation. Front. Med. 12, 1589417. https://doi.org/10.3389/fmed.2025.1589417.

Basha, A., Amarin, Z., Abu-Hassan, F., 2013. Birth-associated fractures of long bones. Int. J. Obstet. Gynecol. 123 (2), 127–130. https://doi.org/10.1016/j.ijgo.2013.05.013.

Bianchin Citton E., 2000. Il popolamento del Bellunese dal Neolitico agli inizi dell'età del ferro. Nuovi dati. Quaderni di Archeologia del Veneto XVI, 23–31.

Bothou, A., Apostolidi, D., Tsikouras, P., Iatrakis, G., Sarella, A., Iatrakis, D., Peitsidis, P., Gerente, A., Anthoulaki, X., Nikolettos, N., Zervoudis, S., 2021. Overview of techniques to manage shoulder dystocia during vaginal birth. Eu. J. Midwif. 5, 1–6. https://doi.org/10.18332/ejm/142097.

Brickley, M., Ives, R., 2008. The Bioarchaeology of Metabolic Bone Disease. Academic Press, Oxford.

Brickley, M.B., Ives, R., 2006. Skeletal manifestations of infantile scurvy. Am. J. Phys. Anthropol. 129 (2), 163–172. https://doi.org/10.1002/ajpa.20265.

Brickley, M.B., Ives, R., Mays, S., 2020. The Bioarchaeology of Metabolic Bone Disease, second ed. Academic Press, San Diego.

Brickley, M.B., Mays, S., George, M., Prowse, T.L., 2018. Analysis of patterning in the occurrence of skeletal lesions used as indicators of vitamin D deficiency in subadult and adult skeletal remains. Int. J. Paleopathol. 23, 43–53. https://doi.org/10.1016/j.ijpp.2018.01.001.

Brickley, M.B., Morgan, B., 2023. Assessing diagnostic certainty for scurvy and rickets in human skeletal remains. Am. J. Biol. Anthropol. 181 (4), 637–645. https://doi.org/10.1002/ajpa.24799.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radioc. 51 (1), 337–360. https://doi.org/10.1017/S0033822200033865.

Brown, M., Ortner, D.J., 2011. Childhood scurvy in a medieval burial from Mačvanska Mitrovica, Serbia. Int. J. Osteoarchaeol. 21, 197–207.

Buikstra, J.E., 2019. Ortner's Identification of Pathological Conditions in Human Skeletal Remains, third ed. Academic Press, San Diego.

Byers, S.N., 2008. Introduction to Forensic Anthropology. Pear-son Education, Boston.

Canepa, M., 1996. Genetic forms of rickets. J. Ped. Endocrin. Metabol 9 (3), 361–368.

Carlan, S.J., Angel, J.L., Knuppel, R.A., 1991. Shoulder dystocia. Am. Fam. Phys. 43 (4), 1307–1311.

Carpenter, K.J., 1988. The History of Scurvy and Vitamin C. Cambridge University Press, Cambridge.

Cappella, A., Amadasi, A., Castoldi, E., Mazzarelli, D., Gaudio, D., Cattaneo, C., 2014. The difficult task of assessing perimortem and postmortem fractures on the skeleton: a blind text on 210 fractures of known origin. J. For. Sci. 59 (6), 1598–1601. https://doi.org/10.1111/1556-4029.12539.

Carrer, F., Cavulli, F., 2023a. Frequentazione umana dei Ripari Alti in valle di Lamen. Frammenti, conoscere la natura bellunese, 13, 85–90.

Carrer, F., Cavulli, F., 2023b. Human frequentation of alpine rockshelters: mobility, seasonality and land use in the eastern Alps. Preistoria Alpina 49, 55–78.

Carvalho, M., Barreto, M.I., Cabral, J., Balacó, I., Alves, C., 2024. Neonatal upper limb fractures: a narrative overview of the literature. BMC Ped. 24, 59. https://doi.org/10.1186/s12887-024-04538-z.

Cattaneo, C., Cappella, A., 2017. Distinguishing between Peri- and Post-Mortem Trauma on Bone. In: Schotsmans, E.M.J., Márquez-Grant, N., Forbes, S.L. (Eds.), Taphonomy of Human Remains: Forensic Analysis of the Dead and the Depositional Environment: Forensic Analysis of the Dead and the Depositional Environment. Wiley-Blackwell, New Jersey.

Chamberlain, G., 2006. British maternal mortality in the 19th and early 20th centuries. J. R. Soc. Med. 99 (11), 559–563. https://doi.org/10.1177/014107680609901113.

Chaplin, G., Jablonski, N.G., 2009. Vitamin D and the evolution of human depigmentation. Am. J. Phys. Anthropol. 139 (4), 451–461. https://doi.org/10.1002/ajpa.21079.

Choi, H.A., Lee, Y.K., Ko, S.Y., Shin, S.M., 2016. Neonatal clavicle fracture in cesarean delivery: incidence and risk factors. J. Matern. Fetal Neonatal Med. 30 (14), 1689–1692. https://doi.org/10.1080/14767058.2016.1222368.

Christensen, A.M., Hefner, J.T., Smith, M.A., Webb, J.B., Bottrell, M.C., Fenton, T.W., 2018. Forensic fractography of bone a new approach to skeletal trauma analysis. For. Anthropol. 1 (1), 32.

Christensen, A.M., Rickman, J., Berryman, H., 2021. Forensic fractography of bone. Forens. Anthopol. 4 (1). https://doi.org/10.5744/fa.2020.0041.

Collins, M.J., Nielsen-Marsh, C.M., Hiller, J., Smith, C.I., Roberts, J.P., Prigodich, R.V., Wess, T.J., Csapò, J., Millard, A.R., Turner-Walker, G., 2002. The survival of organic matter in bone: a review. Archaeom 44 (3), 383–394. https://doi.org/10.1111/1475-4754.t01-1-00071.

Cruz, C.B., Codinha, S., 2010. Death of mother and child due to dystocia in 19th century Portugal. Int. J. Osteoarchaeol. 20, 491–496. https://doi.org/10.1002/oa.1069.

Currey, J.D., Butler, G., 1975. The mechanical properties of bone tissue in children. J. Bone Joint Surg. Am. 57 (6), 810–814.

Dal Rì, L., Rizzi, G., Tecchiati, U., 2002. Una necropoli preistorica a Barbiano in Valle d'Isarco. Atti della XXXIII Riunione Sc. I.I.P.P., Preistoria e protostoria del Trentino Alto Adige/Südtirol, Trento 21-24 ottobre 1997, pp. 335-338.

Delbreil, A., Bouriat, M., Pin, A., Rigoard, P., Vendeuvre, T., Germaneau, A., 2019. Humerus fractures in an infant: which causal mechanisms? Comp. Meth. Biomec Biom. Eng. 22 (1), 510–512. https://doi.org/10.1080/10255842.2020.1715000.

Díaz, P., Powell, T.L., Jansson, T., 2014. The role of placental nutrient sensing in Maternal-Fetal resource allocation1. Biol. Reproduc. 91 (4), 82. https://doi.org/10.1095/biolreprod.114.121798.

Dirkmaat, D.C., Cabo, L.L., 2016. Forensic archaeology and forensic taphonomy: basic considerations on how to properly process and interpret the outdoor forensic scene. Ac. Forens. Pathol. 6 (3), 439–454. https://doi.org/10.23907/2016.045.

Dolivet, E., Delesalle, C., Morello, R., Blouet, M., Bronfen, C., Dreyfus, M., Benoist, G., 2018. A case–control study about foetal trauma during caesarean delivery. J. Gynecol. Obstet. Hum. Reprod. 47 (7), 325–329. https://doi.org/10.1016/j.jogoh.2018.05.002.

Duday, H., 2009. The Archaeology of the Dead: Lectures in Archaeothanatology. Oxbow Books, Oxford.

Dunkow, P., Willett, M.J., Bayam, L., 2005. Fracture of the humeral diaphysis in the neonate. J. Obstet. Gynecol. 25 (5), 510–511. https://doi.org/10.1080/01443610500193387.

Emin, T.E., İsmail, K., 2025. Elastomechanics fundamentals for bones and fractures. Ann. Biotech. Biomed. Sci. 1 (1), 1–12. https://doi.org/10.64258/3069-7557.2025.103001.

Ejsmond, W., Ożarek-Szilke, M., Jaworski, M., Szilke, S., 2021. A pregnant ancient Egyptian mummy from the 1st century BC. J. Archaeol. Sci. 132, 105371. https://doi.org/10.1016/j.jas.2021.105371.

Ekholm, R., Ponzer, S., Törnkvist, H., Adami, J., Tidermark, J., 2008. The Holstein-Lewis humeral shaft fracture: aspects of radial nerve injury, primary treatment, and outcome. J. Orthopaed. Trauma 22 (10), 693–697. https://doi.org/10.1097/bot.0b013e31818915bf.

Fazekas, I.G., Kósa, F., 1978. Forensic Fetal Osteology. Akadémiai Kiadó, Budapest.

Fowden, A., Moore, T., 2012. Maternal-fetal resource allocation: Co-operation and conflict. Plac 33, e11–e15. https://doi.org/10.1016/j.placenta.2012.05.002.

Galimberti, L., Garbetta, G., Rovelli, R., Barera, G., Guindani, N., De Pellegrin, M., 2024. Ultrasound diagnosis of clavicle fractures in newborns: a systematic review. Child 11 (9), 1080. https://doi.org/10.3390/children11091080.

Gandhi, R.A., DeFrancesco, C.J., Shah, A.S., 2019. The association of clavicle fracture with brachial plexus birth palsy. J. Hand Surg. 44 (6), 467–472. https://doi.org/10.1016/j.jhsa.2018.11.006.

Geber, J., Murphy, E., 2012. Scurvy in the Great Irish Famine: evidence of vitamin C deficiency from a mid-19th century skeletal population. Am. J. Phys. Anthropol. 148, 512–524. https://doi.org/10.1002/ajpa.22066.

Gherman, R.B., Ouzounian, J.G., Goodwin, T., 1998. Obstetric maneuvers for shoulder dystocia and associated fetal morbidity. Am. J. Obstet. Gynecol. 178 (6), 1126–1130. https://doi.org/10.1016/s0002-9378(98)70312-6.

Goguen, P., Shyamsunder, L., Joseph, M., Skinner, J., Brown, R., Herrick, J., Rajan, S., Waletzki, B., Langley, N., 2023. Do bone elasticity and postmortem interval affect forensic fractographic analyses? J. For. Sci. 68 (3), 757–767. https://doi.org/10.1111/1556-4029.15237.

Gowland, R., Halcrow, S., 2020. The Mother-Infant Nexus in Anthropology. Springer, Switzerland.

Granger, M., Eck, P., 2018. Dietary Vitamin C in Human Health. Adv. Food Nutrit. Res 83, 281–310. https://doi.org/10.1016/bs.afnr.2017.11.006.

Grauer, A.L., 2011. A Companion to Paleopathology. Wiley-Blackwell, New Jersey.

Gupta, H.S., Zioupos, P., 2008. Fracture of bone tissue: the 'hows' and the 'whys'. Med. Eng. Phys. 30, 1209. https://doi.org/10.1016/j.medengphy.2008.09.007.

Guy, H., Masset, C., Baud, C.A., 1997. Infant taphonomy. Int. J. Osteoarchaeol. 7 (3), 221–229. https://doi.org/10.1002/(SICI)1099-1212(199705)7:3<221::AID-OA338>3.0.CO;2-Z.

Habek, D., Prka, M., Luetić, A.T., Marton, I., Medić, F., Miletić, A.I., 2022. Obstetrics injuries during shoulder dystocia in a tertiary perinatal center. EU. J. Obstet. Gynecol. Rep. Biol. 278, 33–37. https://doi.org/10.1016/j.ejogrb.2022.09.009.

Haeusler, M., Grunstra, N.D., Martin, R.D., Krenn, V.A., Fornai, C., Webb, N.M., 2021. The obstetrical dilemma hypothesis: there's life in the old dog yet. Biol. Rev. Camb. Philos. Soc. 96 (5), 2031–2057. https://doi.org/10.1111/brv.12744.

Haglund, W.D., 2005. Forensic taphonomy. In: James, S.H., Nordby, J.J. (Eds.), Forensic Science. Taylor and Francis, New York, pp. 119–133.

Halcrow, S.E., Tayles, N., 2008. The bioarchaeological investigation of childhood and social age: problems and prospects. J. Archaeol. Meth. Theor. 15, 190–215. https://doi.org/10.1007/s10816-008-9052-x.

Hamilçıkan, Ş., Yilmaz, K., Can, E., 2018. Humeral diaphysis fracture in a neonate after vaginal delivery. Med. Bull. Sisli Hosp. 52 (1), 51–53. https://doi.org/10.14744/semb.2016.25338.

Hawkes, S.C., Wells, C., 1975. An Anglo-Saxon obstetric calamity from Kingsworthy, Hampshire. Med. Biol. Ill. 25 (1), 47–51.

Hedges, R.E.M., 2002. Bone diagenesis: an overview of processes. Archaeom 44 (3), 319–328. https://doi.org/10.1111/1475-4754.00064.

Hochberg, Z., Hochberg, I., 2019. Evolutionary perspective in rickets and vitamin D. Front. Endocrinol. 10, 306. https://doi.org/10.3389/fendo.2019.00306.

Högberg, U., Fellman, V., Thiblin, I., Karlsson, R., Wester, K., 2020. Difficult birth is the main contributor to birth-related fracture and accidents to other neonatal fractures. Acta Paediat. 109 (10), 2040–2048. https://doi.org/10.1111/apa.15217.

Högberg, U., Iregren, E., Siven, C.H., Diener, L., 1987. Maternal deaths in medieval Sweden: an osteological and life table analysis. J. Biosoc. Sci. 19, 495–503. https://doi.org/10.1017/S0021932000017120.

Holick, M.F., 2006. Resurrection of vitamin D deficiency and rickets. J. Clin. Inv. 116 (8), 2062–2072. https://doi.org/10.1172/JCI29449.

Hughes, C., Yim, A., Juarez, C., 2024. Considerations for age estimation accuracy: method-derived outcomes and practitioner interpretations. J. Foren. Sci. 69 (3), 755–764. https://doi.org/10.1111/1556-4029.15505.

Huls, C.K., Detlefs, C., 2018. Trauma in pregnancy. Sem. Perinatol. 42 (1), 13–20. https://doi.org/10.1053/j.semperi.2017.11.004.

Ives, R., 2018. Rare paleopathological insights into vitamin D deficiency rickets, co-occurring illnesses, and documented cause of death in mid-19th century London, UK. Int. J. Paleopathol. 23, 76–87. https://doi.org/10.1016/j.ijpp.2017.11.004.

Jeanty, P., 1983. Fetal limb biometry. Radiology 147 (2), 601–602. https://doi.org/10.1148/radiology.147.2.6836145.

Kemp, W.L., 2016. Postmortem change and its effect on evaluation of fractures. Acad. Forens. Pathol. 6 (1), 28–44. https://doi.org/10.23907/2016.004.

Khalid, G.A., Al-Naji, A., Chahl, J., 2025. Biomechanics of spiral fractures: investigating periosteal effects using digital image correlation. J. Imaging 11 (6), 187. https://doi.org/10.3390/jimaging11060187.

Kim, H., Kim, S., Chang, S., 2011. Bio-mechanical analysis of a fractured tibia with composite bone plates according to the diaphyseal oblique fracture angle. Comp. Part B Eng. 42 (4), 666–674. https://doi.org/10.1016/j.compositesb.2011.02.009.

Knüsel, C.J., Robb, J., 2016. Funerary taphonomy: an overview of goals and methods. J. Archaeol. Sci. Rep. 10, 655–673. https://doi.org/10.1016/j.jasrep.2016.05.031.

Kyriacou, K., Parkington, J.E., Marais, A.D., Braun, D.R., 2014. Nutrition, modernity and the archaeological record: coastal resources and nutrition among Middle Stone Age hunter-gatherers on the western Cape coast of South Africa. J. Hum. Evol. 77, 64–73. https://doi.org/10.1016/j.jhevol.2014.02.024.

L'Abbé, E.N., Symes, S.A., Stull, K.E., Lacroix, M., Pokines, J.T., 2021. Taphonomy and the timing of bone fractures in trauma analysis. In: Pokines, J.T., L'Abbé, E.N., Symes, S.A. (Eds.), Manual of Forensic Taphonomy. Wiley-Blackwell, New Jersey.

Larentis, O., 2023. Rituali e riti funerari della Civiltà celtica di Golasecca. BAR Publishing, Oxford. https://doi.org/10.30861/9781407354064.

Larentis, O., Licata, M., Tonina, E., Pangrazzi, C., 2023. Probable micronutrient deficiency diseases in a rural community. The nonadults of Mary's Nativity church, 16th century, Trentino Alto-Adige, Italy. J. Archaeol. Sci. Rep. 47, 103774. https://doi.org/10.1016/j.jasrep.2022.103774.

Larentis, O., Tonina, E., Iorio, S., Gorini, I., Licata, M., 2020. Osteological evidence of metabolic diseases from a post medieval North Italy archaeological site. Matern. Fetal Neonatal Med. 33 (16), 2735–2742. https://doi.org/10.1080/14767058.2018.1560405.

Larson, G., Piperno, D.R., Allaby, R.G., Purugganan, M.D., Andersson, L., Arroyo-Kalin, M., Barton, L., Climer Vigueira, C., Denham, T., Dobney, K., Doust, A.N., Gepts, P., Gilbert, M.T.P., Gremillion, K.J., Lucas, L., Lukens, L., Marshall, F.B., Olsen, K.M., Pires, J.C., Richerson, P.J., de Casas, R.R., Sanjur, O.I., Thomas, M.G., Fuller, D.Q., 2019. Current perspectives and the future of domestication studies. PNAS 111 (17), 6139–6146. https://doi.org/10.1073/pnas.1323964111.

Leonardi, G., 2004. Note sul popolamento del territorio bellunese tra Neolitico ed Età del Bronzo, in: Leonardi, G. (Ed.), Il popolamento delle Alpi nord-orientali tra Neolitico ed Età del Bronzo. Fondazione Angelini, Belluno, pp. 71–101.

Lešić, S., Ivanišević, Z., Špiljak, B., Tomas, M., Šoštarić, M., Včev, A., 2024. The impact of vitamin deficiencies on oral manifestations in children. Dent. J. 12 (4), 109. https://doi.org/10.3390/dj12040109.

Leung, T., Stuart, O., Suen, S., Sahota, D., Lau, T., Lao, T., 2011. Comparison of perinatal outcomes of shoulder dystocia alleviated by different type and sequence of manoeuvres: a retrospective review. BJOG 118, 985–990. https://doi.org/10.1111/j.1471-0528.2011.02968.x.

Lewis, M.E., 2007. The Bioarchaeology of Children: Perspectives From Biological and Forensic Anthropology. Cambridge University Press, Cambridge.

Lieverse, A.R., Bazaliiskii, V.I., Weber, A.W., 2015. Death by twins: a remarkable case of dystocic childbirth in Early Neolithic Siberia. Antiq 89 (343), 23–38. https://doi.org/10.15184/aqy.2014.37.

Linder, N., Linder, I., Fridman, E., Kouadio, F., Lubin, D., Merlob, P., Yogev, Y., Melamed, N., 2013. Birth trauma – risk factors and short-term neonatal outcome. J. Matern. Fetal Neonatal Med. 26 (15), 1491–1495. https://doi.org/10.3109/14767058.2013.789850.

Lovell, N.C., 1997. Trauma analysis in paleopathology. Am. J. Phys. Anthropol. 104, 139–170. https://doi.org/10.1002/(SICI)1096-8644(1997)25+<139::AID-AJPA6>3.0.CO;2-#.

MacArthur, B., Foley, M., Gray, K., Sisley, A., 2019. Trauma in pregnancy: a Comprehensive approach to the mother and fetus. Am. J. Obstet. Gynecol. 220 (5), 465–468. https://doi.org/10.1016/j.ajog.2019.01.209.

Malgosa, A., Alesan, A., Safont, S., Ballbé, M., Ayala, M.M., 2004. A dystocic childbirth in the Spanish bronze age. Int. J. Osteoarchaeol. 14, 98–103. https://doi.org/10.1002/oa.714.

Mays, S., Brickley, M., Ives, R., 2006. Skeletal manifestations of rickets in infants and young children in a historic population from England. Am. J. Phys. Anthropol. 129, 362–374. https://doi.org/10.1002/ajpa.20292.

Mays, S., 2008. A likely case of scurvy from early Bronze Age Britain. Int. J. Osteoarchaeol. 18, 178–187. https://doi.org/10.1002/oa.930.

Mays, S., 2017. The study of growth in skeletal populations. In: Crawford, S., Hadley, D. M., Shepherd, G. (Eds.), The Oxford Handbook of the Archaeology of Childhood. Oxford University Press, Oxford, pp. 71–89.

Mays, S., Brickley, M., 2018. Vitamin D deficiency in bioarchaeology and beyond: the study of rickets and osteomalacia in the past. Int. J. Paleopathol. 23, 1–5. https://doi.org/10.1016/j.ijpp.2018.05.004.

McDonald, T.C., Higdon, C.L., Cutchen, W.A., 2024. Neonatal birth fractures. J. Pediatr. Orthopaedic Soc. North Am. 9, 100131. https://doi.org/10.1016/j.jposna.2024.100131.

Melvin, J.W., 1993. Fracture mechanics of bone. J. Biomech. Eng. 115 (4B), 549–554. https://doi.org/10.1115/1.2895538.

Misra, M., Pacaud, D., Petryk, A., Collett-Solberg, P.F., Kappy, M., 2008. Drug and Therapeutics Committee of the Lawson Wilkins Pediatric Endocrine Society. Vitamin D deficiency in children and its management: review of current knowledge and recommendations. Pediat 122 (2), 398–417. https://doi.org/10.1542/peds.2007-1894.

Miyasaka, Y., Sakurai, M., Yokobori, A.T., Kuroda, S., Ohyama, M., 1991. Bending and torsion fractures in long bones (a mechanical and radiologic assessment of clinical cases). Bio-Med. Mater. Eng. 1 (1), 3–10. https://doi.org/10.3233/bme-1991-1102.

Moore, K.L., Koon, H.E.C., 2017. Basilar portion porosity: a pathological lesion possibly associated with infantile scurvy. Int. J. Paleopathol. 18, 92–97. https://doi.org/10.1016/j.ijpp.2017.05.010.

Mottes, E. (Eds), 2014. Vasi a Bocca Quadrata. Evoluzione delle conoscenze nuovi approcci interpretativi. Provincia Autonoma di Trento, Trento.

Mottes, E., Nicolis, F., 2019. Forme della ritualità funeraria tra Età del Rame e antica Età del Bronzo nel territorio della Valle dell'Adige (Trentino Alto Adige, Italia settentrionale). Nota di aggiornamento. In: Martini, F., Salzani, L. (Eds.), Un Lungo Percorso Di Scienza. Scritti in Onore Di Leone Fasani. Studi di Archeologia Preistorica, Florence, pp. 191–219.

Mudiyanselage, S.B., Wanni Arachchige Dona, S., Angeles, M.R., Majmudar, I., Marembo, M., Tan, E.J., Price, A., Watts, J.J., Gold, L., Abimanyi-Ochom, J., 2024. The impact of maternal health on child's health outcomes during the first five years of child's life in countries with health systems similar to Australia: a systematic review. PLoS One 19 (3), e0295295. https://doi.org/10.1371/journal.pone.0295295.

Murphy, E.M., 2021. 'The child that is born of one's fair body' – maternal and infant death in medieval Ireland. Child. Past 14 (1), 13–37. https://doi.org/10.1080/17585716.2021.1904595.

Nielsen-Marsh, C.M., Hedges, R.E.M., 2000. Patterns of diagenesis in bone I: the effects of site environments. J. Archaeol. Sci. 27 (12), 1139–1150. https://doi.org/10.1006/jasc.1999.0537.

Nilsson Stutz, L., 2003. Embodied Rituals and Ritualized Bodies: Tracing Ritual Practices in Late Mesolithic Burials. Almqvist and Wiksell International, Stockholm.

Nyman, J.S., Leng, H., Dong, X.N., Wang, X., 2008. Differences in the mechanical behavior of cortical bone between compression and tension when subjected to progressive loading. J. Mech. Behav. Biom. Mat. 2 (6), 613–619. https://doi.org/10.1016/j.jmbbm.2008.11.008.

Onuoha, K.M., Omotola, O.E., Orimolade, E.A., Sotunsa, J.O., Alade, O.A., Owolabi, I.J., 2020. Neonatal birth injuries: an orthopedic clinic presentation. Am. J. Biomed. Sci Res. 7 (6), 505–509. https://doi.org/10.34297/ajbsr.2020.07.001210.

Ortner, D.J., 2003. Identification of Pathological Conditions in Human Skeletal Remains, second ed. Academic Press, San Diego.

Ortner, D.J., Butler, W., Cafarella, J., Milligan, L., 2001. Evidence of probable scurvy in subadults from archaeological sites in North America. Am. J. Physic. Anthropol. 114 (4), 343–351. https://doi.org/10.1002/ajpa.1046.

Ortner, D.J., Ericksen, M.F., 1997. Bone changes in the human skull probably resulting from scurvy in infancy and childhood. Int. J. Osteoarchaeol. 7, 212–220. https://doi.org/10.1002/(SICI)1099-1212(199705)7:3<212::AID-OA346>3.0.CO;2-5.

Ortner, D.J., Kimmerle, E.H., Diez, M., 1999. Probable evidence of scurvy in subadults from archeological sites in Peru. Am. J. Phys. Anthropol. 108, 321–331. https://doi.org/10.1002/(SICI)1096-8644(199903)108:3<321::AID-AJPA7>3.0.CO;2-7.

Ortner, D.J., Mays, S., 1998. Dry-bone manifestations of rickets in infancy and early childhood. Int. J. Osteoarchaeol. 8, 45–55. https://doi.org/10.1002/(SICI)1099-1212(199801/02)8:1<45::AID-OA405>3.0.CO;2-D.

Owsley, D.W., Bradtmiller, B., 1983. Mortality of pregnant females in Arikara villages: osteological evidence. Am. J. Physic. Anthropol. 61, 331–336. https://doi.org/10.1002/ajpa.1330610307.

Patel, N., Bessler, S., Howard, J., Cohen, R., Doshi, B., 2022. Bifrontal epidural hemorrhage secondary to scurvy in a 10-year-old boy. Clin. Pediatr. 61 (11), 745–748. https://doi.org/10.1177/00099228221103975.

Pechníková, M., Porta, D., Cattaneo, C., 2011. Distinguishing between perimortem and postmortem fractures: are osteons of any help? Int. J. Leg. Med. 125 (4), 591–595. https://doi.org/10.1007/s00414-011-0570-9.

Pedrotti A., Poggiani Keller, R., Banchieri, D. Cristina, L., 2022. Il Neolitico in Lombardia. Rivista di scienze preistoriche LXXII, 129–172.

Pedrotti, A., 2001. Il Neolitico. In: Lanzinger, M., Marzatico, F., Pedrotti, A. (Eds.), Storia Del Trentino, La Preistoria e La Protostoria. Il Mulino, Bologna, pp. 119–181.

Perini, R., 1975. La palafitta di Fiavè – Carera (Nota preliminare sugli scavi del 1972). Preistoria Alpina 11, 25–64.

Perry, M.A., 2005. Redefining childhood through bioarchaeology: Toward an archaeological and biological understanding of children in antiquity. Archaeol. Pap. Am. Anthropol. Ass. 15 (1), 89–111. https://doi.org/10.1525/ap3a.2005.15.89.

Persson, O., Persson, E., 1984. Anthropological report on the Mesolithic graves from Skateholm, southern Sweden. I: excavation seasons 1980–82. Institute of Archaeology, Sweden.

Pessina, A., Tiné, V., 2008. Archeologia del Neolitico: l'Italia tra il VI e IV millennio a.C. Laterza, Rome.

Petiti, E., Moser, D., Jantzen, D., Klimscha, F., Fuchs, K., 2025. Embracing complexity. Porous cranial lesions and their paleopathological significance in two population samples from Neolithic Northern Germany. Int. J. Paleopathol. 49, 104–118. https://doi.org/10.1016/j.ijpp.2025.03.001.

Pitre, M.C., Mant, M., Abel, T., Wood, L.J., 2023. Forgotten and found: a case of childhood rickets in the 19th-century settler village of Heuvelton, New York. Int. J. Paleopathol. 40, 77–86. https://doi.org/10.1016/j.ijpp.2023.01.001.

Politi, S., D'Emidio, L., Cignini, P., Giorlandino, M., Giorlandino, C., 2010. Shoulder dystocia: an Evidence-Based approach. J. Prenat. Med. 2010 4(3), 35–42.

Pounder, D., Prokopec, M., Pretty, G., 1983. A probable case of euthanasia amongst prehistoric Aborigines at Roonka, South Australia. Forensic Sci. Int. 23, 99–108. https://doi.org/10.1016/0379-0738(83)90138-X.

Rahayu, T.P., Suparji, S., Nugroho, H.S.W., Sulikah, S., Setiyani, A., Nuryani, N., Hanifah, A.N., 2024. Impact of maternal health on child development: why early intervention is crucial? (A commentary). PAMJ - One Health 15. https://doi.org/10.11604/pamj-oh.2024.15.19.45308.

Rahul, P., Grover, A.R., Ajoy, S.M., 2017. Bilateral humerus and right femur fracture in a Newborn after Cesarean section for breech presentation in a twin pregnancy: a very rare case report. J. Orthop. Case Rep. 7 (1), 9–11. https://doi.org/10.13107/jocr.2250-0685.664.

Rascón Pérez, J., Cambra-Moo, O.G., Martín, A., 2007. A multidisciplinary approach reveals an extraordinary double inhumation in the osteoarchaeological record. J. Taphon. 5, 91–101.

Rasmussen, K.L., Milner, G., Skytte, L., Lynnerup, N., Thomsen, J.L., Boldsen, J.L., 2019. Mapping diagenesis in archaeological human bones. Herit. Sci. 7 (1). https://doi.org/10.1186/s40494-019-0285-7.

Rehm, A., Promod, P., Ogilvy-Stuart, A., 2020. Neonatal birth fractures: a retrospective tertiary maternity hospital review. BJOG 40 (4), 485–490. https://doi.org/10.1080/01443615.2019.1631770.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edward, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Manning, S.W., Muscheler, S.W., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E. M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Capano, M., Fahrni, S.M., Fogtmann-Schultz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radioc 62, 725–757. https://doi.org/10.1017/RDC.2020.41.

Ribeiro, P., Jordana, X., Scheirs, S., Ortega-Sánchez, M., Rodriguez-Baeza, A., McGlynn, H., Galtés, I., 2020. Distinction between perimortem and postmortem fractures in human cranial bone. Int. J. Leg. Med. 134 (5), 1765–1774. https://doi.org/10.1007/s00414-020-02356-3.

Rittemard, C., Colombo, A., Desbarats, P., Dutailly, B., Dutour, O., Coqueugniot, H., 2019. The periosteum dilemma in bioarcheology: Normal growth or pathological condition? – 3D discriminating microscopic approach. J. Archaeol. Sci. Rep. 24, 236–243. https://doi.org/10.1016/j.jasrep.2018.12.012.

Roberts, C.A., Manchester, K., 2010. The archaeology of disease, third ed. Cornell University Press, New York.

Roncoroni, F., 2013. Le sepolture secondarie e collettive in ripari sotto roccia nel Bresciano. In: de Marinis, R.C. (Ed.), L'età Del Rame: La Pianura Padana e Le Alpi Al Tempo Di Ötzi. La compagnia della stampa Massetti Rodella, Brescia, pp. 405–422.

Rosenberg, K., Trevathan, W., 2002. Birth, obstetrics and human evolution. BJOG 109 (11), 1199–1206. https://doi.org/10.1046/j.1471-0528.2002.00010.x.

Rotschild, B.M., Surmik, D., Bertozzo, F. (Eds.), 2023. Modern Paleopathology, the Study of Diagnostic Approach to Ancient Diseases, Their Pathology and Epidemiology. Springer, Switzerland.

Rubin, A., 2013. Neonatal birth injuries: incidence, mechanisms, and prevention. Obstet. Gynecol. 23, 218–221.

Sahay, M., Sahay, R., 2012. Rickets–vitamin D deficiency and dependency. Indian J. Endocrinol. Metab. 16 (2), 164–176. https://doi.org/10.4103/2230-8210.93732.

Sayer, D., Dickinson, S.D., 2013. Reconsidering obstetric death and female fertility in Anglo-Saxon England. World Archaeol. 45 (2), 285–297. https://doi.org/10.1080/00438243.2013.799044.

Saunier, J., Chapurlat, R., 2018. Stress fracture in athletes. Joint Bone Spine 85 (3), 307–310. https://doi.org/10.1016/j.jbspin.2017.04.013.

Schattmann, A., Bertrand, B., Vatteoni, S., Brickley, M., 2016. Approaches to co-occurrence: scurvy and rickets in infants and young children of 16–18th century Douai. France. Int. J. Paleopathol. 12, 63–75. https://doi.org/10.1016/j.ijpp.2015.12.002.

Scheuer, J.L., Musgrave, J.H., Evans, S.P., 1980. The estimation of late fetal and perinatal age from limb bone length by linear and logarithmic regression. Ann. of Hum. Biol. 7 (3), 257–265. https://doi.org/10.1080/03014468000004301.

Schwetje, D., Zillekens, A., Kieback, J.-D., Koob, S., Placzek, R., 2020. Infantile scurvy: still a relevant differential diagnosis in Western medicine. Nutrit 75–76, 110726. https://doi.org/10.1016/j.nut.2020.110726.

Sherr-Lurie, N., Bialik, G.M., Ganel, A., Schindler, A., Givon, U., 2011. Fractures of the humerus in the neonatal period. IMAJ 13, 363–365.

Singh, V., Hayes, H.V., Kazemi, N., Dey, S., Parikh, S.N., 2021. The Holstein–Lewis humerus shaft fracture in children: are they different from adults? J Ped. Orthopaed. B 31 (3), 274–280. https://doi.org/10.1097/bpb.0000000000000863.

Sjovold, T., Swedborg, I., Diener, I., 1974. A pregnant woman from the Middle Ages with exostosis multiplex. OSSA 1, 3–23.

Skinner, J., Langley, N., Fahrenholtz, S., Shanavas, Y., Waletzki, B., Brown, R., Herrick, J., Shyamsunder, L., Goguen, P., Rajan, S., 2024. Microscopic characteristics of peri- and postmortem fracture surfaces. Forensic Sci. Int. 365, 112223. https://doi.org/10.1016/j.forsciint.2024.112223.

Slaus, M., 2000. Biocultural analysis of sex differences in mortality profiles and stress levels in the late medieval population from Nova Raca, Croatia. Am. J. Phys. Anthropol. 111, 193–209. https://doi.org/10.1002/(SICI)1096-8644(200002)111:2<193::AID-AJPA6>3.0.CO;2-0.

Smith, L.A., Price, N., Simonite, V., Burns, E., 2013. Incidence of and risk factors for perineal trauma: a prospective observational study. BMC Preg, Childb. 13, 59. https://doi.org/10.1186/1471-2393-13-59.

Snoddy, A.M.E., Buckley, H.R., Elliott, G.E., Standen, V.G., Arriaza, B.T., Halcrow, S.E., 2018. Macroscopic features of scurvy in human skeletal remains: a literature synthesis and diagnostic guide Am. J. Phys. Anthropol. 167, 876–895. https://doi.org/10.1002/ajpa.23699.

Sorg, M.H., 2019. Differentiating trauma from taphonomic alterations. Foren. Sci. Int. 302, 109893. https://doi.org/10.1016/j.forsciint.2019.109893.
Sparacello, V., Varalli, A., Rossi, S., Panelli, C., Goude, G., Palstra, S., Conventi, M., Del Lucchese, A., Arobba, D., De Pascale, A., Zavattaro, M., Garibaldi, P., Rossi, G., Molinari, I., Maggi, R., Moggi-Cecchi, J., Starnini, E., Biagi, P., Dori, I., 2019. Dating the funerary use of caves in Liguria (northwestern Italy) from the Neolithic to historic times: results from a large-scale AMS campaign on human skeletal series. Quatern. Int. 536, 30–44. https://doi.org/10.1016/j.quaint.2019.11.034.
Storey, R., 1986. Perinatal mortality at pre-Columbian Teotihuacan. Am. J. Phys. Anthropol. 69 (4), 541–548. https://doi.org/10.1002/ajpa.1330690415.
Surel, F., Bilir, E.E., Elbaşı, D., Şahingöz Bakırcı, E., Canpolat, F.E., Adıgüzel, E., 2025. Incidence and risk factors of clavicle, humerus fractures, and brachial plexus injuries due to birth trauma in the neonatal period. Turk. J. Phys. Med. Rehab. 71 (4), 587–594. https://doi.org/10.5606/tftrd.2025.16232.
Symes, S.A., L'Abbé, E.N., Chapman, E.N., Wolff, I., Dirkmatt, D.C., 2012. Interpreting traumatic injury to bone in medicolegal investigations. In: Dirkmaat, D.C. (Ed.), A Companion to Forensic Anthropology. Wiley-Blackwell, Hoboken, pp. 340–388.
Tecchiati, U., 2013. Luoghi di culto, sepolture e sepolcreti dell'età del Rame dell'area atesina. In: de Marinis, R.C. (Ed.), L'età Del Rame: La Pianura Padana e Le Alpi Al Tempo Di Ötzi. La compagnia della stampa Massetti Rodella, Brescia, pp. 457–480.
Theobald, P.S., Qureshi, A., Jones, M.D., 2012. Biomechanical investigation into the torsional failure of immature long bone. J. Clin. Orthopaed. Trau. 3 (1), 24–27. https://doi.org/10.1016/j.jcot.2012.02.001.
Thomas, F., Teriokhin, A.T., Budilova, E.V., Brown, S.P., Renaud, F., Guegan, J.F., 2004. Human birthweight evolution across contrasting environments. J. Evolut. Biol. 17 (3), 542–553. https://doi.org/10.1111/j.1420-9101.2004.00705.x.
Tommasini, S.M., Nasser, P., Schaffler, M.B., Jepsen, K.J., 2005. Relationship between bone morphology and bone quality in male tibias: implications for stress fracture risk. J. Bone Min. Res. 20 (8), 1372–1380. https://doi.org/10.1359/jbmr.050326.
Updegrove, G.F., Mourad, W., Abboud, J.A., 2017. Humeral shaft fractures. J. Should. Elb. Surg. 27 (4), e87–e97. https://doi.org/10.1016/j.jse.2017.10.028.
VanCourt, R., Byron, S., Ali, S., Caldwell, B., 2000. Fracture mechanics. A comparison study of torsional stress on bone. J Am. Pod. Med. Ass. 90 (4), 167–174. https://doi.org/10.7547/87507315-90-4-167.
Vieth, R., Fraser, D., 2002. Vitamin D insufficiency: no recommended dietary allowance exists for this nutrient. CMAJ 166 (12), 1541–1542.
Von Heideken, J., Thiblin, I., Högberg, U., 2020. The epidemiology of infant shaft fractures of femur or humerus by incidence, birth, accidents, and other causes. BMC Musculoskel. Disord 21 (1), 840. https://doi.org/10.1186/s12891-020-03856-4.
Villa, P., Mahieu, E., 1991. Breakage patterns of human long bones. J. Hum. Evolut. 21 (1), 27–48. https://doi.org/10.1016/0047-2484(91)90034-S.
Vlok, M., Oxenham, M.F., Domett, K., Trinh, H.H., Minh, T.T., Huong, N.T.M., Matsumura, H., Huu, N.T., Nguyen, L.C., Willis, A., Buckley, H., 2023. Scurvy in the tropics: evidence for increasing non-adult micronutrient deficiency with the transition to agriculture in northern Vietnam. Am. J. of Biol. Anthropol. 180 (4), 715–732. https://doi.org/10.1002/ajpa.24698.
Vlok, M., Oxenham, M., McFadden, C., Domett, K., Trinh, H.H., Minh, T.T., Huong, N.T. M., Matsumura, H., Buckley, H., 2024. Hypomineralization disorder in tropical Southeast Asia during the agricultural revolution: Analysis of morbidity and mortality. Int. J. Osteoarchaeol. 34 (2). https://doi.org/10.1002/oa.3288.
Waldron, T., 2012. Palaeopathology. Cambridge University Press, Cambridge.
Warke, C., Malik, S., Chokhandre, M., Saboo, A., 2012. Birth Injuries-a Review of incidence, perinatal risk factors and outcome. Bombay Hosp. J. 54 (2), 202–208.
Wells, C., 1978. A medieval burial of a pregnant woman. Practitioner 221, 442–444.
Weston, D.A., 2009. Brief communication: paleohistopathological analysis of pathology museum specimens: can periosteal reaction microstructure explain lesion etiology? Am. J. Phys. Anthropol. 140, 186–193. https://doi.org/10.1002/ajpa.21081.
Wharton, B., Bishop, N., 2003. Rickets. Lancet 362 (9393), 1389–1400. https://doi.org/10.1016/S0140-6736(03)14636-3.
Wetzel, C., Rohl, M., Manes, T., Kadado, A., 2026. Plastic deformation of the pediatric forearm: recognition, radiographic measurement, and management. J. Ped. Orthopaed. Soc. North Am. 15, 100372. https://doi.org/10.1016/j.jposna.2026.100372.
Willis, A., Oxenham, M.F., 2013. A Case of Maternal and Perinatal Death in Neolithic Southern Vietnam, c. 2100–1050 BCE. Int. J. Osteoarchaeol. 23(6), 676–684. https://doi.org/10.1002/oa.1296.
Woods, R., 1994. La mortalité infantile en Grande-Bretagne: un bilan des connaissances historiques. Ann. Demogr. Hist. 119–134, French.
Yaliwal, R.G., Biradar, A., Sri, V.G.V., 2024. Expecting the unexpected in obstetrics: shoulder dystocia causing humerus fracture in an average-weight fetus. BMJ Case Rep. 17 (12), e261948. https://doi.org/10.1136/bcr-2024-261948.
Yenigül, A.E., Yenigül, N.N., Başer, E., Özelçi, R., 2020. A retrospective analysis of risk factors for clavicle fractures in newborns with shoulder dystocia and brachial plexus injury: a single-center experience. Acta Orthop. Traumatol. Turc. 4 (6), 609–613. https://doi.org/10.5152/j.aott.2020.19180.
Zhou, Y., Zhang, A., Garvie-Lok, S., Gu, W., Xin, Y., 2020. A possible case of dystocia due to foetal macrosomia at Shuanghuaishu site (3500–2900 BCE), Henan, China. Int. J. Osteoarchaeol. 30 (5), 700–711. https://doi.org/10.1002/oa.2904.
Zinn, A., Thomann, A., Lefrais, Y., Dutour, O., Colombo, A., 2025. Archeometric detection of mercury: a paleopharmacological case study of skeletal remains of a child with vitamin deficiencies (Rouen, France, late 18–19th centuries). Int. J. Paleopathol. 49, 29–36. https://doi.org/10.1016/j.ijpp.2025.02.006.