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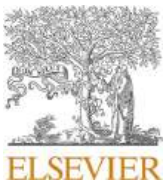

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Vitamin D deficiency, pregnancy, and childbirth in early medieval Milan

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ABSTRACT

This paper explores the burden of osteomalacia on pregnancy and childbirth through two cases from early medieval urban Milan. Two skeletons of female individuals with skeletal deformities and associated with 25–36 gestational weeks fetuses, excavated from the *Ad Martyres* and *San Vittore al Corpo* urban cemeteries and dated to the Early Middle Ages, were examined. Paleopathological and historical analyses were performed in a biocultural approach to investigate the impact of clinical complications and skeletal deformities on their daily life, the course of their pregnancy, and childbirth. The women showed severe skeletal deformities attributable to osteomalacia including scoliosis, reduced rib-neck angle, *coxa vara*, severe bending of the pelvic bones, *protrusio acetabuli*, and narrowed pelvic outlet. The condition and its biomechanical complications impacted the health of both mothers and fetuses, the quality of life of the women (i.e., gait alteration, difficult and limited mobility, compression of internal organs), as well as pregnancy outcomes. It is possible that both the mothers and fetuses died due to childbirth complications. Bioarchaeological cases of osteomalacia, pregnancy, and death during childbirth are excessively rare. This paper also provides insight into how maternal experiences and biocultural environments in early medieval Milan impacted childbirth outcome. The study of the *Ad Martyres* and *San Vittore al Corpo* necropolises is still ongoing and could provide further insight. Isotopic and paleogenomic analyses may shed more light into the factors that led to vitamin D deficiency in these women.

1. Introduction

Vitamin D is a hormone precursor that holds a key role in various functions of the organism including metabolic regulation of calcium and phosphorus, bone mineralization and health, innate immunity, cell growth and differentiation, and neuromuscular and cardiovascular health (Brickley and Ives, 2010; Holick, 2006). Vitamin D is primarily acquired by cutaneous exposure to sunlight, specifically solar ultraviolet B irradiation at 280–315 nm (with peak synthesis at wavelengths between 295 and 297 nm), and dietary sources, although amounts in food are low (Holick, 2006; Jablonski and Chaplin, 2018). In fact, as Jablonski and Chaplin (2018, p. 56) explain "Outside of the tropics, the challenge is getting enough vitamin D throughout the year, when one accounts for the fact that stored serum vitamin D can be exhausted after 2–3 UVB [ultraviolet B]-free months and is insufficient to satisfy physiological needs through the months of the year when active production in the skin is not possible". Its synthesis in the skin from sun exposure earned it the moniker "sunshine vitamin" (Uday and Högler, 2020). The main function of vitamin D is to regulate intestinal absorption of calcium. Thus, vitamin D insufficiency leads to poor intestinal calcium absorption and impaired calcium and phosphorus homeostasis. Low serum calcium levels stimulate the increase of production and release of

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parathyroid hormone which restores calcium levels but triggers secondary hyperparathyroidism which acts on osteoclasts by increasing bone turnover and causing progressive bone loss (Holick, 2006; Uday and Högler, 2020).

There are many factors that may limit vitamin D synthesis. Biological factors include skin pigmentation (as melanin levels in increased skin pigments may reduce by up to 99.9% ultraviolet B-mediated production of vitamin D), use of specific medication (e.g., anticonvulsants, corticosteroids), body fat content, malabsorption disorders that can alter calcium uptake from the intestines (e.g., celiac disease, cystic fibrosis, Crohn's disease), genetic diseases linked to rickets, and advanced age. Physical factors consist in natural variables such as latitude, altitude, cloud cover, and local climatic conditions that can restrict sunlight. Cultural and environmental factors include concealing clothing, sun avoidance in hot climates, high indoor lifestyle, high air pollution limiting penetration of ultraviolet rays, night or low sunlight work shifts, heavy and concealing make-up, vegetarian diets, and diets with a high content of phytates (that bind and sequester calcium) (Bhan et al., 2010; Brickley et al., 2014; Holick, 2006; Snoddy et al., 2016; Uday and Högler, 2019, 2020). Overall, sunlight exposure necessary to maintain vitamin D levels are low and correspond to about 5–10 min, 2 to 3 times a week with limited skin exposure (Brickley et al., 2014). Dietary sources of vitamin D are limited and consist of oily fish (e.g., tuna, salmon, eel, mackerel, sardines, trout), some fishy oils (cod liver oil), mushrooms (including shiitake mushrooms), and egg yolk. Phosphorous-lacking diets may lead to metabolic diseases, but the mineral can be found in all natural foods and as such deficiency is excessively rare. Calcium absorption by the intestines is about 25% of its dietary intake and varies with age and pregnancy. Food sources rich in calcium include oily fish, egg yolk, and milk products (Brickley et al., 2014; Cardwell et al., 2018; Holick, 2006). Regardless of the source, irregular intake of vitamin D can lead to chronic vitamin D insufficiency.

Classically, vitamin D deficiency is referred to as "rickets" in infants, children, and adolescents and "osteomalacia" in the grown skeleton (Mays and Brickley, 2018). While sharing the same etiology, the conditions differ in terms of process: rickets affects endochondral bone growth, and in particular refers to a defective mineralization of the growth plates, whereas osteomalacia interests cell turnover in the maintenance of the bone tissue, corresponding to a defective mineralization of the preformed osteoid (Snoddy et al., 2016; Uday and Högler, 2020). The term "osteomalacia" etymologically derives from two Greek words: ὀστέον (bone) and μαλακός (soft), referring a general softening of the bones.

Written sources suggest that vitamin D deficiency, and in particular rickets, has been known and recognized since Ancient Rome. Indeed, since the 2nd century AD, physicians remarked upon the frequency of young children with bowed and knock-kneed legs in Rome (Mays, 2018; Watts and Valme, 2018). Texts in reference to the condition were also found dating back to 8th century AD in China (Mays, 2018). Clear clinical descriptions of the symptoms of rickets can be found by the English medical community from the mid-17th century with authors including Daniel Whistler, Arnoldus Boot, Francis Glisson, and John Mayow (Mays, 2018; Veselka et al., 2021). The history of osteomalacia appears much less ancient. In fact, no clear mention of osteomalacia or description of its skeletal deformities could be found in the texts attributed to Trota/Trotula de Ruggiero (ca. second half of 11th century) (Green, 2013); Soranus of Ephesus' "*Gynaeciorum liber*" from the 2nd century AD (based on Muscio's translation from Greek to Latin in the 5th century AD, making it more accessible to midwives) (Temkin, 1991); Hildegard of Bingen's (1098–1179) "*Liber causae et curae*" dealing with pregnancy, childbirth and menstruation (Pereira, 1980); Mattioli's work on medicinal plants for therapeutic use (Mattioli, 1555); "*De secretis mulierum*" (13th-14th century AD) attributed to Albertus Magnus (late 12th/early 13th century-1280), but actually written by his disciples (Lemay, 1992); or in Ricci's reference work on the history of gynecology and obstetrics from 2000 BCE to 1800 AD (Ricci, 1950). The book "*Observations sur la grossesse et l'accouchement des femmes et sur leurs maladies, et celles des enfants nouveau-nés*" by delivery surgeon François Mauriceau is a casuistry in which he presented 700 cases from 1668 to 1693 of unnatural childbirth, difficult pregnancies, and post-partum complications. Among these, only one may potentially be related to osteomalacia: case n°190 of February 7, 1677, describes a woman with "*les os du passage si serrées et le croupion recourbé en dedans*" ("the passage bones so tight and the rump curved inwards") (Mauriceau, 1695). However, this description is not unequivocal and may not refer to osteomalacia-related skeletal deformities. Several mentions are made in gynecology works of difficult labor because of the baby's head being too big or the pelvic canal being too narrow, but they are generally blamed on the women being too small, too tall, or even too fat (Green, 2013; Ricci, 1950; Temkin, 1991). We know that osteomalacia has been known since the 17th century, but it was not studied until the second half of the 18th century (Loudon, 1992).

Vitamin D deficiency is clinically associated with a wide range of negative health outcomes. Osteomalacia may manifest with indefinite clinical symptoms such as bone pain, muscle weakness, and fatigue. Because of its importance in enabling proper osteoid mineralization, vitamin D deficiency results in delays in bone mineralization, bowing deformities (i.e., bone bending, kyphosis, *coxa vara*, pigeon breast, *protrusio acetabuli*, triradiate pelvis with narrow pelvic arch), osteopenia and osteoporosis, increased risk of fractures, and pseudofractures (Bhan et al., 2010; Brickley and Ives, 2010; Morgan et al., 2020), leading to clinical complications such difficulties in rising from a seated position, waddling gait, and falls (Uday and Högler, 2020). The onset of skeletal defects associated with vitamin D deficiency is marked by a decrease in the serum levels of 25(OH)D (calcifediol), which persists below the physiological threshold of 25 nmol/L for a prolonged period (Snoddy et al., 2016). In addition, vitamin D deficiency is clinically associated with an increased risk of multiple cancers, autoimmune diseases, opportunistic infections (regarding susceptibility and ability to combat infections), cardiovascular diseases, and type 1 diabetes mellitus, having an overall impact on quality of life and increased risk of mortality (Brickley et al., 2014; Lockau and Atkinson, 2018; Snoddy et al., 2016). While clinical symptoms and pseudofractures may be resolved if treated, bone deformities and cortical thinning are irreversible and accompanied by an increased lifetime fracture risk (Bhan et al., 2018; Uday and Högler, 2019).

Osteomalacia is clinically diagnosed based on large amounts of accumulated osteoid. In bioarchaeological cases, the diagnosis is more challenging as some of its features are not specific to the condition (i.e., skeletal deformations) and pseudofractures, considered virtually pathognomonic, can be elusive (Jennings et al., 2018; van der Merwe et al., 2018). However, histomorphometric techniques have proven to be a reliable tool for the identification of characteristic features of osteomalacia, including areas of incomplete mineralization, defective mineralization adjacent to cement lines, resorptive bays (Howship lacunae), bearded/halo lacunae, and enlarged osteocyte lacunae (Bhan et al., 2018; van der Merwe et al., 2018; Welsh et al., 2020).

Pregnancy constitutes in itself a state of high physiological demand of vitamin D. During pregnancy, the physiological requirements of the fetus are fulfilled in priority, even at the expense of the mother (Ortner, 2003, p. 393). Adaptations to maternal calcium homeostasis are implemented during pregnancy. Indeed, the rate or efficiency of intestinal is doubled early in pregnancy to meet the calcium needs of the fetus (Kovacs, 2008). Additionally, clinical literature on vitamin D metabolism during pregnancy and fetal development suggested that while 1, $25(OH)_2D$ (calcitriol) concentrations in fetuses are inferior to maternal levels (from low parathormone and high phosphorus levels), 25(OH)D (calcifediol) is likely to cross the hemochorial placenta, which may lead to reduced maternal concentrations, especially if the mother suffers from vitamin D deficiency (Kovacs, 2008). As such, vitamin D deficiency in a woman will only be exacerbated during pregnancy. Among the demographic groups most affected by vitamin D deficiency are pregnant

and breastfeeding women, who should receive up to 2000 IU (International Units) of vitamin D daily to maintain the infant's calcifediol levels and sustain their own metabolism (Brickley and Ives, 2010, p. 84). In fact, despite the prevalent usage of supplements in pregnancy, research has shown that they continue to experience vitamin D deficiency even 12 months postpartum (Kramer et al., 2016). Circulating concentrations of $1,25(OH)_2D$ (calcitriol) are multiplied by 2–3 to support placental calcium transfer for fetal bone mineral growth from fourth weeks of gestation; as such, from this stage on, the fetus becomes dependent upon the vitamin D status of the mother. Maternal vitamin D status is a major factor in placental development and fetal programming, which may lead to poor bone health outcomes across the lifespan of the future child (Lockau and Atkinson, 2018). Pregnancy has also been linked with an increase in bone remodeling, due to temporary bone loss related to increased serum calcium concentration required for fetal development. Then, bone loss can be further exacerbated by the eventual onset of secondary hyperparathyroidism (Brickley and Ives, 2010, p. 75).

Few bioarchaeological cases of osteomalacia have been published in the literature (Brickley et al., 2007, 2005, 2018; Brickley and Ives, 2010, pp. 147–150; Ives and Brickley, 2014; Khudaverdyan et al., 2020; Mays and Brickley, 2018; Morgan et al., 2020; Welsh et al., 2020). This may be explained by its challenging diagnosis with subtle and non-pathognomonic lesions (Jennings et al., 2018; van der Merwe et al., 2018; Veselka et al., 2018) and the low bone density that characterizes bones with the metabolic condition which are more likely to be affected by diagenetic changes, resulting in skeletons that are more prone to poor preservation and fragmentation because of substantial bone loss and fragility (Khudaverdyan et al., 2020; Welsh et al., 2020).

In this paper, we explore the interplay between osteomalacia and pregnancy in the past through two cases from urban necropolises of Milan, dated to the Early Middle Ages. The two skeletons belonged to women with pathological signs attributable to osteomalacia who were found associated with 25–36 gestation weeks fetuses. Paleopathological, clinical, and historical analyses were undertaken to investigate the impact of the skeletal deformities on daily life, the influence of vitamin D deficiency on the course of pregnancy and childbirth, as well as the care and assistance available to these women at this time in Milan. The present study is based on a biocultural approach, which brings an important perspective to archaeological studies, bridging the gap between past individuals and their living environment, and breaking down the separation between human biology and social, cultural, and physical factors in understanding past ways of life (Dufour, 2006). Considering these aspects as fundamentally linked provides a more complete picture of past societies, allowing researchers to explore how the social, historical and cultural environment impacted health in the past, and how past individuals and populations interacted and adapted to changes in their environment (Grauer, 2012).

2. Materials and methods

This study is part of an ongoing project on the reconstruction of the life of the Milanese throughout history (Biehler-Gomez et al., 2021, 2022a, 2022b, 2023a, 2023c; Giordano et al., 2023; Mattia et al., 2021). The skeletal remains in the present paper are part of the CAL (*Collezione Antropologica LABANOF* – Anthropological Collection of the LABANOF), currently under study at the Laboratory of Forensic Anthropology and Odontology (LABANOF) and housed at the University of Milan (Cattaneo et al., 2018). The skeletons originate from two urban necropolises of the city of Milan: the *Ad Martyres* cemetery at the Basilica of Saint Ambrose and the necropolis of *San Vittore al Corpo* associated with the eponym basilica.

The *Ad Martyres* necropolis of *Sant'Ambrogio* is located at the entrance to the basilica and extends over 270 m^2. Started in 2018, an emergency excavation, initiated for the construction of the new urban metropolitan line, has brought to light 319 tombs with an occupation period ranging from the Roman era (1st-5th century AD) to the Late Middle Ages (11th-15th century AD). Tomb 230, subject of this paper, was recovered in the stratigraphic units dated to the early medieval phase (6th-10th century AD). The depositions of this phase were commonly deposited in earthen pits, with variable orientations and a chaotic arrangement (Cooperativa Archeologia, 2018a). Based on the available archaeological evidence, and in particular the modesty of the burials and associated grave goods, this necropolis appears to have been populated by individuals of a common low to middle socioeconomic background (Biehler-Gomez et al., 2023b; Cooperativa Archeologia, 2018a).

The emergency excavations of 2018 also uncovered another necropolis underneath the square that faces the Basilica of *San Vittore al Corpo*. Like the *Ad Martyres* necropolis, this area is located in the southwestern suburb of Milan and is part of a major urbanistic complex, where the imperial authority built the Imperial Mausoleum by the end of the 4th century AD. (Baratto and Massara, 2014, p. 41). The archaeological excavations shed light on a specific area of the major complex, used as a necropolis, related to the Basilica of *San Vittore al Corpo*. The stratigraphic evidence showed a multilayered context, dated from the 1st-2nd centuries AD to the 16th century AD. (Cooperativa Archeologia, 2018b). Tomb 31 – focus of the present paper – could be dated to the beginning of the early medieval period. Its stratigraphic unit belongs to a phase of usage of the necropolis dated between the 3rd and 6th century AD, with depositions homogeneously structured as earthen pits and brick-box tombs. According to archaeological data, a considerable number of burials show a lack of associated grave goods, except for a limited number of high-quality funerary objects. In particular, tomb 31 was a brick-box deposition covered with tiles and no associated grave goods. Based on the evidence just mentioned, and the relevance of the context related to the Basilica of *San Vittore al Corpo*, it has been suggested that the individuals deposited belonged to both upper and lower social segments (Cooperativa Archeologia, 2018b).

Anthropological analyses included estimation of biological sex based on morphological aspects of the pelvis (Klales et al., 2012; Phenice, 1969) and post-cranial measurements (Spradley and Jantz, 2011); age-at-death from epiphyseal bone fusion (Scheuer and Black, 2004), dental eruption (AlQahtani et al., 2010) and degenerative changes at the pubic symphysis (Brooks and Suchey, 1990), auricular surface, acetabulum (Rougé-Maillart et al., 2009), and sternal end of the fourth rib (Iscan and Loth, 1986); stature based on the regression formulae elaborated by Trotter (1970); and pathological analysis according to paleopathological standards and manuals (Biehler-Gomez and Cattaneo, 2021; Buikstra, 2019; Ortner, 2003). Description of bone lesions and diagnosis of osteomalacia was based on Brickley's extensive literature on the subject (Brickley et al., 2005, 2007, 2010; Brickley and Ives, 2010; Ives and Brickley, 2014; Mays and Brickley, 2018). Conventional radiographic imaging was performed trou using a Poskom PXM-40BT and an X-DR L WiFi with the following technical parameters: 50 kV and 4 mAs and then acquired using Examion® software. 3D acquisition of the skeletal human remains was performed using the Artec Space Spider scanning device (Artec 3D, Luxembourg), a high-resolution, hand-held 3D scanner based on blue light technology (structured light scanner). The acquired data were processed with its software (Artec Studio Professional 17) to obtain the 3D models of the original bones, allowing for copies of both the shape and the superficial texture of the specimens to be produced and digitally stored. To visualize the original anatomical structure, the 3D models were imported into Blender Software (Blender Foundation), an open-source 3D modeling and animation software. A 2D illustration of the superior view of a healthy female pelvic girdle was produced, imported in Blender software, and superimposed to the pelvic bones of each individual (skeletons of Tomb 230 US 840 of the *Ad Martyres* necropolis and Tomb 31 US 231 of the *San Vittore al Corpo* necropolis) to visualize the extent of the obstruction of the pelvic canal. Transparency of the image was set to 25%, in order to see the underlying 3D model.

3. Results

Bioarchaeological investigations of the *Ad Martyres* necropolis are still underway and have evidenced one individual from the early medieval phase with vitamin D deficiency (frequencies calculated as *n present/n observable* * 100): Tomb 230, subject of the present study (1.6% of the early medieval sample). Similarly, in the *San Vittore al Corpo* necropolis, bioarchaeological analysis is still ongoing and so far, have revealed two early medieval individuals (5.7%) with signs of vitamin D deficiency: one adult male with residual rickets (diagnosed based on the criteria by Brickley and Ives (2010)) and one adult female (Tomb 31, focus of the present paper) (see Fig. 1). To date, no clear case of vitamin D deficiency in juveniles were found.

3.1. Tomb 230 US 840 of the Ad Martyres necropolis

Tomb 230 was found in the ninth excavation level, in stratigraphic units 839, 840 and 841. The woman was buried within an earthen pit oriented according to a NW-SE axis and was in a supine position -.

The study of the individual belonging to tomb 230 revealed a female of about 21–30 years old. The skeleton was unfortunately largely incomplete (less than 25% of the skeleton was preserved), and the bones were very fragmented and fragile. Hence, estimates regarding population affinity and stature could not be performed. *In situ*, within the pelvic girdle, were found the skeletal remains of a fetus of about eight lunar months. The fetal remains were incomplete, very fragile, and fragmented, and did not show any pathological sign through naked eye observation (Fig. 2).

The adult skeleton was immediately striking because of the great deformity of its bones, particularly at the level of the pelvic girdle, lower limbs, ribs, and spinal column. The vertebral column, once assembled, showed signs of scoliosis with its characteristic lateral bending; that is, an alteration of the curves with vertebral bodies slightly rotated on the axial plane. In fact, two such curvatures were found: one on the high thoracic segment with a Cobb's angle of 48°, the other on the thoracic-lumbar segment with a Cobb's angle of 40° (Fig. 3).

In addition to the vertebral column, all bones present showed signs of skeletal deformities. At the level of the thoracic cage, the rib evidenced reduction of the rib-neck angle (Fig. 4). The femora, present only in their proximal half, showed a closure of the femoral neck angle or *coxa vara* (i.e., angle <120°; here, 111° on the right, and 107° on the left) as well as medio-lateral subtrochanteric widening (Fig. 4). The most pronounced deformities can be observed in the pelvic girdle (Figs. 4 and 5): the fourth and fifth lumbar vertebrae descend and protrude into the pelvic canal, the iliac crests are forcibly bent inward, folding over into the body of the ilium, the pubic rami are bent, meet parallelly and project anteriorly with the pubic symphyses projecting forward, the acetabuli are pushed dorsally into the pelvic cavity (*protrusio acetabuli*) and face anteriorly, and the sacrum is bent and projects ventrally; all these deformities lead to a significant narrowing of the pelvic canal, causing it to take on a triangular shape.

Despite the extensive bending of the bones, radiographic imaging shows no clear evidence of antemortem trauma. No pseudofractures were found macroscopically or on radiographs. Consequent to the bone fragility caused by the pathology are the compressions of the thoracic vertebral bodies as well as those of L3-L4 and S1-S2. There is also a partial fusion of the 5th lumbar vertebra to the sacrum.

3.2. Tomb 31 US 231 of the San Vittore al Corpo necropolis

Tomb 31 was uncovered in the second level of the third phase of the *San Vittore al Corpo* necropolis. This multiple burial was structured as a brick-box tomb with a S-N orientation axis and refers to the stratigraphic units 230, 231, 237 and 238.

Based on anthropological analyses, a minimum number of seven individuals was uncovered in Tomb 31, the material was mainly constituted of commingled remains with the exception of two individuals identified by their bones in anatomical connection. Both individuals were buried in supine position: one was a middle-aged male and the other, of interest to the present paper, was a female of about 31–45 years (Fig. 6). Because of the state of incompleteness (50–74% of the skeleton was preserved) and fragmentation of the skeleton, analysis

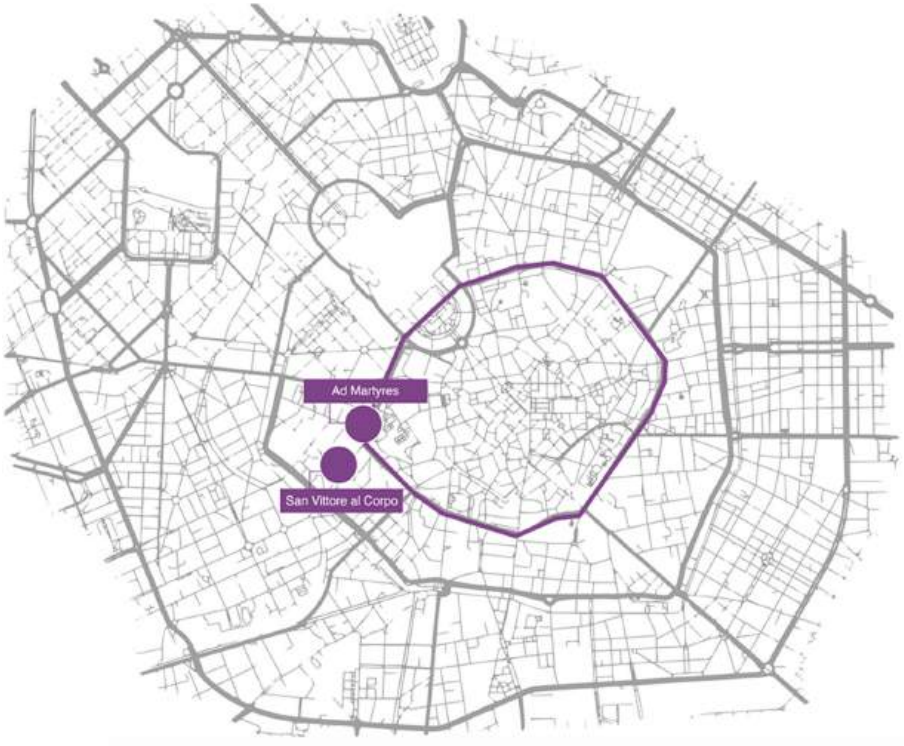

Fig. 1. Map of Milan showing the location of the *Ad Martyres* and *San Vittore al Corpo* necropolises and city walls in the Early Middle Ages.

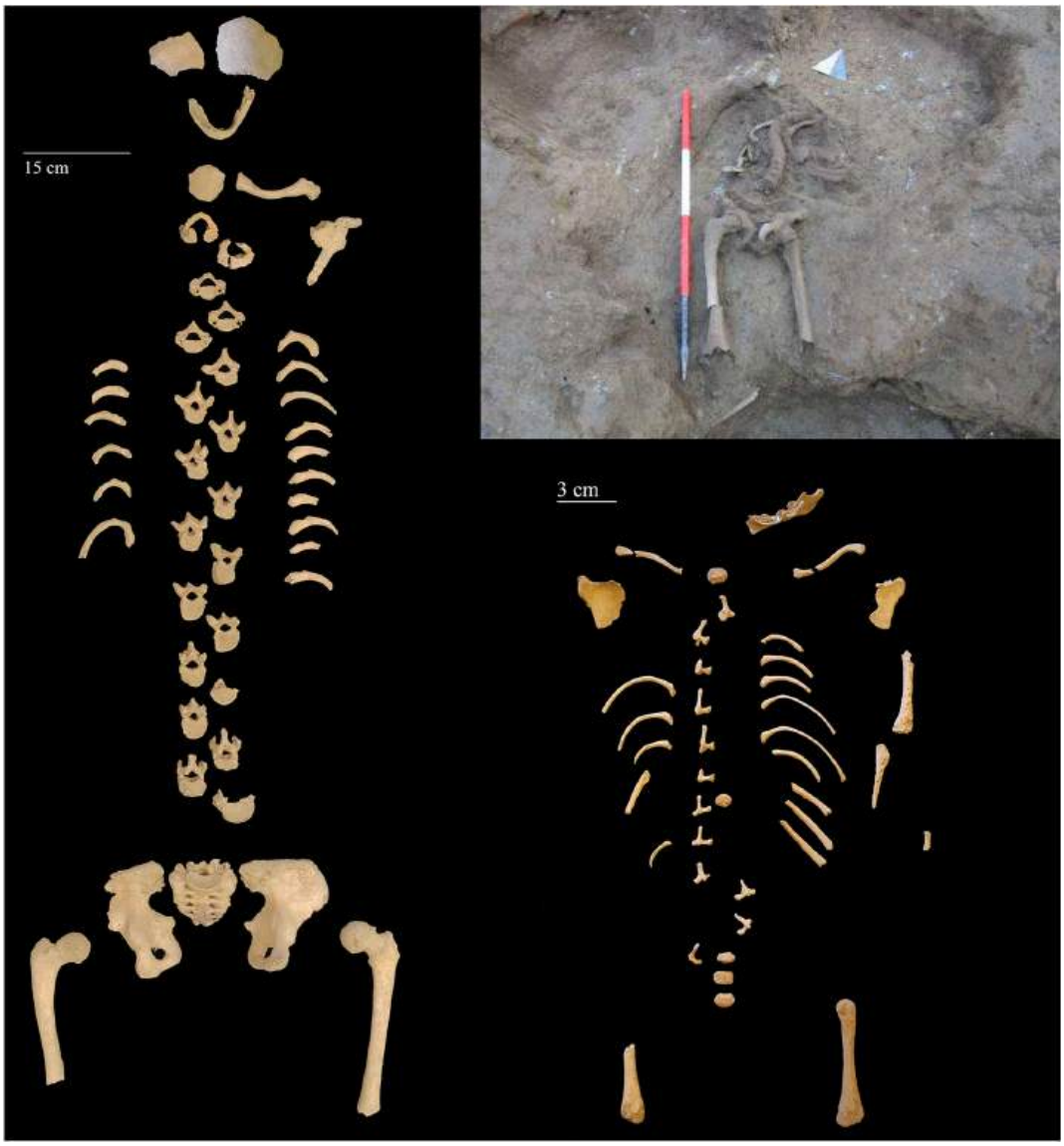

Fig. 2. Skeleton TB 230 US 840. Left: photograph of the skeletal remains of the adult female; top right: photograph of the tomb; bottom right: photograph of the fetal skeletal remains.

of population affinity could not be performed. Yet, stature could be estimated at approximately 152 cm, by measuring both right humeral and tibial maximum lengths. Initially unnoticed by the archaeologists, the skeletal remains of a fetus of about 8 lunar months were recovered within the soil found inside Tomb 31 and associated with the individuals. Consequently, *in situ* position was lost during excavation, and it is no longer possible to trace the exact position of the fetus in the tomb. Given their association in the grave, it is possible that the fetal remains and the adult female skeleton were related. Nonetheless, paleogenomic analyses would be required to confirm kinship. The fetal bones were largely incomplete, fragile, and did not show gross pathological signs.

The adult skeletal remains showed significant deformities, in particular at the level of the pelvic girdle, the upper and lower limbs, and the spinal column. Both humeri show abnormal inferior bending of the head (Fig. 7). Similarly, the coracoid process of the left scapula is bent inferiorly (the contralateral coracoid process was not recovered).

The femora presented a decreased angle of the femoral neck or *coxa vara* (102° on the right and 93° on the left). Femorotibial angle was calculated on the right side by measuring the angle formed by the intersection of the anatomical axes of the femur (from the center of the femoral head to the center of the knee, or the mechanical axis of the femur) and tibia (from the center of the knee to that of the ankle), and showed of degree of deformity of 12°, evidence of *genum valgum* or knock-knee deformity (Fig. 8). The vertebral column was assembled and did not manifest any sign of spinal bending; however, all vertebral bodies of the thoracic segment showed biconcave compressions on the superior and inferior surfaces, more marked inferiorly (Fig. 7). The anterior surface of the vertebral bodies, partially damaged by taphonomic processes, allowed the observation of a coarsening of the vertebral trabeculae and a loss of the horizontal trabeculae (Brickley and Ives, 2010, p. 126). These compressions are associated with acute and chronic pains (Leidig et al., 1990; Razi and Hershman, 2020). The bones of the pelvic girdle showed the most noticeable deformities (Fig. 9). The sacrum was very fragmented and was only represented by the left side of the first sacral vertebra and a fragment of the fourth and fifth sacral crests. Both ilia showed marked anterior bending and folding over of the iliac crest into the body of the ilium, projecting into the pelvic canal. The pubic rami are bent anteriorly, resulting in the pubic bones meeting parallelly instead of opposingly. The symphyseal surfaces project anteriorly and are buckled to maintain contact. The acetabulae are also oriented anteriorly, instead of laterally. Despite the extensive bending of the bones, radiographic imaging shows no clear evidence of antemortem

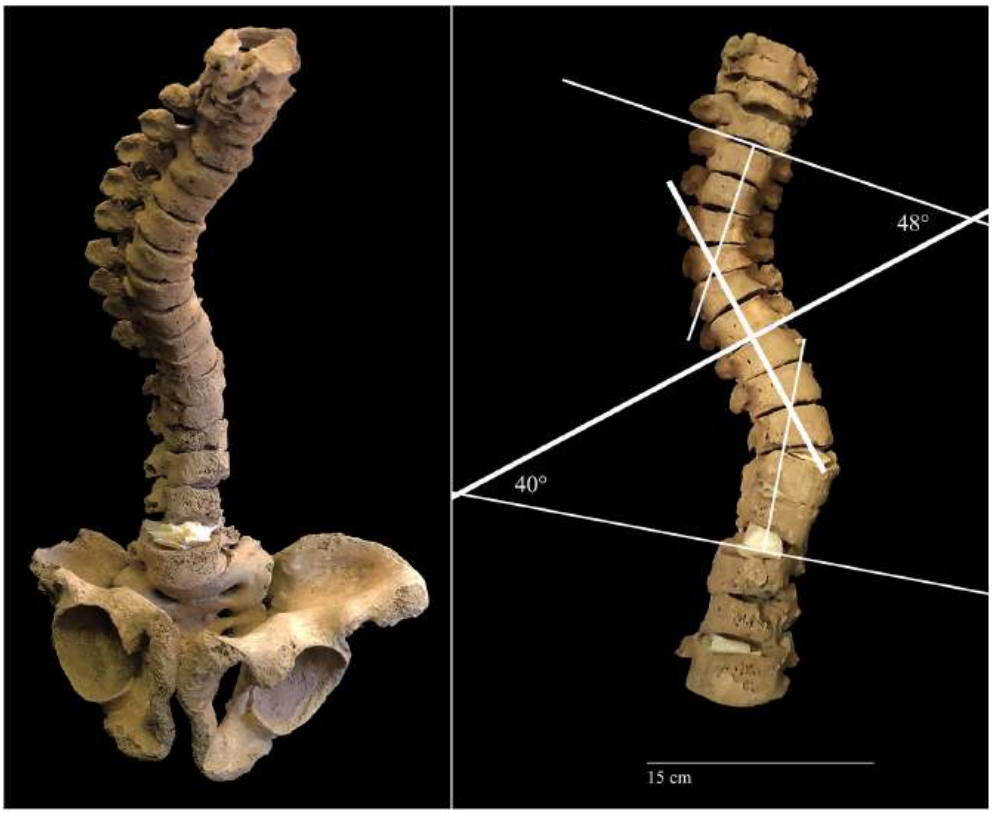

Fig. 3. Vertebral column of the skeleton of TB 230 US 840 of the *Ad Martyres* necropolis.

Fig. 4. Skeletal deformities of skeleton of TB 230 US 840 of the *Ad Martyres* necropolis. Left: radiograph of the femora showing *coxa vara* and subtrochanteric widening (D: *destra* = right; S: *sinistra* = left); top right: superior view of a rib showing reduced rib-neck angle; bottom right: anterior and lateral views of the sacrum.

trauma. No pseudofractures were found macroscopically or on radiographs. The deformities caused a significant narrowing of the pelvic canal which took on a triangular shape.

4. Discussion

a Differential diagnosis

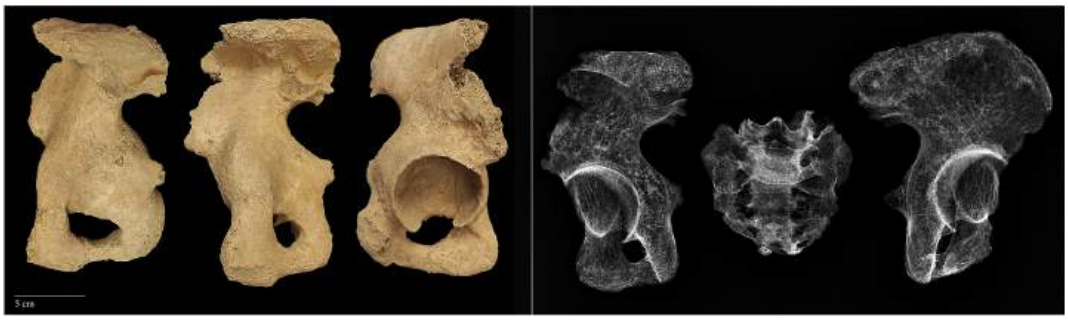

Fig. 5. Pelvic deformities of the skeleton of TB 230 US 840 of the *Ad Martyres* necropolis. Left: medial, anterior, and lateral views of the right innominate bone; right: radiograph of the pelvic bones.

Fig. 6. Skeleton TB 31 US 231. Left: photograph of the skeletal remains of the adult female; top right: photograph of the tomb; bottom right: photograph of the fetal skeletal remains.

Individually, several conditions may be responsible for the lesions observed. Indeed, the extreme ventral angulation of the sacrum of Tomb 230 US 840 could be caused by traumatic lesions or congenital defects, and the biconcave compression on the superior and inferior surfaces of all thoracic vertebral bodies seen in Tomb 31 US 231 may be found in osteoporosis, although usually in a single site (Brickley and Ives, 2010). Vitamin D status is related to bone mineral density, and its deficiency can cause or exacerbate osteoporosis (Lips and Van Schoor, 2011). Both conditions may coexist and further analyses (e.g., bone densitometry techniques) would be required to quantify bone mineral density in these cases. Scoliosis may also result from infections to the spine (e.g., tuberculosis), though no signs of infectious diseases were found on the skeleton and the vertebral column did not present the body cavitations or Pott's disease deformity typically associated with tuberculosis (Ortner, 2003). Blount's disease is a rare growth disorder affecting children that causes bowlegs due to excessive compressive forces on the proximal medial metaphysis of the tibia; yet the condition is a *genu varus* deformity, contrasting with the *genu valgum* angulation of Tomb 31 US 231 (Brickley and Ives, 2010). Anterior folding of iliac crest may be found in Paget's disease, a skeletal growth disorder, but no other lesion suggestive of the disorder (such as thickened bones of the cranial vault, unilateral involvement of the pelvis, wedged or V-shaped areas of

Fig. 7. Skeletal deformities of skeleton of TB 31 US 231 of the *San Vittore al Corpo* necropolis. Left: anterior view of the left proximal humerus and scapula showing inferior bending of the humeral head and coracoid process; right: anterior view of five thoracic vertebrae showing biconcave compressions of the vertebral bodies and coarsening of the vertical trabeculae.

radiolucency, enlargement and thickening of vertebral bodies plates) could be found on either of the skeletons under study (Roches et al., 2002; Whyte, 2006). The deformation of the pubic rami, appearing adjacent instead of opposing, the dislocation of the pubic symphysis, and the obstruction of the pelvic inlet are strongly diagnostic features of osteomalacia (Brickley and Ives, 2010; Ortner, 2003, pp. 399–400). Other diagnostic features found on the skeletons presented here include the biconcave compression of the vertebral bodies of Tomb 31 US 231, the reduced rib-neck angles of Tomb 230 US 840, the narrowing of the pelvis, curving of the ilia, folding of the iliac crest and *protrusio acetabuli* of both pelvic girdles, the *coxa vara* deformities in both women, and the "knock-knees" with *genu varum* angulation of Tomb 31 US 231. The anterior curvature of the sacrum projecting in the pelvic inlet and scoliosis of Tomb 230 US 840 are general but non diagnostic features of osteomalacia (Brickley and Ives, 2010). Nonetheless, recent research has shown a correlation between the angulation of the sacrum and the metabolic condition (Lamer et al., 2023). Specifically, the authors suggest that anterior sacral angulation may be the result of vitamin D deficiency developed during the critical phases of adolescent growth. Overall, the pathological signs observed on the skeleton are typical of osteomalacia (Appleby et al., 2015). However, residual rickets may also be responsible for the aforementioned features observed in the ribs, sacrum, and femoral neck (Brickley and Ives, 2010). The two conditions are not mutually exclusive and the onset of osteomalacia may be explained in a life course perspective by chronic or recurrent vitamin D deficiency since childhood.

Consequently, based on pathological signs observed on the skeletons presented in this paper and in accordance with clinical and paleopathological literature, the two women were suffering from vitamin D deficiency. Additionally, both skeletons showed changes consistent with those described by Brickley et al. (2005) in severe osteomalacic deformities, informing on the severity of the cases presented here. Indeed, severe folding over of the iliac crests into the body of the ilium was seen, reducing the size of the pelvic inlet. Obstruction of the pelvic inlet and reduction of the pelvic canal was worsened by the abnormal anterior angulation of the sacrum and anterior protrusion of L4 and L5 in skeleton TB 230 US 840 (not observable in skeleton TB 31 US 231). The pubic rami were forcibly bent, projecting anteriorly, further deforming and narrowing the pelvic inlet. The pubic symphyses buckled attempting to maintain contact between the symphyseal surfaces, and the acetabulae were oriented anteriorly instead of more laterally.

b. Causes of vitamin D deficiency

As previously mentioned, causes of vitamin D deficiency can be classified into biological, physical, and cultural factors. Given the lack of bones of the cranium and their fragmentation, population affinity could not be performed; we therefore cannot provide information regarding the skin pigmentation of these two women, which could give important information about the uptake of vitamin D. Indeed, melanin-rich skin is less sensitive to the action of ultraviolet rays leading to a lower synthesis of vitamin D (Libon et al., 2013). Advanced age does not appear as a valid factor given their young age-at-death, and the time period precludes any possible use of specific medication such as anticonvulsants and corticosteroids. Genetic diseases and malabsorption disorders remain possible biological contributing factors. On average, people were more covered by clothing in medieval times than they are today. Women in particular were covered because it was not acceptable to display certain parts of the body, such as the *décolleté*, shoulders, legs, and arms, due to religious and cultural reasons (Muzzarelli, 1996, pp. 23–33). However, people, especially from low socioeconomic status, also spent more time outdoors, working in fields, vineyards, and gardens, and travelling by foot, carts, donkeys, and horses. Indeed, written documents describe how the early medieval city was partly occupied by "*horti*" (gardens), vineyards, cultivated lands, "*sedimi*" (plots) consisting of buildings, sometimes in ruins, and "*terra*" (land) (Augenti, 2006; Balzaretti, 2021, p. 8; Brogiolo and Gelichi, 1998; Rao, 2015, pp. 52–57; Violante, 1981, pp. 140–141, 281, 284–285). Documentation about make-up among the poor population in the Early Middle Ages does not exist, and it is reasonable to expect that early medieval Milanese women of low socio-economic did not use make-up, as it was not tolerated by the Church.

The diet of the Milanese varied according to social status. For the lower segments of society, it consisted in a preponderance of low-cost

Fig. 8. Right femorotibial angle of skeleton of TB 31 US 231 of the *San Vittore al Corpo* necropolis.

cereal-based foods (pastries, pies filled with vegetables, eggs, cheese, and meat or fish depending on their availability), such as rye, barley, and millet (1979). Diet also included legumes, such as beans, chickpeas, peas, and broad beans; vegetables, including turnips, squash, zucchini, leeks, onions, and cabbage; and fruits. Gardens and trees were widespread within the city's many undeveloped spaces, where apple, pear, fig, cherry, black cherry, peach, hazelnut, and plum trees grew. Food products of animal origin came from sheep, wild animals, rabbits, and poultry. The drink par excellence was wine, while milk was consumed in the form of cheeses, especially lightly aged. Freshwater fish was consumed, such as crayfish, trout, carp, barbel, tench, and eels, of which the many streams flowing through the city and surrounding countryside at the time were rich. This type of fish was also raised in the many fishing ponds and city wells. Seafood, due to the difficulties of preservation and the consequent costs, was reserved for the upper strata of the population, although it cannot be ruled out that anchovies and sardines were also consumed by the less affluent (1979). Therefore, the main sources of vitamin D in early medieval Milan for this segment of the population were eggs, cheese, and fish (e.g., trout). In contrast to Late Antiquity, the Middle Ages saw an improvement in the diet of all societal levels, including the lower classes, with increased variety and accessibility of food. This is particularly true for the Early Middle Ages, as barbarian invasions brought marked changes in diet, compared to the Roman age. In fact, meat became more present on the tables of all social segments of the population, due to the contribution of a new food culture that arrived with the Goths and Lombard populations. Gradually, bread and wine also came to dominate thanks to the Catholic religion that made them central to the liturgy and thus familiar and widespread (1979).

One hypothesis that may be advanced is the possibility of celiac disease. As grains were an indispensable and preponderant component of diet (especially for the lower strata of the population), it may be hypothesized that the two women suffered from celiac disease, an autoimmune disorder affecting the digestive system and caused by intolerance to gluten. The gastrointestinal disorder is associated with vitamin D deficiency, with about 25% of celiac patients developing osteomalacia (Javorsky et al., 2006). Moreover, celiac disease in pregnant women is associated with poor health outcomes, including miscarriage (nine times more frequent than in non-celiac women), premature births, intrauterine growth restriction, and poor fetal nutritional intake (Butler et al., 2011). Yet, possible pathological signs on bones are not specific to the condition and ancient DNA analyses can only reveal genetic predisposition and not attest that the individual had the disease, which is why bioarchaeological cases are excessively rare (Simpson, 2017).

c Contextualization

In the early medieval phases of the necropolises considered in the present paper, three individuals with signs of vitamin D deficiency were present (3%), including two with osteomalacia (i.e., the two women subject of this paper) (representing 2% of the early medieval phases) and one with residual rickets. These frequencies are lower than in most bioarchaeological studies. Lockau et al. (2019) found 6.4% of their Imperial sample from Isola Sacra with vitamin D deficiency, including 1.4% (of the adult population) with osteomalacia. In adult Greco-Roman mummies, frequencies of 7.4% have been proposed (El-Banna et al., 2014). In their medieval English sample, Ortner and Mays (1998) found 1.2% of children with rickets, but the active condition was not present in our sample. Many post-medieval population studies, especially in the UK and Netherlands, have examined vitamin D deficiencies, reporting values ranging from 12.5% to 26.9%, with higher frequencies in urban settings (Ives, 2018; Veselka et al., 2015, 2018, 2021; Watts and Valme, 2018). The lack of active lesions among the juveniles of the *Ad Martyres* and *San Vittore al Corpo* necropolises suggests that while they may have suffered from vitamin D deficiency during childhood, as evidenced by the presence of residual rickets, they survived with the condition and

Fig. 9. Pelvic deformities of the skeleton of TB 31 US 231 of the *San Vittore al Corpo* necropolis. Lateral views of the right (left image) and left (right image) innominate bones, note the bending of the iliac bones and pubic rami.

enough intake resumed for lesions to heal. The low frequencies observed in our two sites may be the result of the good availability of dietary sources of vitamin D in early medieval Milan, even for individuals from the middle/low socioeconomic strata of society.

d. Impacts on lived experience

By examining the skeletal deformities, we investigated how the condition and its biomechanical complications impacted the lived experience (Agarwal, 2016; Schrader and Torres-Rouff, 2020; Tilley, 2015; Tilley and Schrenk, 2017) of the two women presented in this study, specifically their daily lives and mobility, and in a second step, how it may have affected the course of their pregnancy and childbirth.

As mentioned earlier, vitamin D deficiency is associated with poor health outcomes affecting innate immunity, susceptibility to autoimmune diseases, cancers, and cardiovascular diseases, and all-risk mortality (Brickley et al., 2014; Lockau and Atkinson, 2018; Snoddy et al., 2016). Classical clinical symptoms of osteomalacia described in the literature include pain, fatigue, muscle weakness, increased fracture risk and overall limited mobility (Bhan et al., 2010; Snoddy et al., 2016; Uday and Högler, 2019), of which these women probably suffered. Additionally, both of these women showed biomechanical complications to osteomalacia that directly impacted their quality of life and their mortality risk. One (Tomb 230 US 840) showed two moderate scoliotic curvatures of the spine and reduced rib-neck angle, causing abnormal compression of the internal organs. Indeed, the Cobb's angle measured make this scoliosis fell within the forms considered "moderate" (between 30° and 50°). While the lumbar curve may have favored the onset of chronic low back pain, the curvature at the thoracic level may have caused more debilitating complications. It is documented that a curve with a Cobb's angle of 20° starts to put pressure on the heart and lungs, and contributes to muscle, lung, heart, and general fatigue, thus affecting breathing patterns (Koumbourlis, 2006). The young woman may therefore have experienced fatigue, breathing difficulty and shortness of breath, in addition to low back pain, from her scoliotic curvatures. Tomb 31 US 231 did not present spinal bending but biconcave compressions of the thoracic vertebral bodies resulting from the metabolic disturbance. This type of compression is associated with acute and chronic pain which may interfere with daily activities, including walking, sitting for prolonged periods, and lifting weights (Leidig et al., 1990; Razi and Hershman, 2020). Even to this day, the only solution – besides medication – to lessen the pain exacerbated by these activities appears to be bed rest. A greater number of compression fractures causes an increased reduction of overall stature, which results in a reduced thoracic capacity and subsequent impaired lung function, pressure on internal organs, as well as a feeling of premature satiety and subsequent weight loss (Razi and Hershman, 2020, p. 97). In an effort to counterbalance the loss of height, back muscles may be subjected to continuous strain, and body weight may be abnormally distributed on the pelvis and lower limbs (Alexandru and So, 2012). Moreover, chronic pain has been clinically associated with insomnia, depression, and anxiety, leading to further negative outcomes in their quality of life (Razi and Hershman, 2020, p. 97). Although, we could not reliably evaluate the stature of the woman, Stokes' (2008) formula suggested that the curvatures of Tomb 230 US 840 may have reduced her height by about 20.22 mm. The scoliosis thus minimally affected the woman's height, though it must have impacted body asymmetry, in particular in view of the different femoral neck angles reported. Tomb 31 US 231 also showed right *genu valgum*. Both skeletons also showed *coxa vara*, *protrusio acetabuli*, asymmetry, and severe deformities of the pelvic bones. These likely affected the women's gait, which, especially in the last months of pregnancy with the weight of the baby bump, could have appeared more awkward and unstable. As documented in clinical literature, these skeletal complications likely led to difficulties in rising from a seated position, waddling gait, limited mobility, and falls (Uday and Högler, 2020).

e. Osteomalacia and pregnancy

Osteomalacia has been described as rare in first pregnancies unless the woman suffered from rickets during childhood and persistent vitamin D deficiency during puberty (Konje and Ladipo, 2000). According to clinical literature, the condition can develop after several pregnancies, in particular in rural and low economic areas where lactation is prolonged and the interval between pregnancies is not temporally distant enough to permit a replenishment of calcium stores (Konje and Ladipo, 2000). In the Middle Ages, the number of pregnancies was often very high and could therefore affect women's health, leading to a prolonged and frequent lowering of vitamin D. It is important to remember that at the time, a woman's duty was to get married and beget children, and only then could her social function be considered fulfilled. Entry into the monastery, which was also a plausible option, was limited to women of the aristocracy, hence not for the two women analyzed here. Women of the lower strata of society married at a more advanced age than aristocratic women. In early medieval sources, the ideal age for a first marriage was noted as 20 years (Herlihy,

1994, p. 97), and it is stated that the spouses should be of the same age (Herlihy, 1994, p. 98), usually between the ages of 25 and 30 (Herlihy, 1994, p. 100). From that point on, women had recurrent pregnancies, while breastfeeding their children and/or fulfilling the function of nannies of infants from families of higher social levels (Herlihy, 1994). Little is known about breastfeeding practices during the Early Middle Ages (Muzzarelli, 2013, pp. 9–11), it can be assumed that breastfeeding lasted from 18 to 24 months, with variations based on gender and social status (Muzzarelli, 2013, pp. 14–15). Thus, a woman could – but this does not mean that it always happened – carry out as many as ten to twelve pregnancies during her fertile period (Herlihy, 1994). Consequently, the older woman (Tomb 31 US 231) (though this may also apply to the younger woman – Tomb 230 US 840), may have faced numerous pregnancies. In the Early Middle Ages, an estimated 30%–45% of infants died by the age of five (Rouche, 1987), due to natural infant mortality, accentuated by the family's economic conditions, continuous pregnancies that adversely affected breast milk production, and the incidence of diseases, such as malarial, typhoid, and dysentery fevers (Urso, 2002). While we cannot ascertain the number of pregnancies the women presented in this paper went through and given the extent of the deformity of the pelvis compromising normal childbirth, chronic or recurrent episodes of vitamin D deficiency may have been a significant contributor to the development of osteomalacia in the case of Tomb 31 US 231 if this was a first pregnancy.

f. Impacts on pregnancy and childbirth

The mother-infant nexus concept considers that the mother and child are not two separate entities but interrelated (Gowland, 2015). In fact, the maternal ability to provide her child with substances required for development, such as calcium, vitamin D or iron, via the placenta and through lactation, is crucial since the fetal, perinatal, and infant life stages are intrinsically fragile and related to the mother's well-being (Goodman and Armelagos, 1989). Therefore, under the mother-infant nexus framework, previous and existing maternal life course experiences must have impacted upon the health of the growing fetus (Gowland and Halcrow, 2020). Here, both the vitamin D deficiency – potentially recurrent in the life course of the women and aggravated by the current pregnancies – and the biomechanical complications observed would have been associated with poor pregnancy outcomes impacting not only the health and survival of the child but also that of the mother. Indeed, in clinical literature, osteomalacia in the mother is associated with intra-uterine growth retardation, pre-term birth, and vitamin D deficiency passed from the mother in the form of congenital rickets (Jablonski and Chaplin, 2018; Konje and Ladipo, 2000; Lockau and Atkinson, 2018; Uday and Högler, 2020). Though no pathological signs were visible macroscopically on the fetal bones, the condition would have undeniably been responsible for harmful effects on the health of the fetus. Histological analyses of mineralization defects in teeth (i.e., interglobular dentin) have proven a useful tool for the recognition of the condition and estimation of the age of occurrence of the deficiency (Brickley et al., 2020; D'Ortenzio et al., 2016). Unfortunately, such analyses could not be undertaken in our case as no dentition was preserved among the fetal skeletal remains. Similarly, histological mineralization defects such as wider osteoid seams and increased mineralization lag time could be used to investigate whether osteomalacia was still active at the time of death (Brickley et al., 2007; Monier-Faugere et al., 1998, p. 259). However, this represents destructive analyses leading to the loss of precious material, which is why it was not undertaken at present, but may be considered in future studies. In the pregnant mother, osteomalacia can cause deleterious effects by affecting blood pressure and the ability to carry to term, leading a wide range of significant complications, including pre-eclampsia, maternal gestational diabetes mellitus, pre-term labor, maternal hypertension, difficulties during labor, and even obstructed labor (i.e., related to osteomalacia-related deformities, in particular at the level of the pelvis) which is a major cause of maternal mortality as well as infant morbidity and mortality (Jablonski and Chaplin, 2018; Konje and Ladipo, 2000; Lockau and Atkinson, 2018; Uday and Högler, 2020). Both women of the present study show severe deformities of the pelvic girdle, with bending and even folding of the ilia, pubic rami, and sacrum causing a significant narrowing of the pelvic canal which assumed a triangular shape (Fig. 10). These deformities undeniably caused abnormal pressure on the internal organs and uterus, compromising the health of the fetus and the ability of the woman to carry to term. In fact, the extensive narrowing of the pelvic canal would have rendered vaginal birth virtually impossible (Brickley and Ives, 2010, p. 85), potentially causing the death of both mothers and fetuses during childbirth.

In Milan, one of the fundamental works on osteomalacia was written by Gaetano Casati (1838–1897), entitled "*Sulla Osteomalacia osservata alla Maternità di Milano e sulle alterazioni apportate alla pelvi studiate specialmente sotto il rapporto ostetrico per le indicazioni che presentano in gravidanza ed all'atto del parto*", and published in 1871. The monograph stems from his experience as a physician at the Maternity of Milan, and in particular based on the 62 cases of osteomalacia he examined among the 8062 women admitted to the hospital between 1852 and 1870. The affected women came from peripheral territories; hence, it appears that prevalence of osteomalacia in women living in Milan was marginal. In his book, the author explained that in the 19th century, osteomalacia was considered a fairly rare affection and its definition was used to indicate "a special disease of the bones, that when fully matured became spongy, friable, porous, soft, and altered even in their form" (Casati, 1871, p. 9). Despite numerous contemporary scholars disagreeing about a relationship between rickets and osteomalacia (such as Plangue, Conradi, Monteggia, Fleischmann, Cartoni, Lobstein, Proesk, and Collineau), Casati (like Duverney, Frank, Eckmann, Richerant, Boyer, Trousseau, Lesegue, Beylard, and Giordano) assumed that both conditions had an intimate connection, defining osteomalacia as "adult rickets" (Casati, 1871, p. 9). The author acknowledged the condition affected both men and women, with a prevalence in the latter, and was caused by "a special inflammatory process of the bones" affecting the whole skeleton, but most particularly the pelvis, creating an angular shape, and the spinal column (Casati, 1871, p. 11). Fractures were commonly observed, especially in the typology defined by scholars as *friabilis* or *fracturosa*, while a higher frequency of "deviations, bending and contortions" were noticed in the osteomalacia *cerea* (Casati, 1871, p. 13). The clavicles were considered the site most prone to fractures, followed by the ribs, the lower limbs, and the pubis. Casati also investigated the etiology of the condition, researching the habits of the women affected, their occupation, and dietary customs, noting that a majority lived in poorly ventilated accommodations and were factory workers, especially weavers, required to work in humid conditions to keep the yarn soft. The author suggested that women affected by "puerperal" osteomalacia should treat their "general constitution" by avoiding cold and damp environments, rain and, most of all, repeated pregnancies, and long-term breastfeeding (Casati, 1871, pp. 13–14). Casati emphasized that women with rickets should avoid pregnancies because of the increased mortality risk, but often women were diagnosed with osteomalacia only once pregnant. In this case, miscarriage could halt the course of the disease. When deformities were too severe, compromising delivery and risking the survival of the mother, abortion was induced or pre-term delivery surgery were performed, such as symphysiotomy, although such an intervention commonly led to the death of the mother. In fact, written sources indicate that abortion was recommended when pregnancy and labor lead to maternal danger and mortality since Soranus in the 2nd century AD (Ricci, 1950, p. 118). A significant difference in approach was indicated by Emilio Alfieri (1874–1949) in his summarized lessons collected in the work "*Le viziature pelviche*", published in 1939. As director of the Obstetrics and Gynecology clinic of the University of Milan since 1927, the author discussed the main characteristics of the pelvic alterations he observed during his career (Franchini et al., 2015). Alfieri believed that the

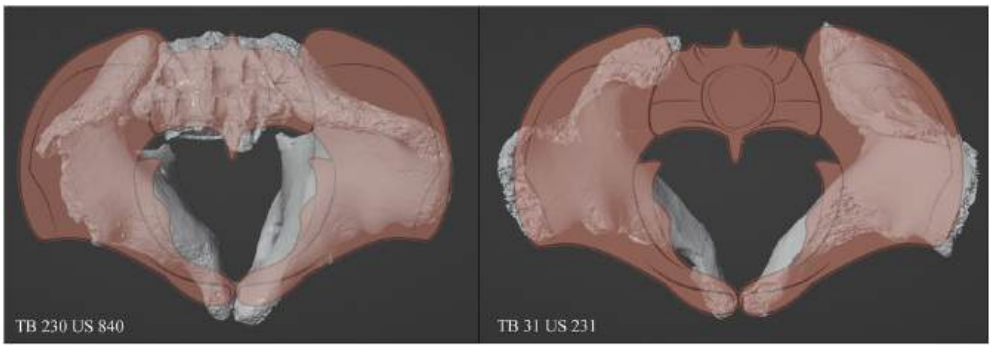

Fig. 10. Superior view of the pelvic girdles of skeletons TB 230 US 840 of the *Ad Martyres* necropolis and TB 31 US 231 of the *San Vittore al Corpo* necropolis, showing the deformation and narrowing of the pelvic canal. 3D models of the original bones (in white) and superimposition with a 2D illustration of a healthy female pelvic girdle in 25% transparency.

condition was not to be attributed to environmental causes nor to infectious conditions, but instead had an endocrine etiology. Like Casati, he observed a worsening of the condition during pregnancy. Whenever skeletal deformities compromised a natural birth, Alfieri argued against abortion or pre-term deliveries, and instead recommended the practice of a cesarean section (Alfieri, 1939, p. 44). Since the first successful procedure by Edoardo Porro in 1876, this intervention became more commonly practiced, as it permitted to save both mother and fetus (Alfieri, 1939, p. 54).

Pregnancy and childbirth represent pivotal moments in a woman's life, bearing significant risks for both the mother and the child carried. Although no quantification is possible, the risk of death was extremely high for both mother and child in pre-industrial times, as medical interventions were limited, and cesarean deliveries were only practiced postmortem (earliest record in the 13th century) (Urso, 2012). Cultural and religious norms dictated that women were solely responsible for the care of expectant mothers as well as the *puerpera*, and for assisting during childbirth (Foscati, 2023). In cases where the mother's life was in jeopardy, the fetus faced similar risks (Urso, 2012). If the child was alive after birth, infancy (in particular the first five years of life) also represented a formidable challenge due to high mortality rates (Duby and Perrot, 1994; Filippini, 2017). Childbirth typically occurred at home, with the assistance of female relatives and a midwife ("*levatrice*"), who possessed expertise in medicinal practices, and/or an obstetrician ("*ostetrica*"), based on knowledge from attending the "*doctae mulieres*". Monasteries were places pregnant women and those in labor could turn to, as Benedictine nuns and monks attended to the sick and needy as part of their duties. Being literate, nuns had access to medical texts (including the few gynecological texts in circulation), enhancing their ability to provide care (Duby and Perrot, 1994; Filippini, 2017). As mentioned earlier, the severe biomechanical abnormalities displayed in the skeletons of these women would have rendered vaginal birth virtually impossible. Given the limited medical interventions of the time, the lack of knowledge regarding osteomalacia-related complications, and the advanced development of both fetuses, it is therefore possible that both the mothers and fetuses presented here died due to childbirth complications.

5. Conclusion

The vertical excavation conducted at the *Ad Martyres* and *San Vittore al Corpo* necropolis, initiated in 2018, brought to light numerous tombs. Among these, two women, central to this study, exhibited pathological signs consistent with osteomalacia.

The individuals were associated with fetuses of about 25–36 weeks of gestation, but presented distinctive burial contexts: the first woman (TB 230 US 840) was interred in a basic earthen pit of the *Ad Martyres* necropolis with the fetal remains still *in situ* in the pelvic girdle; in contrast, the second (TB 31 US 231 – *San Vittore al Corpo* necropolis) was part of a multiple burial within a brick box grave, with the fetal remains found *a posteriori* in the soil of the tomb.

The impact of the vitamin D deficiency and its subsequent biomechanical complications on the health of both women (and their fetuses) was profound. Pregnancy worsened the health challenges faced by these women and considerably increased the physiological demand for vitamin D. The condition is associated with adverse health outcomes for both mother and child, including intra-uterine growth retardation, preterm birth, and complications during labor. In fact, the severe pelvic deformities observed in both women would have obstructed labor and given the advanced stage of development of the fetuses (at/nearing full term), it is likely that the women experienced complications during delivery, which may have ultimately led to their death.

Through a multidisciplinary approach combining paleopathological, clinical, and historical analyses, this paper explored the repercussions of these physical deformities, and the effects of vitamin D deficiency on the pregnancies and daily lives of these women. Ultimately, this investigation not only improves our understanding of the living experience of these two individuals, examining the interplay and intersection between the metabolic condition, maternal health, medical knowledge, and social and cultural processes in the Early Middle Ages in Milan, but also highlights the importance of interdisciplinary research in reconstructing the broader socio-medical context of the past.

CRediT authorship contribution statement

Lucie Biehler-Gomez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Elisa Pera:** Writing – original draft, Investigation, Formal analysis. **Valentina Lucchetti:** Writing – original draft, Investigation, Formal analysis. **Laura Sisto:** Investigation, Formal analysis. **Beatrice del Bo:** Writing – original draft, Investigation. **Mirko Mattia:** Resources. **Lucrezia Rodella:** Software, Investigation. **Giorgio Manzi:** Supervision. **Anna Maria Fedeli:** Resources. **Alessandro Porro:** Resources. **Cristina Cattaneo:** Supervision.

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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References

Agarwal, S.C., 2016. Bone morphologies and histories: life course approaches in bioarchaeology. Am. J. Phys. Anthropol. 159, 130–149.

Alexandru, D., So, W., 2012. Evaluation and management of vertebral compression fractures. Perm. J. 16, 46.

Alfieri, E., 1939. Le Viziature Pelviche. Riassunto Delle Lezioni. Mattioli, Fidenza.

AlQahtani, S.J., Hector, M.P., Liversidge, H.M., 2010. Brief communication: the London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 142, 481–490. https://doi.org/10.1002/ajpa.21258.

Appleby, J., Thomas, R., Buikstra, J., 2015. Increasing confidence in paleopathological diagnosis – application of the Istanbul terminological framework. Int J Paleopathol 8, 19–21. https://doi.org/10.1016/j.ijpp.2014.07.003.

Augenti, A., 2006. Le città italiane tra la tarda Antichità e l'alto Medioevo. All'Insegna del Giglio, Firenze.

Balzaretti, R., 2021. Urban life in lombard Italy: genoa and milan compared in Italy and the East Roman World in the medieval Mediterranean. Cities, Empire and Elites 476–1204.

Baratto, C., Massara, D., 2014. Attività ispettiva sulle aree archeologiche milanesi. Il caso del Mausoleo imperiale. LANX. Rivista della Scuola di Specializzazione in Beni Archeologici-Università degli Studi di Milano, pp. 39–56.

Bhan, A., Qiu, S., Rao, S.D., 2018. Bone histomorphometry in the evaluation of osteomalacia. Bone Rep 8, 125–134. https://doi.org/10.1016/j.bonr.2018.03.005.

Bhan, A., Rao, A.D., Rao, D.S., 2010. Osteomalacia as a result of vitamin D deficiency. Endocrinol Metab Clin North Am 39, 321–331. https://doi.org/10.1016/j.ecl.2010.02.001.

Biehler-Gomez, L., Cattaneo, C., 2021. Interpreting Bone Lesions and Pathology for Forensic Practice. Academic Press.

Biehler-Gomez, L., del Bo, B., Petrosino, D., Morandini, P., Mattia, M., Palazzolo, L., Guerrini, U., Cattaneo, C., 2023a. The diachronic trend of female and male stature in Milan over 2000 years. Sci. Rep. 13, 1343. https://doi.org/10.1038/s41598-023-28406-5.

Biehler-Gomez, L., Lucchetti, V., Mattia, M., Rodella, L., del Bo, B., Cattaneo, C., 2023b. Disability and deformity in early medieval milan: bioarchaeology and pathography of two cases from the Ad Martyres cemetery of the basilica of Saint Ambrose. Medicina nei Secoli - Journal of History of Medicine and Medical Humanities 35, 33–50. https://doi.org/10.13133/2531-7288/2818.

Biehler-Gomez, L., Mattia, M., Mondellini, M., Palazzolo, L., Cattaneo, C., 2022a. Differential skeletal preservation between sexes: a diachronic study in Milan over 2000 years. Archaeol Anthropol Sci 14, 147. https://doi.org/10.1007/s12520-022-01616-0.

Biehler-Gomez, L., Mattia, M., Piccolo, E., Maderna, E., Fedeli, A.M., Messina, C., Slavazzi, F., Cattaneo, C., 2022b. Physical disability in Late Antiquity Milan: slipped capital femoral epiphysis with severe secondary joint disease in the Basilica of San Dionigi. Homo 73, 61–67. https://doi.org/10.1127/homo/2022/1553.

Biehler-Gomez, L., Mattia, M., Sala, C., Giordano, G., Di Candia, D., Messina, C., Sconfienza, L.M., Franchini, A.F., Porro, A., Galimberti, P.M., 2021. Mercury poisoning in two patients with tertiary syphilis from the Ca'Granda hospital (17th-century Milan). Archaeometry 64, 500–510.

Biehler-Gomez, L., Moro, C., Mattia, M., Mazzarelli, D., Cappella, A., del Bo, B., Fedeli, A. M., Cattaneo, C., 2023c. Multiple injuries and injury recidivism in Milan over 2,000 years. J Archaeol Sci Rep 49. https://doi.org/10.1016/j.jasrep.2023.103945.

Brickley, M., Ives, R., 2010. The Bioarchaeology of Metabolic Bone Disease. Elsevier Academic Press, London.

Brickley, M., Mays, S., Ives, R., 2010. Evaluation and interpretation of residual rickets deformities in adults. Int. J. Osteoarchaeol. 20, 54–66. https://doi.org/10.1002/oa.1007.

Brickley, M., Mays, S., Ives, R., 2007. An investigation of skeletal indicators of vitamin D deficiency in adults: effective markers for interpreting past living conditions and pollution levels in 18th and 19th century Birmingham, England. Am. J. Phys. Anthropol. 132, 67–79. https://doi.org/10.1002/ajpa.20491.

Brickley, M., Mays, S., Ives, R., 2005. Skeletal manifestations of vitamin D deficiency osteomalacia in documented historical collections. Int. J. Osteoarchaeol. 15, 389–403. https://doi.org/10.1002/oa.794.

Brickley, M.B., Kahlon, B., D'Ortenzio, L., 2020. Using teeth as tools: investigating the mother–infant dyad and developmental origins of health and disease hypothesis using vitamin D deficiency. Am. J. Phys. Anthropol. 171, 342–353. https://doi.org/10.1002/ajpa.23947.

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., Moffat, T., Watamaniuk, L., 2014. Biocultural perspectives of vitamin D deficiency in the past. J. Anthropol. Archaeol. 36, 48–59. https://doi.org/10.1016/j.jaa.2014.08.002.

Brogiolo, G., Gelichi, S., 1998. La città nell'alto Medioevo italiano: archeologia e storia. Laterza, Roma-Bari.

Brooks, S., Suchey, J.M., 1990. Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Hum. Evol. 5, 227–238. https://doi.org/10.1007/BF02437238.

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

Butler, M., Kenny, L., McCarthy, F., 2011. Celiac disease and pregnancy outcome. Obstetrics Medicine 4, 95–98. https://doi.org/10.1258/om.2011.110007.

Cardwell, G., Bornman, J.F., James, A.P., Black, L.J., 2018. A review of mushrooms as a potential source of dietary vitamin D. Nutrients 10. https://doi.org/10.3390/nu10101498.

Casati, G., 1871. Sulla Osteomalacia osservata alla Maternità di Milano e sulle alterazioni apportate alla pelvi studiate specialmente sotto il rapporto ostetrico per le indicazioni che presentano in gravidanza ed all'atto del parto. Pogliani, Milan.

Cattaneo, C., Mazzarelli, D., Cappella, A., Castoldi, E., Mattia, M., Poppa, P., De Angelis, D., Vitello, A., Biehler-Gomez, L., 2018. A modern documented Italian identified skeletal collection of 2127 skeletons: the CAL Milano Cemetery Skeletal Collection. Forensic Sci. Int. 287, 219-e1.

Cooperativa Archeologia, 2018a. S. Ambrogio Relazione Tecnica Scavo Archeologico. Milan.

Cooperativa Archeologia, 2018b. M4 S. Vittore. Relazione Tecnica Scavo Archaeologico.

D'Ortenzio, L., Ribot, I., Raguin, E., Schattmann, A., Bertrand, B., Kahlon, B., Brickley, M., 2016. The rachitic tooth: a histological examination. J. Archaeol. Sci. 74, 152–163. https://doi.org/10.1016/j.jas.2016.06.006.

Duby, G., Perrot, M., 1994. Storia Delle Donne in Occidente. 2. Il Medioevo.

Dufour, D.L., 2006. Biocultural approaches in human biology. Am. J. Hum. Biol. 18, 1–9. https://doi.org/10.1002/ajhb.20463.

El-Banna, R.A.E.S., Sarry El-Din, A.M., Eid, F.A., Ali, W.Y.M., 2014. The prevalence of vitamin D deficiency in ancient Egyptian population from baharia Oasis ,the Greco Roman period. Egypt J Hosp Med 55, 251–256. https://doi.org/10.12816/0004511.

Filippini, N.M., 2017. Generare, partorire, nascere: una storia dall'antichità alla provetta. Generare, partorire, nascere 1–349.

Foscati, A., 2023. Le meraviglie del parto. Donare la vita tra Medioevo ed Età moderna, Nuova Rivista di Storia della Medicina. Einaudi, Turin.

Franchini, A.F., Galimberti, P., Lorusso, L., Falconi, B., Reggiani, F., Vecchio, L., Porro, A., 2015. Le "Viziature Pelviche" all'Ospedale Maggiore di Milano: Storia e attualità. Med. Nei Secoli: Arte e Scienza 27.

Giordano, G., Mattia, M., Biehler-Gomez, L., Boracchi, M., Tritella, S., Maderna, E., Porro, A., Romanelli, M.M.C., Franchini, A.F., Galimberti, P.M., Slavazzi, F., Sardanelli, F., Candia, D. Di, Cattaneo, C., 2023. Papaver somniferum in seventeenth century (Italy): archaeotoxicological study on brain and bone samples in patients from a hospital in Milan. Sci. Rep. 13, 3390. https://doi.org/10.1038/s41598-023-27953-1.

Goodman, A.H., Armelagos, G.J., 1989. Infant and childhood morbidity and mortality risks in archaeological populations. World Archaeol. 21, 225–243.

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

Gowland, R.L., 2015. Entangled lives: implications of the developmental origins of health and disease hypothesis for bioarchaeology and the life course. Am. J. Phys. Anthropol. 158, 530–540. https://doi.org/10.1002/ajpa.22820.

Grauer, A.L., 2012. A Companion to Paleopathology. John Wiley & Sons.

Green, M.H., 2013. The Trotula: a Medieval Compendium of Women's Medicine. University of Pennsylvania Press.

Herlihy, D., 1994. La Famiglia Nel Medioevo. Laterza, Roma-Bari (No Title).

Holick, M.F., 2006. High prevalence of vitamin D inadequacy and implications for health. Mayo Clin. Proc. 81, 353–373.

Iscan, M.Y., Loth, S.R., 1986. Estimation of age and determination of sex from the sternal rib. Forensic osteology 68–89.

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.

Ives, R., Brickley, M., 2014. New findings in the identification of adult vitamin D deficiency osteomalacia: results from a large-scale study. Int J Paleopathol 7, 45–56. https://doi.org/10.1016/j.ijpp.2014.06.004.

Jablonski, N.G., Chaplin, G., 2018. The roles of vitamin D and cutaneous vitamin D production in human evolution and health. Int J Paleopathol. https://doi.org/10.1016/j.ijpp.2018.01.005.

Javorsky, B.R., Maybee, N., Padia, S.H., Dalkin, A.C., 2006. Vitamin D deficiency in gastrointestinal disease. Pract Gastroenterol 52–72.

Jennings, E., Buckberry, J., Brickley, M.B., 2018. Radiographically recognizable? An investigation into the appearance of osteomalacic pseudofractures. Int J Paleopathol 23, 26–31. https://doi.org/10.1016/j.ijpp.2017.12.003.

Khudaverdyan, A.Yu, Yengibaryan, A.A., Hovhanesyan, A.A., Khachatryan, H.H., Yeganyan, L.G., 2020. A case of osteomalacia in human skeletal remains from St Hripsime Church (Horom, Armenia). Pap. Anthropol. 28 https://doi.org/10.12697/poa.2019.28.2.03.

Klales, A.R., Ousley, S.D., Vollner, J.M., 2012. A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods. Am. J. Phys. Anthropol. 149, 104–114. https://doi.org/10.1002/ajpa.22102.

Konje, J.C., Ladipo, O.A., 2000. Nutrition and obstructed labor. Am. J. Clin. Nutr. 72 https://doi.org/10.1093/ajcn/72.1.291s.

Koumbourlis, A.C., 2006. Scoliosis and the respiratory system. Paediatr. Respir. Rev. 7, 152–160.

Kovacs, C., 2008. Vitamin D in pregnancy and lactation: maternal, fetal, and neonatal outcomes from human and animal studies. Am. J. Clin. Nutr. 88, 520S–528S.

Kramer, C.K., Ye, C., Swaminathan, B., Hanley, A.J., Connelly, P.W., Sermer, M., Zinman, B., Retnakaran, R., 2016. The persistence of maternal Vitamin D deficiency and insufficiency during pregnancy and lactation irrespective of season and supplementation. Clin. Endocrinol. 84, 680–686. https://doi.org/10.1111/cen.12989.

Lamer, M., Veselka, B., Schrader, S., Hoogland, M., Brickley, M.B., 2023. Precarious adolescence: adolescent rickets and anterior sacral angulation in two Dutch skeletal

collections from the 18th–19th centuries. Int J Paleopathol 40, 63–69. https://doi.org/10.1016/j.ijpp.2022.12.006.
Leidig, G., Minne, H.W., Sauer, P., Wüster, C., Wüster, J., Lojen, M., Raue, F., Ziegler, R., 1990. A study of complaints and their relation to vertebral destruction in patients with osteoporosis. Bone Miner. 8, 217–229.
Lemay, H.R., 1992. Women's Secrets: A Translation of Pseudo-albertus Magnus' De Secretis Mulierum with Commentaries. Suny Press.
Libon, F., Cavalier, E., Nikkels, A.F., 2013. Skin color is relevant to vitamin D synthesis. Dermatology 227, 250–254.
Lips, P., Van Schoor, N.M., 2011. The effect of vitamin D on bone and osteoporosis. Best Pract Res Clin Endocrinol Metab. https://doi.org/10.1016/j.beem.2011.05.002.
Lockau, L., Atkinson, S., Mays, S., Prowse, T., George, M., Sperduti, A., Bondioli, L., Wood, C., Ledger, M., Brickley, M.B., 2019. Vitamin D deficiency and the ancient city: skeletal evidence across the life course from the Roman period site of Isola Sacra, Italy. J. Anthropol. Archaeol. 55 https://doi.org/10.1016/j.jaa.2019.101069.
Lockau, L., Atkinson, S.A., 2018. Vitamin D's role in health and disease: how does the present inform our understanding of the past? Int J Paleopathol. https://doi.org/10.1016/j.ijpp.2017.11.005.
Loudon, I., 1992. Death in Childbirth: an International Study of Maternal Care and Maternal Mortality 1800-1950. Oxford University Press.
Mattia, M., Biehler-Gomez, L., Palamenghi, A., Nichetti, D., Caccia, G., Sguazza, E., De Angelis, D., Galimberti, P.M., Fedeli, A.M., Slavazzi, F., 2021. "Man is what he eats". Plant residues from dental calculus in the ancient population of Milano from Roman times to modern age. J Archaeol Sci Rep 39, 103180.
Mattioli, P.A., 1555. I discorsi di M Pietro Andrea Matthioli medico sanese, ne i sei libri della materia medicinale di Pedacio Dioscoride Anazarbeo. Con i ueri ritratti delle piante & de gli animali, nuouamente aggiuntiui dal medesimo. nella bottega d'Erasmo, appresso Vincenzo Valgrisi, et Baldassar Costantini.
Mauriceau, F., 1695. Observations sur la grossesse et l'accouchement des femmes, et sur leurs maladies, et celles des enfants nouveau-nés. Amsterdam.
Mays, S., 2018. The epidemiology of rickets in the 17th–19th centuries: some contributions from documentary sources and their value to palaeopathologists. Int J Paleopathol 23, 88–95. https://doi.org/10.1016/j.ijpp.2017.10.011.
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.
Monier-Faugere, M.-C., Langub, M.C., Malluche, H.H., 1998. Bone biopsies: a modern approach. In: Metabolic Bone Disease and Clinically Related Disorders. Elsevier, pp. 237–280.
Montanari, M., 1979. L'alimentazione Contadina Nell'alto Medioevo (No Title). Napoli.
Morgan, B., Mant, M., de la Cova, C., Brickley, M.B., 2020. Osteoporosis, osteomalacia, and hip fracture: a case study from the Terry collection. Int J Paleopathol 30, 17–21. https://doi.org/10.1016/j.ijpp.2020.03.004.
Muzzarelli, M.G., 2013. Nelle Mani Delle Donne. Nutrire, Guarire, Avvelenare Dal Medioevo a Oggi. Editori Laterza, Rome-Bari.
Muzzarelli, M.G., 1996. Uomini, vesti e regole. Dall'alto medioevo alla prima età moderna. In: Gli Inganni Delle Apparenze. Disciplina Di Vesti e Ornamenti Alla Fine Del Medioevo. Scriptorium, Turin, pp. 23–96.
Ortner, D.J., 2003. Identification of Pathological Conditions in Human Skeletal Remains, second ed. Smithsonian Institution Press, New York.
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.
Pereira, M., 1980. Maternità e sessualità femminile in Ildegarda di Bingen: proposte di lettura. Quad Stor, pp. 564–579.
Phenice, T.W., 1969. A newly developed visual method of sexing the os pubis. Am. J. Phys. Anthropol. 30, 297–301. https://doi.org/10.1002/ajpa.1330300214.
Rao, R., 2015. I Paesaggi dell'Italia Medievale. Carocci.
Razi, A.E., Hershman, S.H., 2020. Vertebral Compression Fractures in Osteoporotic and Pathologic Bone: A Clinical Guide to Diagnosis and Management. Springer.
Ricci, J.V., 1950. The Genealogy of Gynaecology: History of the Development of Gynaecology throughout the Ages 2000B, C.-1800A. D., second ed.,. The Blakiston Company (No Title).
Roches, E., Blondiaux, J., Cotten, A., Chastanet, P., Flipo, R.-M., 2002. Microscopic evidence for Paget's disease in two osteoarchaeological samples from early northern France. Int. J. Osteoarchaeol. 12, 229–234. https://doi.org/10.1002/oa.617.
Rouche, M., 1987. L'Alto medioevo occidentale. In: Ariès, P., Dubby, G. (Eds.), La Vita Privata - Dall'impero Romano All'anno Mille. Bari.
Rougé-Maillart, C., Vielle, B., Jousset, N., Chappard, D., Telmon, N., Cunha, E., 2009. Development of a method to estimate skeletal age at death in adults using the acetabulum and the auricular surface on a Portuguese population. Forensic Sci. Int. 188, 91–95. https://doi.org/10.1016/j.forsciint.2009.03.019.
Scheuer, L., Black, S., 2004. The Juvenile Skeleton. Elsevier.
Schrader, S.A., Torres-Rouff, C., 2020. Embodying bioarchaeology. Theoretical approaches in bioarchaeology 15–27.
Simpson, R., 2017. Gluten-free Rome Celiac disease in the bioarchaeological record. COMPASS 1, 13–24.
Snoddy, A.M.E., Buckley, H.R., Halcrow, S.E., 2016. More than metabolic: considering the broader paleoepidemiological impact of Vitamin D deficiency in bioarchaeology. Am. J. Phys. Anthropol. 160, 183–196. https://doi.org/10.1002/ajpa.22968.
Spradley, K., Jantz, R.L., 2011. Sex estimation in forensic Anthropology: skull versus postcranial elements. J. Forensic Sci. 56, 289–296. https://doi.org/10.1111/j.1556-4029.2010.01635.x.
Stokes, I.A.F., 2008. Stature and growth compensation for spinal curvature. In: Research into Spinal Deformities 6. IOS Press, pp. 48–51.
Temkin, O., 1991. Soranus' Gynecology. John Hopkins Press, Baltimore.
Tilley, L., 2015. Theory and Practice in the Bioarchaeology of Care. Springer.
Tilley, L., Schrenk, A.A., 2017. Introduction: new developments in the bioarchaeology of care. New developments in the bioarchaeology of care: Further case studies and expanded theory 1–10.
Trotter, M., 1970. Estimation of stature from intact long limb bones. In: Stewart, T.D. (Ed.), Personal Identification in Mass Disasters. Smithsonian Institution, National Museum of Natural History, Washington, D.C., pp. 71–83
Uday, S., Högler, W., 2020. Nutritional rickets & osteomalacia: a practical approach to management. Indian J. Med. Res. 152, 356–367. https://doi.org/10.4103/ijmr.IJMR_1961_19.
Uday, S., Högler, W., 2019. Spot the silent sufferers: a call for clinical diagnostic criteria for solar and nutritional osteomalacia. J. Steroid Biochem. Mol. Biol. 188, 141–146. https://doi.org/10.1016/j.jsbmb.2019.01.004.
Urso, C., 2012. «Vetustas»,«anus» e «vetulae» nel Medioevo. Stud Stor 53, 817–854.
Urso, C., 2002. Infanzia negata e infanzia custodita nel Medioevo: la testimonianza di Gregorio di Tours. Annali della facoltà di Scienze della formazione 1, 199–229.
van der Merwe, A.E., Veselka, B., van Veen, H.A., van Rijn, R.R., Colman, K.L., de Boer, H.H., 2018. Four possible cases of osteomalacia: the value of a multidisciplinary diagnostic approach. Int J Paleopathol 23, 15–25. https://doi.org/10.1016/j.ijpp.2018.03.004.
Veselka, B., Brickley, M.B., Waters-Rist, A.L., 2021. A joint medico-historical and paleopathological perspective on vitamin D deficiency prevalence in post-Medieval Netherlands. Int J Paleopathol 32, 41–49. https://doi.org/10.1016/j.ijpp.2020.10.010.
Veselka, B., Hoogland, M.L.P., Waters-Rist, A.L., 2015. Rural rickets: vitamin D deficiency in a post-medieval farming community from The Netherlands. Int. J. Osteoarchaeol. 25, 665–675. https://doi.org/10.1002/oa.2329.
Veselka, B., van der Merwe, A.E., Hoogland, M.L.P., Waters-Rist, A.L., 2018. Gender-related vitamin D deficiency in a Dutch 19th century farming community. Int J Paleopathol 23, 69–75. https://doi.org/10.1016/j.ijpp.2017.11.001.
Violante, C., 1981. La Società Milanese Nell'età Precomunale. Laterza, Roma-Bari (No Title).
Watts, R., Valme, S.R., 2018. Osteological evidence for juvenile vitamin D deficiency in a 19th century suburban population from Surrey, England. Int J Paleopathol 23, 60–68. https://doi.org/10.1016/j.ijpp.2018.01.007.
Welsh, H., Nelson, A.J., van der Merwe, A.E., de Boer, H.H., Brickley, M.B., 2020. An investigation of micro-CT analysis of bone as a new diagnostic method for paleopathological cases of osteomalacia. Int J Paleopathol 31, 23–33. https://doi.org/10.1016/j.ijpp.2020.08.004.
Whyte, M.P., 2006. Paget's disease of bone. N. Engl. J. Med. 355, 593–600. https://doi.org/10.1056/NEJMcp060278.