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Pulmonary pathologies: bioarchaeological insights from the adult individuals of the church of San Colombano, Bobbio

Arianna Vanni[1], *Roberta Fusco*[2], *Nicol Rossetti*[1], *Eleonora Destefanis*[3], *Marta Licata*[2]

[1] Department of Medicine and Surgery, University of Insubria, Varese, Italy
[2] Department of Biotechnology and Life Science, University of Insubria, Varese, Italy
[3] Department of Humanities, University of Eastern Piedmont, Vercelli, Italy

Abstract

Introduction

The Church of San Colombano in Bobbio, Italy, represents one of the most important centers of early medieval monasticism in Europe and offers a valuable context for bioarchaeological research. Among the most significant discoveries is Tomb 1, a deep, multi-use burial chamber containing commingled remains of numerous individuals. The assemblage provides an opportunity to investigate health conditions and lived experiences within a medieval monastic community.

Study aim

This study aims to investigate external rib lesions in adult individuals interred in Tomb 1, with particular attention to pathological alterations potentially related to respiratory disease, trauma, or nonspecific inflammatory processes, while also reconstructing aspects of the individuals' biological profiles.

Materials and Methods

Anthropological analysis was conducted on the osteological remains recovered, comprising a minimum of 11 adults. Standard methods were applied for sex and age-at-death estimation, while rib preservation and fragmentation were assessed following established protocols. Macroscopic paleopathological examination focused on ribs, with detailed photographic documentation used to record surface alterations, new bone formation, and degenerative changes.

Results

Five adult individuals preserved rib fragments suitable for pathological assessment. Observed lesions include periosteal new bone formation, microporosity, striations, widened costal grooves, and degenerative changes at articular facets. Notably, most alterations affect the ventral rib surface, while visceral involvement is limited and focal. Vertebral remains show degenerative changes but no clear evidence of infectious destruction.

Original article

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Conclusions
The predominance of external rib surface lesions, combined with the absence of osteolytic changes, suggests that healed trauma, mechanical stress, or chronic nonspecific periosteal reactions are more likely than classic pleuro-pulmonary infections such as tuberculosis. Although definitive diagnoses are precluded by fragmentation and commingling, the Bobbio assemblage highlights the interpretative complexity of rib pathology and underscores the importance of cautious, contextualized approaches in paleopathological research on medieval populations.

Keywords: bioarchaeology, paleopathology, rib lesions, respiratory disease, Bobbio-San Colombano abbey, medieval population

Introduction

The Church of San Colombano in Bobbio (PC) represents a site of exceptional historical and cultural importance, as well as one of the most significant centers of early medieval monasticism in Europe, also providing a rich context for bioarchaeological and anthropological research. Founded in 613 CE through the joint initiative of the Irish monk Columbanus and the Lombard king Agilulf, the abbey soon emerged as a major religious and cultural hub in medieval Europe (Conversi & Destefanis, 2014). Strategically located in the Piacenza Apennines, the institution was not only a focal point of religious and cultural life but also played a significant role in regional politics and territorial organization during a period of profound transformation (Conversi & Destefanis, 2014; Conversi & Destefanis, 2017).

In 2015, the San Colombano complex was the subject of the first systematic archaeological investigation, carried out under the joint scientific direction of the University of Eastern Piedmont (Department of Humanities) and the Superintendency for Archaeological Heritage of Emilia Romagna. The excavation specifically involved the central section of the church's main nave.

These studies have revealed a complex history of the church and its associated funerary practices. Among the most significant discoveries is Tomb 1 (T1), a brick-built burial chamber originally covered by a lowered-arch vault. Located west of the medieval entrance, T1 is part of a group of five tombs (T1–T5) that have lost their original covers and were later filled with construction debris from the building of the Renaissance church. The western side of T1 is slightly oblique in relation to the orthogonal layout of the structure, while the southern side is reinforced with brick fragments and mortar, forming the outer northern wall of Tomb 2. The coffin-shaped chamber is relatively long and narrow (2,05 × 0,65 m) and very deep, reaching about 1,45 m. Remains of a brick arch vault are preserved along the eastern side; however, the cover was rebuilt with mortar different from the original, probably after repeated openings and resealings over time. The tomb shows clear evidence of alterations, particularly in the upper sections of its perimeter walls. It is possible that the deeper parts of the structure belong to an earlier phase than the surrounding tombs, which were built successively. The base of the tomb lies below the walking surface, cocciopesto, and mosaic floor levels, pointing to a complex stratigraphy. In its final construction phase, based on building techniques and materials, the tomb can be dated to the late Middle Ages.

Beneath the fill layer, a burial deposit was identified containing several individuals in anatomical connection, with at least 11 adults and 10 non-adults recovered (Figure 1) (Conversi & Destefanis, 2017). All were buried with their heads oriented westward.

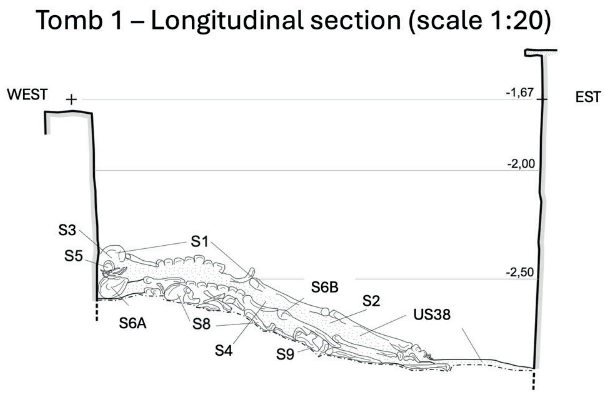

Figure 1. Schematic representation of the deposition of the individuals in Tomb 1 at the time of discovery and recovery (modified from Conversi & Destefanis, 2017)

Although the investigation could not be completed due to safety concerns linked to the considerable depth of the structure, taphonomic analysis suggests that T1 was not an ossuary but rather a multiple-use tomb employed continuously over a defined period of time.

Detailed anthropological analyses of the osteological material focused on reconstructing the biological profiles of the individuals, including sex, age at death and evidence of pathological conditions. The bioarchaeological study of these remains offers a window into the health, living conditions, and broader socio-environmental challenges faced by the medieval population.

This research focuses on the adult individuals interred in Tomb 1 of the Church of San Colombano, with particular attention to suspected respiratory pathologies. By examining skeletal evidence from the ribs, the study aims to reconstruct the health profiles of these individuals, shedding light on the challenges they faced in life.

This focus was chosen because lesions affecting the ribs, often associated with respiratory disease processes, are frequently overlooked or considered secondary in osteoarchaeological analyses. However, these skeletal markers can provide valuable insights into pulmonary conditions and the overall health status of past populations. In this context, the evaluation of rib lesions was considered particularly informative for exploring potential respiratory pathologies among the individuals interred in Tomb 1.

Moreover, the analysis of these pathological indicators also contributes to a broader attempt to understand the cultural and funerary context of this burial assemblage. Given the absence of detailed historical documentation for this specific funerary context, the osteological evidence represents one of the few available sources through which aspects of the individuals' health and the circumstances surrounding their burial may be explored.

Materials and methods

The anthropological study began with an examination of the morphological and morphometric characteristics observable on the skeletons to estimate the biological profile, encompassing the set of biological traits of each individual. Standard anthropological data sheets were compiled for every individual interred to gather the most comprehensive dataset possible for each burial. Alongside standard analytical protocols, district-specific methods were employed for anatomical areas characterized by extensive fragmentation, with the aim of optimizing data collection and interpretive potential.

A visual assessment of skeletal preservation was conducted using the HumanOS platform (https://www.humanos.cnrs.fr) to document the degree of completeness and fragmentation of different anatomical regions. In cases where skeletal districts such as the rib cage or the vertebral column were extremely fragmented, the entire region was classified as "undetermined". This methodological choice was adopted when individual fragments could not be reliably assigned to specific anatomical elements, sides, or vertebral classes. Consequently, these regions were recorded as highly fragmented assemblages rather than as incomplete but serializable anatomical units, as their preservation state did not allow for accurate anatomical attribution or seriation.

Morphological methods applied in this study included the observation of specific sexually dimorphic features (Acsádi & Nemeskéri, 1970; Phenice, 1969). Additionally, the DSP (Diagnose Sexuelle Probabiliste – Probabilistic Sex Diagnosis) method was employed, which is a probabilistic diagnostic tool based on discriminant analysis, comparing metric data from the iliac bone against a reference database of measurements from various global populations (Murail et al., 2005). In cases of partial or minimal skeletal preservation, particularly when both the cranial and pelvic regions were absent, other morphological and metrical techniques were used (e.g. Bass, 1995; Rogers, 1999).

For age-at-death estimation, the sample was divided into age classes based on Buikstra and Ubelaker (1994): Young Adult (21–34 years old), Middle Adult (35–49 years old) and Old Adult (50+ years old). When skeletal preservation did not allow for reliable estimation, individuals were classified as generally adult (Ad).

The estimation of age-at-death for adults relied primarily on the degree of articular degeneration of the auricular surface of the ilium (Buckberry & Chamberlain, 2002; Lovejoy et al., 1985) and the surface of the pubic symphysis (Brooks & Suchey, 1990; Hartnett, 2010a). Changes to the surface and margins of the sternal end of the ribs were also assessed (Hartnett, 2010b; İşcan et al., 1985). Where possible, stature was estimated using the formulas proposed by Trotter and Gleser (1952).

For the description and recording of the ribs, we followed the methodological framework proposed by Davies-Barrett et al. (2018), while retaining the classification system introduced by Roberts et al. (1994) for the description of rib fragments. In addition, the approach outlined by Knüsel and Outram (2004) was applied to tabulate and code the preserved portions of the ribs. The combined use of these three methodologies was adopted in order to achieve a more accurate and comprehensive description of rib preservation. Specifically, the approach proposed by Davies-Barrett et al. (2018) was employed to assess the degree of rib fragmentation. The classification system introduced by Roberts et al. (1994) was used to assign rib fragments to one of the three anatomical categories (upper, middle, lower);

due to the high level of fragmentation observed in the assemblage, this simplified classification was considered the most appropriate and reliable. In addition, the method outlined by Knüsel and Outram (2004) provides a systematic coding system to quantify and tabulate the preserved anatomical portions. Together, these approaches enable a nuanced assessment of both fragmentation patterns and overall preservation state.

Macroscopic paleopathological investigations were conducted through direct visual observation of bone alterations and detailed imaging techniques. High-magnification photographs were captured using a Canon 50D camera equipped with a Canon 100mm macro lens, allowing for precise documentation of skeletal anomalies.

To support the interpretation of the observed lesions, the rib pathological changes were evaluated through comparison with previously published clinical and bioarchaeological studies addressing pathological alterations of the rib surface. In particular, the analysis considered both documented osteological collections and archaeological case studies in which rib lesions have been associated with pulmonary conditions.

Special attention was given to pathological alterations affecting the external surface of the ribs. The observed features were therefore assessed within a differential diagnostic framework, taking into account the morphology, distribution and localization of the lesions as described in the relevant literature.

Results

The archaeological excavation conducted at Tomb 1 of the Church of San Colombano initially led to the recovery of nine skeletons. Anthropological analysis was performed on the exhumed individuals, provided to the authors for study, with the aim of defining their basic biological profiles and identifying major pathologies.

The analysis revealed that the individuals, initially considered nine adults, actually represent 11 adults (Figure 2 and Table 1) and a total of 10 non-adults. Specifically, Subject 7, represented only by the lower limbs and pelvis, was determined to be part of Subject 3, whose upper body was the only portion previously recovered. Consequently, these remains were grouped under Subject 3. Subject 6 was divided into 6a and 6b because two distinct individuals were identified among the skeletal remains recovered by archaeologists. Subject 5 was found to consist of multiple non-adult individuals. Within the bag labeled “filling” by the excavation and recovery team, a minimum of 3 individuals were identified, all female, based on the presence of pubic symphysis. Owing to their high degree of fragmentation and commingling, these individuals were not schematically represented in Figure 2, and their state of preservation did not allow for reliable age estimation.

Due to the fragmentary condition of the remains, it was not possible to seriate the ribs; however, lateralization was achievable in many cases. The data relating to the ribs, together with selected observations on the vertebrae, are presented below. The tables summarize the results of the descriptions coded according to the adopted methods. Fragments classified as indeterminable were affected by such a high degree of taphonomic degradation that reliable siding was not possible and were therefore grouped into broader, non-specific categories.

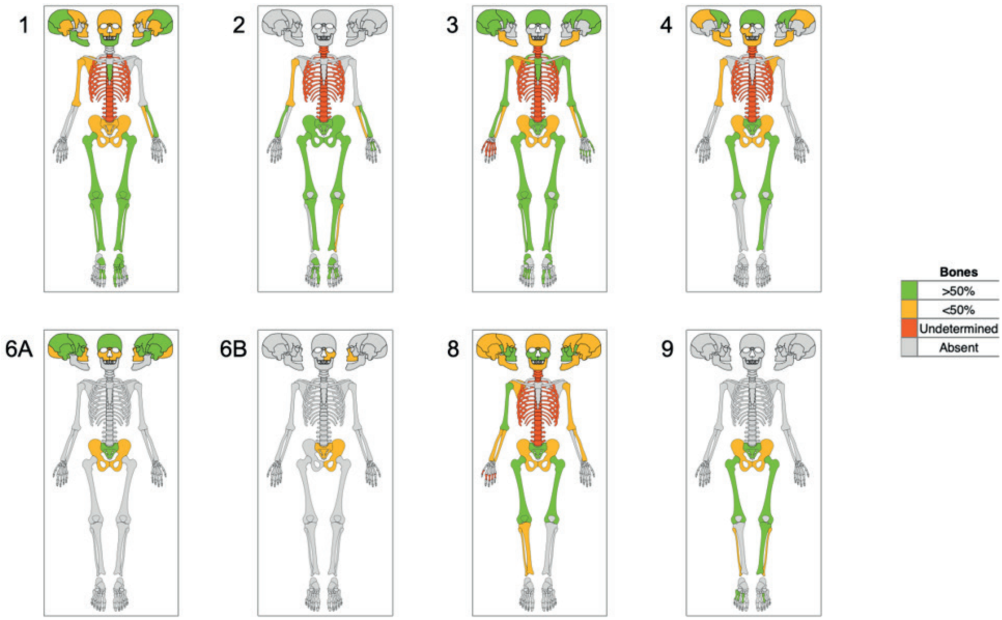

Figure 2. Visual representation of the preservation levels of bone regions

Table 1. Biological profiles of the adult individuals of Tomb 1. *ND: Not Detectable* (due to incompleteness or fragmentation). See the Materials and methods section for details on the methods used for the assessment

Subject n.	Sex	Age class	Age-at-death	Methods used	Height	Pathologies
1	M	OAd	40–50 years	Dental wear, cranial sutures	176,1±3,27 cm	Maxillary abscess, periosteal bone reaction of the external face of the costae
2	M	OAd	45–50 years	Auricular surface of the ilium, dental wear, cranial sutures	171,9±3,27 cm	Osteoarthrosis, vertebral hernias, periosteal bone reaction of the external face of the costae
3	M	MAd	35–40 years	Auricular surface of the ilium, cranial sutures	175±3,27 cm	Periosteal bone reaction of the external face of the costae
4	M	OAd	40–50 years	Dental wear, cranial sutures	ND	? (see results)
6A	F	YAd	25–30 years	Auricular surface of the ilium, pubic symphysis, cranial sutures	ND	
6B	M	MAd	35–40 years	Auricular surface of the ilium, pubic symphysis	ND	

Subject n.	Sex	Age class	Age-at-death	Methods used	Height	Pathologies
8	F	YAd	20–35 years	Dental wear	ND	
9	F	MAd	25–30 years	Auricular surface of the ilium	154,9±3,72 cm	
Filling A	F	ND	ND	Pubic symphysis	ND	
Filling B	F	ND	ND	Pubic symphysis	ND	
Filling C	F	ND	ND	Pubic symphysis	ND	

Subject 1

The ribs exhibit irregularities on the external surface, primarily concentrated near the sternal extremity. These irregularities manifest as bone overgrowth (neoproduction) combined with microporosity (<1mm) (Figure 3A). On three ribs (Figure 3B), anomalies were observed on the visceral surface near the sternal extremity. Two ribs (red and green boxes of Figure 3B) display circular or curved bone projections smaller than 10mm in diameter, while the third rib (yellow box of Figure 3B) presents a linear projection parallel to the margins, approximately 15mm in length. One right floating rib shows bone overgrowth along the margins of the external surface and an oblique groove delineated by raised edges (Figure 3C). Additionally, ribs with preserved vertebral extremities exhibit degeneration of the articular facets with lipping and microporosity (Figure 3D).

A total of eight fragmentary vertebral bodies are preserved, one attributable to an upper lumbar vertebra and the remaining fragments to thoracic vertebrae that could not be seriated (Table 2). In addition, four articular facet fragments pertaining to thoracic vertebrae are present but cannot be assigned to the vertebral bodies listed above.

Table 2. Degree of fragmentation and preservation of the ribs of Subject 1

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
#1	right		Middle	1
#2	right		Lower	2,3
#3	left		Middle	2
#4	left		Middle	3 (with sternal end)
#5	left	3	Lower	3 (with sternal end)
#6	left		Lower	3 (with sternal end)
n.8 fragments	ND		ND	3
n.1 fragment	ND		ND	1
n.3 fragments	ND		Lower	3 (with sternal end)

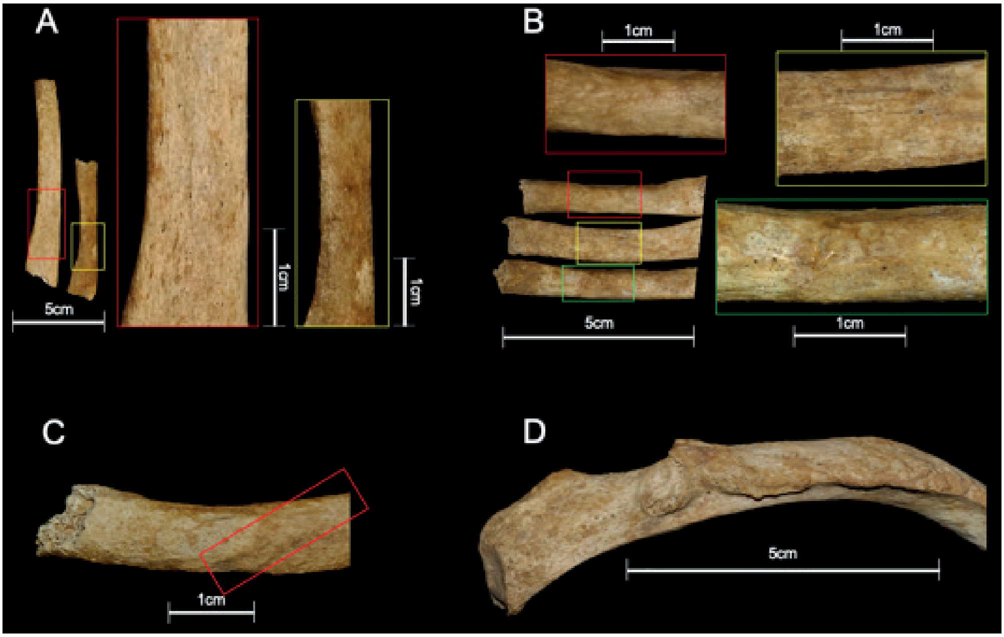

Figure 3. Subject 1, A: from the left, external view of fragments from a left and a right rib, with boxes for magnification of details; B: visceral surfaces of two left ribs (red and green boxes for magnification) and one right rib (yellow box for magnification); C: fragment of a right floating rib (oblique groove bordered with a red box); D: fragment of a left rib head

Subject 2

The ribs exhibit irregularities on the external surface, primarily near the sternal extremity, characterized by diffuse bone overgrowth with microporosity (<1mm) (Figure 4A). Some ribs display unique features, including oblique bands delineated by raised edges (Figure 4B) and bone spurs along the rib margins (Figure 4C). In both cases, the bone overgrowth is associated with microporosity (<1mm), concentrated near the tubercle (Figure 4B) or on the spurs (Figure 4C). One right rib displays a particularly wide costal groove (~15mm), with an undulated superior margin (Figure 4D). Another right rib fragment exhibits perpendicular bone formation along the superior margin of the visceral surface, which is relatively ordered, while the inferior margin shows disorganized deposition with diffuse microporosity (<1mm) (Figure 4E). Ribs with preserved vertebral extremities exhibit lipping and porosity on the articular facets (Figure 4F).

The preserved vertebral elements include lumbar vertebrae, middle and lower thoracic, and two fused cervical fragments (Table 3). The lower thoracic vertebrae exhibit degenerative changes of the vertebral bodies, characterized by the presence of osteophytic lipping. Two of these vertebrae are fused on the right side, while the immediately superior and inferior vertebrae show bony exostoses on the same side that had not yet progressed to complete ankylosis.

Table 3. Degree of fragmentation and preservation of the ribs of Subject 2

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
#1	right	3	Upper	2,3
#2	right		Upper	3
#3	right		Middle	3
#4	right		Middle	1,2
#5	right		Middle	1,2
#6	right		Middle	1,2
#7	right		Middle	3 (with sternal end)
#8	right		Middle	3 (with sternal end)
#9	right		Middle	3 (with sternal end)
#10	right		Middle	1,2
#11	right		Middle	1
#12	right		Middle	1
#13	right		Middle	1
#14	right		Lower	1,2
#15	left		Upper	3 (with sternal end)
#16	left		Upper	2
#17	left		Upper	1,2
#18	left		Upper	1
#19	left		Middle	2
#20	left		Middle	1,2
#21	left		Middle	2,3
#22	left		Middle	1
#23	left		Middle	1
#24	left		Middle	1
#25	left		Middle	1,2
#26	left		Lower	1,2
n.19 fragments	ND		ND	3
n.14 fragments	ND		Upper, middle, lower	3 (with sternal end)

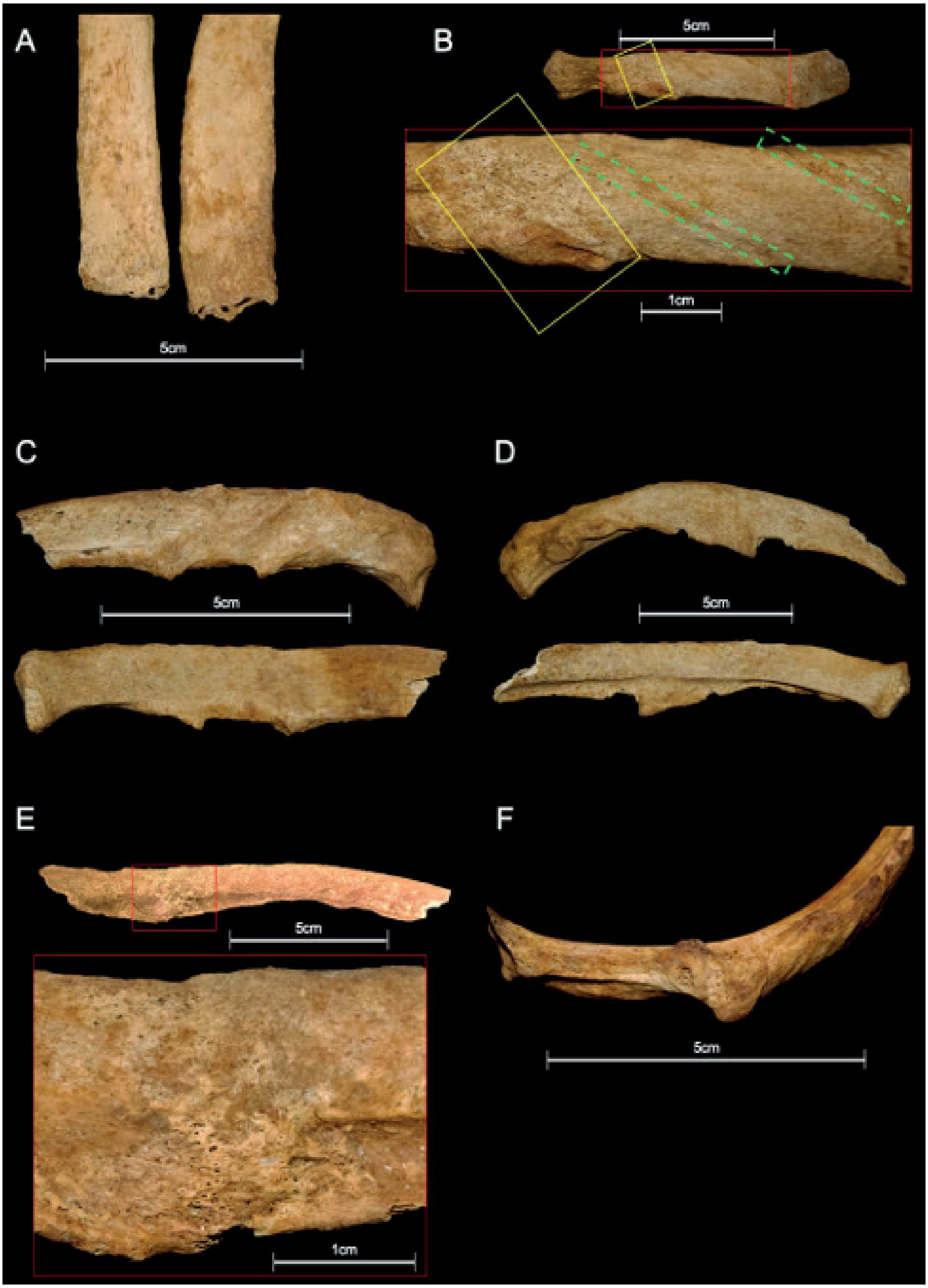

Figure 4. Subject 2, A: fragments of two right ribs' bodies, with sternal end; B: fragment of a right rib with bone overgrowth and microporosity (yellow box) and oblique bands (green dashed rectangles); C: fragment of a left rib; D: fragment of a right rib; E: right rib fragment with bone formation and microporosity (red box for magnification); F: fragment of a left rib head

Subject 3

The ribs exhibit irregularities on the external surface, primarily near the sternal extremity, characterized by diffuse bone overgrowth without microporosity (as in Figure 5A). Ribs with preserved vertebral extremities show lipping and porosity on the articular facets (Figure 5B–C). In Figure 5C, it presents an oblique groove on the external surface with raised margins. One right rib presents an altered margin, with the superior margin featuring a curved protuberance consistent with the surrounding surface (Figure 5D). A single fragment of the vertebral arch from a cervical vertebra is preserved (Table 4).

Table 4. Degree of fragmentation and preservation of the ribs of Subject 3

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
#1	right		Upper	2,3 (with sternal end)
#2	right		Upper	1
#3	right		Middle	1
#4	right		Middle	1
#5	right		Middle	2
#6	right		Middle	3
#7	right		Middle	3
#8	left		Upper	1
#9	left		Upper	1,2
#10	left		Upper	2,3
#11	left	3	Upper	2,3 (with sternal end)
#12	left		Middle	1
#13	left		Middle	1
#14	left		Middle	1
#15	left		Middle	1
#16	left		Middle	1,2
#17	left		Middle	3
#18	left		Middle	3
#19	left		Middle	3 (with sternal end)
n.8 fragments	ND		Middle, lower	3
n.12 fragments	ND		Middle, lower	3 (with sternal end)

Figure 5. Subject 3, A: fragment of a right rib body; B: fragment of a right rib head; C: fragment of a left rib head; D: fragment of a right rib body (red box for magnification)

Subject 4

Only a few rib fragments were attributed to Subject 4, and none of them showed pathological alterations (Table 5). The preserved cervical vertebrae include a fragment of C1, part of the body of C2, one complete cervical vertebra, and an isolated vertebral body and bifid spinous process. The thoracic vertebrae of this individual are represented by four fragmentary vertebral bodies and ten articular facet fragments pertaining to thoracic vertebrae that cannot be assigned to the elements listed above. Three lumbar vertebrae are preserved in a fragmentary condition; among these, only L5 could be identified, preserving part of the left transverse process.

Table 5. Degree of fragmentation and preservation of the ribs of Subject 4

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
#1	left	3	Middle	1,2
n.4 fragments	ND		Middle	3
n.2 fragments	ND		Lower	3
n.1 fragment	ND		Middle	3 (with sternal end)

Unassignable rib fragments from S3 or S4

Two fragments of left rib bodies, which could not be assigned to either subject, display a wide costal groove (~10mm), along with small oblique grooves and cavitations (~1mm) (Table 6, Figure 6).

Table 6. Degree of fragmentation and preservation of ribs not confidently attributable to Subjects 3 and 4

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
#1	right	3	Upper	3 (with sternal end)
#2	right		Upper	2
#3	right		Middle	2
#4	left		Upper	2
#5	left		Upper	2,3
#6	left		Middle	1
#7	left		Middle	2
#8	left		Middle	3
#9	left		Middle	3
#10	left		Middle	3
#11	left		Middle	3
#12	left		Middle	3
#13	left		Lower	3
n.26 fragments	ND		Middle	3

Figure 6. Unassignable fragments of the bodies of the left ribs (either from subject 3 or 4).

Subject 8

Only a limited number of rib fragments were attributed to Subject 8, none of which displayed evidence of pathological alterations (Table 7).

Four fragmentary vertebral bodies are preserved, three attributable to upper thoracic vertebrae that could not be seriated, while the fourth is compatible with the seventh cervical vertebra. The remaining thoracic vertebrae are present but preserved only as vertebral bodies, making reliable seriations difficult (T2–T8 and T10–T12). The lumbar vertebrae are also present but, as with the thoracic elements, are represented solely by vertebral bodies. In addition, five articular facet fragments pertaining to thoracic vertebrae are preserved but cannot be assigned to the elements listed above.

Table 7. Degree of fragmentation and preservation of the ribs of Subject 8

Rib fragments	Siding	Davies-Barrett et al. (2018) – fragmentation score	Roberts et al. (1994) – most likely position	Knüsel and Outram (2004) – Zonation method
n.27 fragments	ND	3	Middle (?)	3
n.6 fragments	ND		Middle	3 (with sternal end)

Discussion with conclusions

Of the five individuals presenting rib fragments, it was possible to assign some elements to the corresponding side in four cases; however, in all individuals, several rib fragments were too small and fragmented to allow reliable lateralization. Three of the five individuals exhibit morphological alterations of the ribs, including porosity, striations, new bone formation, widening of vascular grooves, and, in some cases, bone production and porosity around the articular facets of the rib head.

The rib lesions observed in the medieval assemblage from Bobbio present several interpretative challenges. First, due to the fragmented and commingled nature of the skeletal assemblage, it is not possible to attribute the pathological findings with certainty to a single individual. However, the analysis followed the subdivision established during the excavation and was supported by comparison with the in situ documentation recorded at the time of recovery. Second, the inability to reassemble or serially align the ribs prevents any reliable determination of whether the affected elements derive from the upper, middle, or lower thoracic cage (excluding the floating ribs), although an attempt was made to assign lateralized fragments to one of these three categories. This limitation significantly hampers the reconstruction of potential clinical implications, as the location within the rib cage may influence the interpretation of the lesions. Third, the pathological evidence is not confined to a single anatomical region of the ribs: alterations are distributed from the posterior portion, close to the rib head, to the anterior segment near the sternal end.

Another noteworthy aspect is the surface distribution of the lesions. The majority of pathological changes affect the external (abdominal) surface of the ribs. In the paleopathological literature, rib lesions are more frequently described on the internal (visceral) surface, where they are commonly associated with chronic pulmonary and pleural infections, especially tuberculosis (e.g. Assis & Keenleyside, 2019; Mays et al., 2002; Nicklisch et al., 2012; Roberts et al., 1998). In such cases, new bone formation and porosity typically appear as reactive responses to pleuritis (Baumer, 2008; Davies-Barrett et al., 2018). The findings from Bobbio, however, differ in that the alterations predominantly occur on the external surface.

Exceptions to this pattern are: the widening of the costal groove, appreciable especially from the visceral surface (Figures 4D and 6), that may suggest a remodeling process potentially linked to vascular stress (Mays et al., 2002); and three ribs attributed to Individual 1 that show parallel thickenings aligned with the long axis of the rib on the visceral surface, near the sternal end (Figure 3B). These lesions differ morphologically from the external surface alterations and may indicate a localized irritative process, distinct from the other pathological changes.

Periosteal reactions represent a response of the periosteum to external stimuli, which can vary according to the intensity, duration and pace of the underlying pathological process (Assis & Keenleyside, 2019). Slowly progressing diseases tend to produce solid, compact and well-organized lesions, while chronic processes of moderate intensity may result in compact but less aggressive new bone formations (Assis & Keenleyside, 2019).

The thoracic region, due to its protective role for the heart and lungs and its close proximity to the lungs, can reflect signs of chronic respiratory disease (Baumer, 2008). However, post-mortem fragmentation of ribs often limits the observation of certain areas and affects comparability between individuals and studies (Davies-Barrett et al., 2018).

Although rib lesions are most commonly associated with pulmonary infections such as tuberculosis, other respiratory or systemic conditions can produce similar periosteal responses. Bacterial or viral pneumonia, chronic bronchitis, trauma, and neoplastic conditions may generate overlapping skeletal changes, complicating the attribution of lesions to a single disease (Assis & Keenleyside, 2019; Lambert, 2002; Molto, 1990).

In summary, the presence of periosteal reactions on archaeological ribs is a non-specific indicator of lower respiratory tract disease, useful for inferring the burden of pulmonary pathology in past populations but insufficient for a definitive diagnosis of a specific condition.

A possible differential diagnosis for the Bobbio sample is presented below.

Chronic periosteal reaction and its relevance to ribs. Because ribs lie adjacent to lungs and pleura, they frequently register thoracic insults; however, rib preservation is uneven and post-mortem fragmentation can bias which surfaces/segments are observable (Davies-Barrett et al., 2018). Despite this, periosteal change on ribs remains an underused but informative stress index in past populations (Lambert, 2002). In the Bobbio ribs, most alterations occur on the external/ventral surface rather than the visceral surface. Where the newly formed bone is compact and remodeled, a chronic periosteal process is plausible (e.g., a latent infection persisting over time). Yet, because external-surface rib reactions are not specific and can be triggered by mechanical irritation (e.g., minor trauma and muscle-related strain), this category overlaps with the traumatic spectrum (Assis & Keenleyside, 2019; Davies-Barrett et al., 2018). This provides a chronic, non-specific explanation especially for smooth, lamellar, "mature" new bone.

Pulmonary tuberculosis (TB). Studies of documented collections consistently report a strong association between periosteal new bone on the visceral rib surface and TB, often interpreted as reaction to pleural inflammation; occasional shallow, circumscribed lytic foci are also described (Assis & Keenleyside, 2019; Mays et al., 2002; Nicklisch et al., 2012; Roberts et al., 1998). TB may involve the ribs through hematogenous spread, direct extension from the lung or pleura, or from spinal foci (Mays et al., 2002). In the latter case, lesions tend to affect the rib head or neck and are often associated with destructive changes, whereas other routes may involve any segment of the rib (Mays et al., 2002). Thoracic rib enlargement has been noted in chronic pleural disease clinically (Matos & Santos, 2006). In addition, spinal involvement is commonly reported in skeletal tuberculosis, typically affecting the vertebral bodies and resulting in destructive lesions, collapse, and angular deformity. In the Bobbio ribs, the predominant external-surface distribution and absence of osteolysis argue against classic pleuro-pulmonary TB presentations on ribs. No serial alignment is possible and ribs are non-attributable to individuals, which limits case-level inference; nevertheless, the pattern observed here does not match the usual visceral-surface bias reported for TB-related rib change (Assis & Keenleyside, 2019; Mays et al., 2002; Nicklisch et al., 2012; Roberts et al., 1998). Moreover, in the Bobbio assemblage, however, the vertebrae examined do not show pathological changes consistent with spinal tuberculosis. The absence of such lesions further weakens the attribution of the observed rib alterations to TB.

Some exceptions to note include: (i) widened costal groove appreciated mainly from the visceral side (Figures 3D and 5) indicates remodeling but is not specific for TB (Mann & Hunt, 2005; Matos & Santos, 2006; Nicklisch et al., 2012); and (ii) three ribs (Individual 1) show parallel thickenings aligned with the long axis on the visceral surface near the sternal end (Figure 3B). These could reflect localized pleural or soft-tissue irritation, but without additional TB markers they remain non-diagnostic. Overall, TB is unlikely given surface distribution and absence of destructive change; cannot be completely excluded but not favored.

Other lower-respiratory infections and pleural disease (pneumonia, bronchopneumonia, chronic bronchitis, actinomycosis; pleurisy/effusion). Multiple respiratory conditions can provoke periosteal reaction on the visceral rib surface due to pleural inflammation; this includes bacterial and viral pneumonias and other agents (Davies-Barrett et al., 2018; Lambert, 2002). Historically, respiratory infections were common causes of morbidity and mortality, particularly among vulnerable groups (Molto, 1990). Pleural effusion/pleurisy is frequently cited as a driver of visceral-surface change (Nicklisch et al., 2012). In the Bobbio ribs, because the lesions are chiefly external/ventral, the expected visceral pattern is lacking. No osteolysis is present. The three visceral thickenings near the sternal end (Individual 1) remain compatible with localized pleural irritation, but they are few and focal relative to the external-surface burden. Overall possible in principle for the small visceral subset, but the dominant external pattern makes widespread respiratory/pleural disease less likely.

Osteomyelitis. What is expected: subperiosteal spread elevates the periosteum and deposits layered new bone parallel to the shaft; disruption of blood supply may yield *sequestra* and cortical destruction (Rana et al., 2009). In the Bobbio ribs there is no macroscopic osteolysis and no necrotic morphology. The distribution across multiple ribs without clear focal destructive centers argues against classic pyogenic osteomyelitis. Overall, it is unlikely.

Hypertrophic pulmonary osteoarthropathy. A systemic process that produces bilateral, fairly symmetric periosteal reactions, classically along the diaphysis of long tubular bones, rather than isolated rib-dominant change (Rana et al., 2009). In the Bobbio ribs the pattern is not systemically widespread nor described on long bones; rib-only external change without symmetric appendicular involvement is not characteristic.

Skeletal fluorosis. It is expected a generalized osteosclerotic diathesis with dense periosteal deposition, frequent enthesophytes/osteophytes, rib enlargement, and dental changes; vertebral/trabecular sclerosis is common (Nelson et al., 2019). In the Bobbio ribs the assemblage does not present a systemic sclerotic signature or dental fluorosis pattern; rib changes are focal and surface-biased.

Environmental irritants and airway stressors. In past populations, smoke, dust, agricultural particulates, molds and crowding/poor ventilation increased susceptibility to respiratory disease (Rana et al., 2009). Muscle attachments can extend onto rib surfaces and introduce surface variability; transverse or cortical thickening can resemble entheseal or exostotic change (Davies-Barrett et al., 2018). In the Bobbio ribs these factors may explain minor visceral-side remodeling (e.g., costal-groove widening; the three parallel visceral thickenings near the sternal end in Individual 1) as localized mechanical/pleural responses, but they do not account for the predominant external-surface pattern across the assemblage.

Healed rib fractures/trauma. Rib fractures are common in archaeological series and may be multiple; healing produces periosteal new bone and callus, often more appreciable on the external surface with localized thickening and contour change (Brickley, 2006; Matos, 2009; Rana et al., 2009; Roberts et al, 1998). The morphology can be solid and organized in uncomplicated, chronic healing phases (Rana et al., 2009). In the Bobbio ribs the external/ventral predominance, irregular thickening and remodeling seen on several ribs, together with the absence of lytic destruction, fit best with healed traumatic change. The heterogeneous distribution (from near the head to pre-sternal portions) is also compatible with non-contiguous injuries accrued over time rather than a single pleural disease process. Limited serial attribution prevents demonstrating adjacency of affected ribs, but this does not contradict a trauma explanation. Overall, this is the most likely etiology for the external-surface lesions (including the reaction illustrated in Figure 4E).

Evidence of new bone formation on the external, muscular surface of the ribs is significantly less well documented as a specific pathological marker. Most periostitis related to pulmonary TB or other pleural infections develops instead on the visceral surface, where inflammatory processes directly affect the rib cortex through contact with the pleura (Nicklisch et al., 2012).

Anatomically, the external rib surface serves as the attachment site for several thoracic wall muscles, including the external, internal, and innermost intercostals, as well as the subcostals and the transversus thoracis. These muscles play essential roles in breathing by elevating or depressing the ribs, and their attachments can sometimes create irregularities or striated/nodular textures on the rib surface (Davies-Barrett et al., 2018).

Some rib surface changes, such as dense transverse cortical bone formation, may reflect entheseal activity or exostoses, complicating differentiation between mechanical and pathological processes. Moreover, while clinical descriptions of rib enlargement and destructive lesions exist, their correlation with pulmonary infections in the paleopathological record is inconsistent, as similar changes may arise from hematogenous spread or soft-tissue involvement (Nicklisch et al., 2012).

Rib enlargement, often appearing as sclerosis and thickening on ventral and visceral surfaces, may reflect chronic inflammatory changes or ossification of adjacent soft tissue or ligaments (Nelson et al, 2019). However, these features remain nonspecific, with pneumonia, bronchiectasis, metastases, osteomyelitis, and mycoses all potential alternative diagnoses (Nicklisch et al., 2012). Taken together, the rib lesions from Bobbio underscore the complexity of paleopathological interpretation.

In medieval European skeletal studies, particular diagnostic significance has traditionally been attributed to lesions affecting the visceral surface of the ribs, especially in relation to pulmonary infections such as tuberculosis, for which a strong association with internal periosteal reactions has been proposed (Mays et al., 2002). However, medieval rib pathology is not restricted to infectious processes. Research on skeletal trauma has shown that rib fractures were relatively common during the Middle Ages and frequently associated with everyday activities, occupational stress, interpersonal violence, or accidental falls. Healed fractures may result in localized periosteal new bone formation and irregular cortical thickening, often involving the external surface of the ribs (Brickley, 2006).

Comparative studies of late medieval urban populations further support a multifactorial interpretation of rib lesions. High prevalences of nonspecific periosteal reactions have been documented in densely populated urban contexts, where mechanical stress, recurrent minor trauma, and chronic inflammatory conditions were likely exacerbated by crowding, poor air quality, and physically demanding labor (Gernay, 2015). In this context, the Bobbio assemblage expands the spectrum of rib involvement documented for medieval populations. While the literature predominantly links internal rib surface lesions to infectious disease, particularly tuberculosis, the predominance of external surface alterations observed at Bobbio is more consistent with trauma-related or nonspecific periosteal responses. Moreover, the challenges posed by the fragmentary and commingled nature of the assemblage stress the importance of cautious interpretation: without precise individual attribution, rib seriality and thoracic context, hypotheses on the etiology of these lesions remain necessarily tentative.

This study demonstrates the potential of rib analyses to contribute significantly to the understanding of past health conditions, particularly those affecting the respiratory system. The presence of periosteal reactions, rib remodeling and other pathological alterations provides valuable, though often nonspecific, evidence for chronic inflammatory and infectious processes. However, as highlighted in the present material from Bobbio, interpreting rib lesions remains challenging for several reasons: the difficulty in assigning isolated ribs to specific individuals, the impossibility of seriating them to determine their thoracic position and the variability of lesion distribution across both posterior and anterior rib segments.

These limitations underline the importance of adopting a cautious and contextualized approach. As Rana et al. (2009) observed, in the evaluation of periosteal reactions, the primary goal should be the recognition of their presence rather than the attempt to strictly categorize their subtypes, given the considerable overlap among different etiologies. Similarly, while clinical and paleopathological literature often associates visceral rib lesions with pulmonary tuberculosis and other pleural infections, the evidence from Bobbio also involves external surfaces, which may reflect mechanical stress, trauma, or nonspecific infections rather than a direct pulmonary origin.

Taphonomic and preservation biases further complicate interpretation. As Mays (1992) emphasized, ribs are among the most fragile skeletal elements due to their high trabecular component, often leading to poor preservation and underrepresentation in archaeological studies. This may explain why rib lesions, despite their diagnostic potential, have historically received relatively little attention (Brickley, 2006). Nonetheless, the thoracic skeleton plays a crucial role in protecting vital organs and supporting the mechanics of respiration, making pathological changes in ribs an important avenue for bioarchaeological inquiry.

Ultimately, the Bobbio assemblage illustrates both the promise and the limitations of rib paleopathology. While specific diagnoses remain elusive, the identification of rib alterations contributes to broader discussions of respiratory disease, mechanical stress and nonspecific infection in medieval populations. Future studies that integrate macroscopic, radiological, and biomolecular analyses, in conjunction with archaeological and environmental data, will be essential to refine interpretations and to better situate rib pathology within the lived experiences of past communities.

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Author contributions

Arianna Vanni and Roberta Fusco: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. Nicol Rossetti: Conceptualization, Investigation, Writing – review & editing. Eleonora Destefanis: Conceptualization, Investigation, Supervision, Writing – review & editing. Marta Licata: Supervision.

Ethics statement

All analyses were conducted with the authorization of the competent Italian Superintendency (Soprintendenza).

Data availability statement

The data supporting the findings of this study are included within the article. Additional information may be made available by the corresponding author upon request.

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Conflict of interest

The authors declare no conflict of interest.

Corresponding author

Nicol Rossetti, University of Insubria, Polo didattico Molini Marzoli, via Alberto da Giussano, 12 – 21052, Busto Arsizio, Italy, phone number: +39 0331 339404, e-mail: nrossetti@uninsubria.it

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