Rib fractures in the Coimbra Identified Skeletal Collection: potential associations with biological sex, age-at-death and bone mineral density

Fraturas das costelas na Coleção de Esqueletos Identificados de Coimbra: possíveis associações com o sexo biológico, idade à morte e densidade mineral óssea

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Abstract There is a high prevalence of rib fractures in human remains from archaeological contexts, but these are seldom the focus in paleopathological studies pertaining skeletal trauma. This study aims to document rib fracture patterns in the Coimbra Identified Skeletal Collection, Department of Life Sciences, University of Coimbra. Specific aims of this study included the estimation of rib fracture prevalence in 252 individuals, from both sexes (females: 128; males: 124), with age-at-death varying from 20 to 96 years; and the analysis of the relationship between rib fractures andbiological sex, age-at-death, and bone mineral density measured at the proximal femur. The crude prevalence of rib fractures was 6.3% (N=16); while the true prevalence rate

Resumo A prevalência de fraturas das costelas é elevada em contextos arqueológicos, contudo, estas raramente são o foco de estudos paleopatológicos sobre traumatismos esqueléticos. Neste trabalho, pretende-se documentar os padrões de fratura das costelas na Coleção de Esqueletos Identificados de Coimbra, Departamento de Ciências da Vida, Universidade de Coimbra. Os objetivos específicos incluem a estimativa da prevalência de fraturas das costelas em 252 indivíduos, de ambos os sexos (mulheres: 128; homens: 124), com idades à morte compreendidas entre os 20 e os 96 anos; e a análise da relação entre fraturas das costelas e o sexo biológico, a idade à morte, e a densidade mineral óssea mensurada no fémur proximal. A prevalência bru-

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was 0.7% (38 fractured ribs in relation to 5656 ribs studied). Males have been more affected than females (males: 10.5%, 13/124; females: 2.3%, 3/128). Individuals with one or more rib fractures were significantly older (mean=66.19 years old; standard deviation [SD]=14.08) than those who have not experienced any rib fracture (mean=50.41 years old; SD=19.45). Low bone mineral density was also associated with the presence of rib fractures but only in females. These results expand the scientific awareness about the prevalence of rib fractures in human skeletal collections.

Keywords: Skeletal trauma; paleopathology; bioarchaeology; forensic anthropology; reference skeletal collections; Portugal.

ta de fraturas das costelas foi de 6,3% (N=16); enquanto a prevalência real foi de 0,7% (38 costelas fraturadas em 5656 observadas). Os homens foram mais afetados que as mulheres (homens: 10,5%, 13/124; mulheres: 2,3%, 3/128). Os indivíduos com uma ou mais fraturas das costelas eram significativamente mais velhos (média=66,19 anos; desvio padrão [DP]=14,08) que aqueles que não sofreram qualquer fratura (média=50,411 anos; DP=19,45). Valores baixos de densidade mineral óssea encontravam-se também associados à presença de fraturas das costelas, mas apenas no grupo feminino. Estes resultados incrementam a consciência científica acerca da prevalência de fraturas das costelas em coleções osteológicas humanas.

Palavras-chave: Traumatismos esqueléticos; paleopatologia; bioarqueologia; antropologia forense; coleções osteológicas de referência; Portugal.

Introduction

Skeletal trauma — and particularly fractures — is undoubtedly a prominent finding in human remains from past communities (Lovell, 1997; Redfern et al., 2017; Redfern and Roberts, 2019). Bone fractures are hybrid events, permeated by interlacing threads of biological, social, cultural or political factors, and their historical/diachronic analysis has made consequential contributions to the interpretation of multidimensional expressions of human life experiences in the past, including the provision of care to suffering individuals, interpersonal and structural violence, the effects of age, and sex and/or gender, medical procedures, among many others (Domett and Tayles, 2006; Piombino-Mascali et al., 2006; Redfern, 2010; de la Cova, 2012; Robbins et al., 2012; Šlaus et al., 2012; Milner et al., 2015; Binder et al., 2016; Lovell, 2016; Pfeiffer, 2016; Lambert and Welker, 2017; Antunes-Ferreira et al., 2018; Mant, 2019). It is crucial to be familiar with the information potential provided by different types of fracture. Nonetheless, most of the studies in archaeological contexts have been focused either on cranial fractures (maybe a reminiscence of what Saul Jarcho (1966) once described as a cranial fixation by anthropologists), fractures of the long bones, or an assortment of these, undervaluing fractures in other areas of the skeleton, such as the ribs (Brickley, 2006; Matos, 2009).

In the classical medical textbook "A practical treatise on fractures and dislocations", Frank H. Hamilton admitted the scarcity of rib fractures when compared with fractures of the long bones (Hamilton, 1860). Lewis Stimson, just two decades after Hamilton's remarks, espoused a divergent perception, stating that rib fractures were "among the commonest of all fractures"(Stimson, 1883: 190). In modern clinical data, these are very common injuries, occurring in 10 – 20% of all blunt trauma patients (Ismail et al., 2006; Talbot et al., 2017; Liebsch et al., 2019; Peek et al., 2022). Nonetheless, rib fractures' clinical awareness is not flawless and the exact incidence may be higher than what is reported (Ismail et al., 2006; Talbot et al., 2017). Rib fractures are also a very common finding in archaeological populations (Lovell, 1997; Brickley, 2006; Redfern and Roberts, 2019) but they are seldom the focal point of comprehensive bioarchaeological or forensic studies about skeletal trauma (Brickley, 2006; Matos, 2009). Exceptions comprise analyses of archaeological populations (Brickley, 2006; Garcia, 2019), reference skeletal collections (Matos, 2009) and forensic contexts (Love and Symes, 2004; Daegling et al., 2008; Christensen et al., 2013).

The paucity of published paleopathological reports focusing on rib fractures thwarts any attempt to identify and understand historical patterns of injury in the thoracic region and restrains diachronic and geographic comparisons between archaeological samples. Some studies include reports on rib fractures from archaeological samples (e.g., Robledo and Trancho, 1999; Roberts and Cox, 2004; Assis, 2007; Jordana, 2007; de la Cova, 2010; Agnew et al., 2015), but confined the scope of analysis to the global prevalence of fractures. Other authors state that rib fractures were analyzed but no specific statistics are given (Scott and Buckley, 2010). A while back, Brickley (2006) recommended a higher level of detail and specificity when recording rib fractures, towards comprehensive paleoepidemiological studies that aim to reproduce the complexity of biological, social and cultural factors that influence rib fracture patterns in a certain geographical and chronological context.

Rib fractures are not only common but also contribute disproportionately to patients' morbidity and mortality. Formerly considered relatively innocuous, their various detrimental effects are now well-known (Flagel et al., 2005; Peek et al., 2022). Fractured ribs are clinically relevant for numerous reasons. Very often they are an indication of a more serious injury, with high morbidity and mortality from associated lesions such as head injuries and lung, heart and abdominal visceral organ complications. Pulmonary problems due to rib fractures comprise hemothorax, pneumothorax, flail chest, pulmonary contusion, pneumonia and atelectasis (Barnea et al., 2002; Sirmali et al., 2003; Palvanen et al., 2004; Freixinet et al., 2008; Lin et al., 2016; Talbot et al., 2017; Liebsch et al., 2019; Peek et al., 2020; 2022). Rib fractures are associated with pain because of movements of fractured sections with each respiratory effort (Shukla et al., 2008).

The aetiology of rib fractures is intricate and multidimensional, but most epidemiological studies have been showing that the leading causes of these fractures include road traffic accidents (unusual or non-existent in many past societies), accidental falls, interpersonal violence and work-related hazards (Sirmali et al., 2003; Freixinet et al., 2008; Ingoe et al., 2020; Peek et al., 2022). Chronic alcoholism (González-Reimers et al., 2005), domestic violence (Porter et al., 2019), and child abuse (Cattaneo et al., 2006) are also acknowledged as important causes of rib fractures. Bone fragility caused by osteoporosis, which facilitates fractures in the ribs when less kinetic force is applied to the thorax, is also considered a major predisposition factor (Flagel et al., 2005; Prins et al., 2020).

Following the suggestions by Brickley (2006) highlighting the potential relevance of the paleopathological study of rib fractures, and related works by Matos (2009) and Garcia (2019) in Portuguese skeletal samples, the purposes of this investigation include: 1.) the assessment of rib fracture prevalence in an identified skeletal study-base from Coimbra, Portugal (Coimbra Identified Skeletal Collection); and 2.) the analysis of the relationship between rib fractures, assigned sex at birth (i.e., biological sex), age-at-death, and bone mineral density measured at the proximal femur.

Materials and methods

The Coimbra Identified Skeletal Collection (CISC) was collected between 1915 and 1942, by Eusébio Tamagnini, and is at present curated at the Department of Life Sciences in the University of Coimbra. The collection is composed by 505 skeletons; and most of them were exhumed from shallow graves in the *Cemitério Municipal da* Conchada (Rocha, 1995). These individuals were predominantly manual workers with low socioeconomic status (Cunha and Wasterlain, 2007). A corpus of biographical data pertaining these individuals was assembled in a *Registry Book*, which is, in effect, an anthology of lives condensed in a clear and scrupulous, almost bureaucratic, record. The data collected for every individual include the biological sex, age-at-death, occupation, cause-of-death, and marital status, amongst others. The majority of the skeletons is complete and well preserved, although some display taphonomic alterations, essentially due to continuous handling over the years (Rocha, 1995; Cunha and Wasterlain, 2007; Curate et al., 2019).

Only adults (age-at-death ≥ 20 years) with no signs of gross taphonomic damage were incorporated in the sample. Individuals that lacked supporting biographical information, such as age-at-death, biological sex, or cause of death, were excluded. The study sample consists of 252 adults from both sexes (females: 128; males: 124), with ages-at-death ranging from 20 to 96 years (Mean=51.4; SD=19.5; Figure 1). It comprises individuals born between 1827 and 1914 that died between 1910 and 1936. The majority came from central and northern Portugal, especially from the Coimbra District.

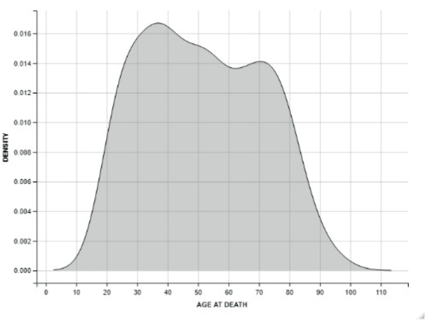

Figure 1. Probability density distribution of age-at-death in the Coimbra Identified Skeletal Collection sample.

The ribs from every individual were observed macroscopically, and the bone representation index, which measures the frequency of each bone in the sample, was evaluated. It is simply the ratio between the actual number of bones observed and the total number of elements of the skeleton that should have been present. Also, the state of preservation of rib cortical surfaces was assessed by the qualitative bone index, which is the ratio between the flawless cortical surface and the damaged cortical surface of each bone (Bello et al., 2006; Robb, 2016).

Fractures (i.e., any break in the continuity of the bone; Lovell, 1997) were recorded according to the protocol proposed by Brickley (2006). All visible antemortem (and, if present, perimortem) rib fractures were included irrespective of the state of healing. For each individual all the ribs were counted and identified. The number of fractures present in each individual and, when possible, the actual rib number at which the fracture was observed were recorded. The fracture location in the anatomy of the rib (sternum or vertebral ends, and shaft), the healing state (healed, healing), the presence of callus or remodeled bone and the occurrence of associated features, such as angular displacement, were also recorded (Lovell, 1997; Matos, 2009).Fracture prevalence was estimated as a crude ratio — a proportion of the total number of rib fractures and the total number of individuals — and as a true ratio — a proportion of the total number of fractured ribs and the total number of ribs in the sample (Judd, 2002a; Lovell, 2008).

Bone mineral density (BMD) at the proximal femur (regions of interest "Total Hip" and "Neck") was assessed through Dual X-ray absorptiometry (DXA), according to Curate et al. (2013; 2017), in a subsample of 204 individuals (112 females and 92 males).

A Fisher's exact test was performed to examine the association between two categorical variables. Additionally, the odds ratio (and corresponding 95% confidence interval, CI) was employed to measure the strength of association between two binary variables (Szumilas, 2010). Pearson's correlation was used to measure the linear association between two sets of data. A Student's t-test was employed in order to evaluate the null hypothesis that the means of two groups were identical. When a violation of normality was detected with the Shapiro-Wilk test, a non-parametric alternative (Mann-Whitney U) was used. Logistic regression, a non-parametric statistical classifier, was employed to describe the association of one or more independent variables to a dichotomous dependent variable. A p-value ≤0.05 was considered statistically significant. All statistical analyses were performed with SPSS (v. 28) and R language (R Core Team, 2021).

Results

A total of 5656 ribs were observed from 256 individuals, representing 93.5% of the total number of ribs expected (i.e., 6048 presuming the existence of 24 ribs for each individual). The number of ribs present ranged from 18 (1.2%; 3/252) to 24 (29.8%; 75/252), with an average of 22.4 ribs per individual affected (SD=1.4; Mode=24). The bulk of the sample (98.0%, 247/252) showed at least 20 preserved ribs per individual. Of the 5656 ribs present in the sample, 1598 (28.3%) presented cortical surface damage, with an average of 6.3 damaged ribs per individual (SD=6.9; Mode=0). Of the damaged ribs, 2.1% (33/1598) were placed in the Class 3, 8.3% (133/1598) in the Class 4, and 89.6% (1432/1598) in the Class 5 of the qualitative bone index (Bello et al., 2006).

The crude prevalence for rib fractures per individual observed in this study is summarized in Table 1. The overall prevalence rate for both sexes is 6.3% (16/252). The true prevalence of rib fractures (i.e., considering the total number of fractured ribs and the total number of observed ribs) is 0.7% (38/5656; Table 2). All fractures occurred antemortem.

Males were significantly more affected than females (males: 10.5%, 13/124; females: 2.3%, 3/128; Fisher's exact test: p=0.009; Odds Ratio: 4.88, 95%CI: 1.35 – 17.57). Individuals with one or more rib fracture were older (Mean=66.19 years old; SD=14.08) than those who do not present with fractures (Mean=50.41 years old; SD=19.45; Mann-Whitney U: 985.500; Z=-3.199; p=0.001). Eight of the affected individuals, one female and seven males, presented with multiple (two or more) rib fractures (50.0%; 8/16). Within the multiple fractures' group, an overwhelming majority of individuals (87.5%; 7/8) showed two or more adjacent ribs with fractures. Contiguous rib involvement ranged from two to four ribs. Just one individual exhibited adjacent broken ribs in both sides of the thoracic cage. Multiple fractures in the same rib (Figure

Table 1. Crude prevalence of rib fractures in each age / sex category (CISC).

Age Categories	Males			Females			Total		
	N	NF	%	N	NF	%	N	NF	%
20-29	18	0	0.0	23	0	0.0	41	0	0.0
30-39	23	0	0.0	22	0	0.0	45	0	0.0
40-49	21	3	14.3	16	0	0.0	37	3	8.1
50-59	18	0	0.0	20	0	0.0	38	0	0.0
60-69	17	4	23.5	16	1	6.3	33	5	15.2
70-79	20	4	20.0	17	1	5.9	37	5	13.5
80+	7	2	28.6	14	1	7.1	21	3	14.3
Total	124	13	10.5	128	3	2.3	252	16	6.3

N: sample size; NF: number of individuals with one or more rib fractures; %: percentage.

Table 2. True prevalence of fractures by sex / age categories (CISC).

Age Categories	Males			Females			Total		
	N	NF	%	N	NF	%	N	NF	%
20-29	410	0	0.0	515	0	0.0	925	0	0.0
30-39	524	0	0.0	494	0	0.0	1018	0	0.0
40-49	474	4	0.8	357	0	0.0	831	4	0.5
50-59	411	0	0.0	449	0	0.0	860	0	0.0
60-69	376	15	4.0	357	1	0.3	733	16	2.1
70-79	463	13	2.8	374	2	0.5	837	15	1.8
80+	147	2	4.3	305	1	0.3	452	3	0.7
Total	2805	34	1.2	2851	4	0.1	5656	38	0.7

N: the number of left and right ribs; NF: the total number of rib fractures; %: percentage.

2) were observed in a total of five ribs belonging to two individuals. The number of fractured ribs was positively associated, albeit moderately, with age-at-death (Pearson's r: 0.165; p=0.009), and varied between one and eight per individual, with an average of 2.4 fractures per individual (SD=1.9; Mode=1).

Three males (20%; 3/15) showed rib fractures still healing at the time of death (Figure 3). One of these individuals presented with well-healed fractures adding up to the rib fractures with active callus formation, suggesting that the injuries happened in more than one traumatic event.

The left side of the rib cage was affected more often (81.3%%; 13/16) than the right side (6.3%; 1/16). Two individuals (12.5%; 2/16) suffered rib lesions in both sides of the rib cage. The ribs most frequently affected were those in the middle region (fourth to ninth rib), encompassing 65.8% (25/38) of the recorded cases, followed by those of the lower region (tenth to twelfth rib), with 18.4% (7/38), and those of the upper region (first to third rib), with 15.8% (6/38). The seventh rib was the most frequently fractured (14.7%; 5/38), followed by the fourth (11.8%; 4/38) and the eighth ribs

Figure 2. Two fractures in the 8th left rib. In one of the fractures, near the sternal end, the callus is visibly healing, while in the other the callus is well-remodeled. This individual (CISC, number 212), a 78-year-old male, suffered fractures in five ribs as well as in the distal radius (Colles' fracture).

Figure 3. Fracture in the shaft of the 5th left rib in a 79 year-old-male (CISC, number 303). Woven bone and porosity are noticeable adjacent to the margins of the fracture.

(11.8%; 4/38). The first (with no fracture recorded) and the twelfth (only one case recorded) were the least affected ribs. Of the 38 ribs with at least one fracture, 31 (81.6%) were fractured in the shaft (matching the lateral portion of the rib cage), and 7 (18.4%) near the sternal end (corresponding to the anterior region of the rib cage). There were none in the vertebral end region (posterior rib cage).

Bone mineral density values at the total hip and the neck of the femur in women without rib fractures are significantly larger than in women with fractures (BMD Total Student's independent sample t-test: 1.773; df=100; p=0.039 / BMD Neck Student's independent sample t-test: 2.071; df=100; p=0.020). In men, bone mineral density is also larger in individuals without rib fractures but the differences are not statistically significant (BMD Total Student's independent sample t-test: 1.439; df=90; p=0.077 / BMD Neck Student's independent sample t-test: 1.214; df=90; p=0.114). Descriptive statistics for the bone mineral density are summarized in Table 3.

Additionally, a stepwise logistic regression was implemented to ascertain the effects of biological sex, age-at-death, BMDTotal on the likelihood that an individual from the study-sample suffered one or more rib fractures. Stepwise selection removed BMD Total from the resulting model, and only sex and age-at-death remained as explanatory variables (Table 4). The model was statistically significant (X^2: 18.773; df=2; p<0.001), explaining 19.1% (Nagelkerke R^2) of the variance in the occurrence of rib fractures and correctly classified 93.7% of cases. Males were 4.9 times more likely

Table 3. Bone mineral density at the Total Hip (BMD Total) and Neck (BMD Neck) in individuals without and with rib fracture, according to sex (CISC).

	Without Rib Fracture				With Rib Fracture			
	Mean	**SD**	**95% CI**	**N**	**Mean**	**SD**	**95% CI**	**N**
Females								
BMDTotal	0.792	0.16	0.762 – 0.823	109	0.626	0.10	0.373 – 0.879	3
BMDNeck	0.690	0.15	0.661 – 0.719	109	0.506	0.08	0.298 – 0.714	3
Males								
BMDTotal	0.891	0.17	0.854 – 0.928	82	0.810	0.16	0.693 – 0.928	10
BMDNeck	0.765	0.16	0.729 – 0.800	82	0.699	0.16	0.582 – 0.816	10

SD: standard deviation; 95%CI: 95% confidence interval; N: sample size.

Table 4. Stepwise logistic regression model fitting for the likelihood of having suffered one or more rib fractures (CISC).

	Variable	**β**	**SE**	**Wald**	**Sig.**	**Exp (β)**	**95% CI for Exp (β)**
Rib Fractures (CISC)	Sex	1.598	0.695	5.288	<0.001	4.944	1.266 – 19.302
	Age	0.057	0.020	7.964	<0.001	1.059	1.018 – 1.102
	Constant	-6.772	1.276	28.160	<0.001	0.001	

β: the coefficient for the constant in the null model; SE: standard error; Wald: Wald chi-square test; Exp (β): exponentiation of the β coefficient; 95% CI: 95% confidence interval.

to exhibit rib fractures than females. Increasing age was also associated with an increased probability of showing a rib fracture. Bone mineral density was not linked with the likelihood of exhibiting a rib fracture in the logistic model.

Discussion

It is becoming increasingly obvious that the nature and amount of information that may be obtained from skeletal assemblages are correlated not only with the demographic profile of the sample but also with the completeness/incompleteness of the skeleton and the state of preservation of the osseous remains (Mays, 1992; Bello et al., 2006; Robb, 2016). The completeness/incompleteness and the state of preservation of skeletal remains are linked to the action of taphonomic agents, as well as on excavation procedures and recovery circumstances. Results on the rib preservation index and the qualitative bone index in the CISC sample suggest that the observed rib sets were fundamentally complete and very well preserved.

In archaeological studies, there is a common perception that the post-mortem survival of ribs is poor (Brickley, 2006). Waldron (1987) and Mays (1992) reported rib survival rates largely inferior to the postmortem preservation of other skeletal components, and Bello et al. (2006) observed a substantial variability in rib conservation. Good rib preservation and qualitative bone indices in the sample from the CISC — similar to what was recorded by Matos (2009) in the Lisbon Identified Collection — can be explained by the short time period between the inhumation of the individuals and their exhumation (less than 10 years), which is unusual in archaeologically-derived samples; and careful excavation of the skeletons. Postmortem damage in this sample is mostly limited to the continuous handling of bones over the years.

Rib fractures are a common injury following blunt chest trauma, accounting for a substantial number of thoracic injuries from non penetrating trauma (Liebsch et al., 2019; Kim and Moore, 2020; Peek et al., 2022). Rib fractures are also a frequent finding in the paleopathological literature (Mays, 2000; Judd, 2002b; Brickley, 2006; Mant, 2019; Redfern and Roberts, 2019; Scott et al., 2019) and this type of injury was already observed in the Pliocene fossil "Lucy", the female *Australopithecus afarensis* with 3.18 million years (Kappelman et al., 2016). Notwithstanding, rib fractures are hardly ever the focus of studies investigating physical trauma in the past. As such, published reports on their specific prevalence are relatively scarce (Brickley, 2006; Matos, 2009; Garcia, 2019), with some comprehensive studies of skeletal trauma in the past omitting rib fractures from the analysis (Gilmour et al., 2015; Milner et al., 2015; Lambert and Welker, 2017).

A few paleopathological studies reported a crude prevalence ranging from 0.0% (Lambert, 2002) to 63.3% (de la Cova, 2010). Also, a substantial disparity between the true prevalence rates in the available studies was found, varying between 2.3% (Brickley, 2006) and 5.6% (Garcia, 2019; Tables 5 and 6). Therefore, the crude prevalence (6.3%) and true prevalence (0.7%) found in the present study are among the lowest reported in the available literature. The low prevalence in the CISC sample is even more obvious if compared with the frequencies reported by Matos (2009) — 23.9% and 2.6% — in a seminal study completed in a well-preserved sample of identified skeletal individuals from the National Museum of Natural History of Lisbon (Portugal). The sample of Lisbon comprises relatively more males (with a higher risk of suffering rib fractures), but sex-specific prevalences are also higher in the Lisbon collection. Also, unlike what was observed in the Coimbra study-base, some younger individuals from the Lisbon sample suffered rib fractures.

Of course, the interpretation and comparison of these rates, especially the true prevalence rate, are convoluted because they depend on highly variable features such as the representativeness and preservation of bones (Bello et al., 2006). The importance of the differential survival of bones to achieve accurate estimates of disease prevalence in the past is unquestionable (Waldron, 1987). The good preservation of ribs in this analysis is not a common finding, with the study by Matos (2009) featuring another exception; this complicates comparisons with other paleopathological studies, especially those that do not report rib survival rates. Comparisons with modern epidemiological studies are also difficult as the incidence and prevalence of rib fractures are significantly underreported (Cattaneo et al., 2006; Ingoe et al., 2020).

Fracture patterns within a population are highly informative (Lovell, 1997), and sex and age influence the frequency and nature of skeletal trauma. In this study, there is a significant statistical difference in rib fracture prevalence between females and males, with the latter presenting a higher likelihood of having suffered a rib fracture. These results are similar to other studies (Robledo and Trancho, 1999; Brickley, 2006; Assis, 2007; Jordana, 2007; Matos, 2009; Garcia, 2019), that also fathom that males in the past were probably more prone to this kind of fracture. Epidemiological studies also suggest that men are more frequently affected by rib fractures (Palvanen et al., 2004; Ismail et al., 2006; Liebsch et al., 2019; Peek et al., 2022). Most thoracic trauma patients are males involved in high-energy accidents, but also in work-related incidents or alcoholism (Sirmali et al., 2003; González-Reimers et al., 2005; Lin et al., 2016). Interestingly, the association of injury recidivism, including multiple rib fractures, and substance abuse has been proposed in a middle-aged man that was buried in the Chapel of the Holy Spirit in Bucelas, Portugal (Antunes-Ferreira et al., 2021). Also, in bioarchaeological contexts rib fractures are often the outcome of interpersonal violence, a behavioral pattern more common in males (Lovell, 1997; de la Cova, 2012; Antunes-Ferreira et al., 2021).

In the CISC sample, the prevalence of rib fractures and the number of fractured ribs increased with age. The results are in agreement with those reported in other paleopathological (Brickley, 2006; Matos, 2009; Garcia, 2019), and clinical studies (Palvanen et al., 2004; Ismail et al., 2006; Elmistekawy et al., 2007; Coary et al., 2020; Kim et al., 2020). Advanced age is associated with comorbidities, increased frailty and geriatric conditions that amplify the propensity to fall (Coary et al., 2020). Multiple lines of epidemiological evidence suggest that falls are central in fracture risk determination, and particularly rib fractures (Sirmali et al., 2003; Liebsch et al., 2019; Coary et al., 2020). Amongst the aged, home and leisure accidents are frequent and almost always due to fortuitous falls with a single, low impact chest injury (Freixinet et al., 2008; Peek et al., 2020). It must be cautiously noted that in paleopathological studies, it is not absolutely clear whether the

Table 5. Crude prevalence of rib fractures in archaeological and reference skeletal samples.

Study reference	Provenience	Chronology	N	NF	%
Agnew et al. (2015)	Giecz, Poland	11th–12thAD	142	32	22.5
Agnew et al. (2015)	Poznan-Sródka, Poland	10th–12thAD	57	1	1.8
Assis (2007)	Constância, Portugal	14th–19th AD	36	6	16.7
Brickley (2006)	St. Martin's, Birmingham, UK	18th–19thc. AD	352	55	15.6
de la Cova (2010)	African-Americans♂, TC, USA	19th–20thc. AD	345	105	30.4
de la Cova (2010)	Euro-Americans♂,TC, USA	19th–20thc. AD	289	183	63.3
Garcia (2019)	Leiria, Portugal	12th–16thc. AD	64	21	32.8
Jordana (2007)	Sant Pere Church, Terrasa, Spain	4th–8th c. AD	53	7	13.2
Lambert (2002)	Ute Mountain, USA	1075–1280 AD	25	---	20.0
Lambert (2002)	Pueblo Bonito, USA	900–1050 AD	45	---	6.7
Lambert (2002)	Eldon Pueblo, USA	1100–1300 AD	20	---	0.0
Matos (2009)	NMSMH, Lisbon, Portugal	19th–20th c. AD	197	47	23.9
Roberts and Cox (2004)	Several locations, UK	Late Medieval	2515	157	6.2
Roberts and Cox (2004)	Several locations, UK	Neolithic	41	1	2.4
Roberts and Cox (2004)	Several locations, UK	Iron Age	113	3	2.7
Robledo and Trancho (1999)	Xarea, Almeria, Spain	9th–15th c. AD	142	15	10.6
Present Study	University of Coimbra, Portugal	19th-–20th c. AD	252	16	6.3

N: sample size; NF: number of individuals with one or more rib fractures;%: percentage; TC: Terry Collection; NMSMH: National Museum of Science & Natural History of Lisbon.

Table 6. True prevalence of rib fractures in archaeological and reference skeletal samples.

Study reference	Provenience	Chronology	RO	NF	%
Assis (2007)	Constância, Portugal	14th–19th c. AD	498	24	4.8
Brickley (2006)	St. Martin's, Birmingham, UK	18th–19th c. AD	5975	138	2.3
Garcia (2019)	Leiria, Portugal	12th–16th c. AD	1169	66	5.6
Matos (2009)	NMSMH, Lisbon, Portugal	19th–20th c. AD	4276	123	2.9
Roberts and Cox (2004)	Several locations, UK	Post-Medieval	2081	88	4.2
Present Study	University of Coimbra, Portugal	19th–20th c. AD	5656	38	0.7

RO: ribs observed; NF: the total number of rib fractures; %: percentage; NMSMH: National Museum of Science & Natural History of Lisbon.

higher prevalence of fractures in elderly individuals is the outcome of the accretion of fractures during lifetime, or the result of other phenomena, such as falls or underlying diseases. The longer an individual lives, the higher the probability of suffering bony lesions (Glencross and Sawchuck, 2003).

In the elderly, even low trauma injuries can result in multiple rib fractures. This can be explained, at a population level, by reduced bone mass, i.e., osteopenia and osteoporosis (Ismail et al., 2006; Wuermser et al., 2011; Prins et al., 2020). While the association between low bone mass density (BMD) and bone strength is not straightforward, low BMD values are related to increased fracture risk at a population level (Curate, 2014). Bone mineral density in the proximal femur seems to be related with rib fractures in the CISC sample only in women. However, the effect disappears in the logistic regression model. An association between rib fractures and lower cortical bone mass (measured in the second metacarpal), especially noticeable in women, was also observed in a smaller sample of the CISC (Curate and Cunha, 2009).Concurrently, 36.7% (6/16) CISC individuals affected by rib fractures also sustained fractures that are usually considered to be of osteoporotic nature, namely hip, Colles' and vertebral fractures.

Only three aged (ages-at-death between 70 and 79 years) male individuals presented fractures that were still in the process of healing at the time of death. In the study by Brickley (2006), most of the individuals with healing fractures were older males. Age is a critical determinant of mortality and morbidity caused by rib fractures (Sirmali et al., 2003; Peek et al., 2020; 2022). Also, these three individuals suffered multiple fractures; each one had sustained at least four rib fractures. The number of fractured ribs is directly related to the severity of the injury (Sirmali et al., 2003; Flagel et al., 2005; Freixinet et al., 2008; Witt and Bulger, 2017; Ingoe et al., 2020), with higher rates of pleural involvement, health complications, including flail chest and pneumonia, longer hospital length of stay, and mortality. The three individuals died from heart diseases (ICD-10: I00-I99) and not from complications directly related to rib fractures. This conveys an important concern: as the cause of death is largely indeterminable based entirely on skeletal evidence (Cunha and Pinheiro, 2005), it is important to be circumspect with interpretations about the health outcomes of rib fractures in paleopathological studies even when multiple, still healing, rib lesions with a life-threatening prognostic, and an "appropriate" demographic profile, are observed.

The ribs most commonly involved were those from the midsection of the thorax, from the fourth to the ninth, as in the study by Sirmali et al. (2003). In other epidemiological and anthropological studies the midsection ribs are usually the most frequently affected (Brickley, 2002; Kara et al., 2003; Matos, 2009). Ribs from the upper region (but not the first rib) and the lower region (tenth to twelfth ribs) were also affected. Fractures of the upper ribs typically involve a severe physical trauma, being frequently associated with injuries to great vessels. Injury of the lower ribs may result in damage of the liver, diaphragm, spleen or the kidneys (Sirmali et al., 2003; Talbot et al., 2017).

Final remarks

Rib fractures are common in both archaeological and epidemiological contexts, usually encompassing modest to severe health outcomes (Brickley, 2006; Peek et al., 2022). Nonetheless, the paleopathological analyses of this particular type of bone injury have been uncommon, while epidemiologically relevant (Brickley, 2006; Curate and Cunha, 2009; Matos, 2009; Garcia, 2019). Results in the CISC sample broaden the knowledge about the prevalence of rib fractures in skeletal collections from the past, interspersing in a wider pattern of sample and individual heterogeneity. Assigned sex and age-at-death patterns of fracture are largely comparable to those that have been reported by previous studies, with males linked to an increase in the likelihood of presenting with at least one rib fracture, and a positive association of age with rib fractures. Low bone mineral density is also correlated with the presence of rib fractures — but only in females. Limitations of this study obviously incorporate the collecting biases of the CISC, in particular, and of any skeletal collection, in general (Albanese, 2003). Future analyses of rib fractures in archaeological contexts should aim toward a geographic and diachronic integration of data, grounded on detailed and multilayered descriptions of the fractures.

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