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Metacarpal cortical bone loss and osteoporotic fractures in the Coimbra Identified Skeletal Collection

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Abstract

There has been considerable progress in recent years in our understanding of the patterns of cortical bone loss in the second metacarpal in archeological skeletal samples. Nevertheless, cortical data from reference skeletal collections are insufficient, and the possible connection of metacarpal cortical parameters with osteoporotic fractures has not been thoroughly addressed. As such, this article aims to identify and explain sex-specific and age-associated metacarpal cortical bone loss in a large sample (N = 302; females: 154/males: 148) from the Coimbra Identified Skeletal Collection. Another objective is to evaluate the association of cortical and demographic features with osteoporotic fractures. Age-related endocortical bone loss is significant in women but not evident in men. Periosteal accretion of the bone is absent in both sexes. Overall, there is a net loss of the cortical bone in women, whereas cortical bone strength seems to be preserved in men. The prevalence of osteoporotic fractures is similar in both sexes, with age at death significantly influencing the probability of exhibiting a fracture. Metacarpal cortical index does not seem to be an independent risk factor for osteoporotic fractures in this sample.

KEYWORDS

bone fragility, fragility fractures, identified reference skeletal collections, osteoporosis

1 | INTRODUCTION

Worldwide demographic changes have resulted in the ageing of large segments of the population, an ongoing social process with massive public health implications. Osteoporosis, bone fragility, and associated fractures are gradually more frequent at older ages, particularly affecting postmenopausal women and ageing individuals of both sexes (Sattui & Saag, 2014). Bone loss has been repeatedly evaluated in historical skeletal samples, adding diachronic depth to the biomedical knowledge about bone health associated with age, hormonal status, physical activity or nutrition, among others (Brickley & Ives, 2008; Curate, 2014).

Research of the structural basis of bone fragility have typically concentrated on trabecular bone loss and fractures at trabecular-rich skeletal areas (Zebaze & Seeman, 2015). However, the conceptualization of osteoporosis as a disorder of trabecular bone loss does not fathom its complexity and heterogeneity (Seeman, 2013). Indeed, 70% of all age-related appendicular bone loss is cortical, despite the faster remodelling rate of the trabecular bone (Zebaze et al., 2010). Throughout the first years after menopause, cortical and trabecular bone loss is balanced, but the cortical bone is accountable for greater bone loss after 60 years of age (Seeman, 2013; Zebaze et al., 2010). The cortical bone is a major contributor to the overall bone strength, influencing resistance to external force loads and the occurrence of fractures (Holzer, Von Skrbensky, Holzer, & Pichl, 2009; Piemontese, Xiong, Fujiwara, Thostenson, & O'Brien, 2016). This is especially relevant because nonvertebral fractures compose the bulk of osteoporotic fractures and ensue predominantly at cortical sites (Center, 2010; Zebaze & Seeman, 2015).

Cortical bone loss occurs mostly through intracortical remodelling (Zebaze & Seeman, 2015). Radiogrammetry, a method that determines the amplitude or geometry of the cortical bone in tubular bones, is

suitable to evaluate cortical bone loss in historical/archeological contexts (e.g., Beauchesne & Agarwal, 2014, 2017; Glencross & Agarwal, 2011; Ives & Brickley, 2005; Lazenby, 1998; Mays, 1996, 2000, 2015; Mays, Lees, & Stevenson, 1998; Umbelino et al., 2016). Metacarpal radiogrammetry was independently and formally described in 1960 (Barnett & Nordin, 1960; Virtamä & Mähönen, 1960). There are normative reference values for radiogrammetry in living populations (e.g., Black et al., 2001; Hyldstrup & Nielsen, 2001; Shepherd et al., 2005; Virtamä & Helelä, 1969), but data from reference skeletal collections are scarce (e.g., Curate & Cunha, 2017). As such, this study aims to establish a normative reference database for metacarpal cortical index based on a large sample from the Coimbra Identified Skeletal Collection (CISC), to identify and interpret the patterns of sex-specific and age-related cortical bone loss in the second metacarpal, and to test possible associations of cortical parameters of bone and demographic features with the so-called osteoporotic fractures.

2 | MATERIALS AND METHODS

The CISC includes 505 individual skeletons primarily recovered in the largest public cemetery of Coimbra (Portugal). Biographical details for the skeletal individuals are accessible, for example, place of birth, sex, age at death, and occupation (Cunha & Wasterlain, 2007). The sample studied comprises 302 individuals (females: 154; males: 148), with an age at death ranging from 20 to 96 years old (M = 51.79; SD = 18.67; Table S1). All individuals were born in Portugal between 1827 and 1914 and died between 1910 and 1936 (i.e., before the introduction of biomedical therapies for bone loss).

Conventional radiogrammetry was used to assess cortical parameters (DTW: diaphysis total width, MW: medullary width, and MCI: metacarpal cortical index) at the second metacarpal midpoint (Ives & Brickley, 2004; raw data available upon reasonable request). MCI is defined as follows:

$$\mathrm{MCI} = \frac{\mathrm{DTW} - \mathrm{MW}}{\mathrm{DTW}} \times 100.$$

Radiographs were obtained in a digital radiographic system (Senographe DS, GE Healthcare) at the Coimbra University Hospitals (focal distance 50 cm, Kv 27–30 and mAseg 14–20, in compliance with the characteristics of each bone), and measurements were performed with Centricity DICOM Viewer 3.1.1.

Osteoporotic, or fragility, fractures (vertebrae, hip, distal radius, and proximal humerus) were macroscopically recorded with the support of clinical and paleopathological protocols (Curate, 2011; Curate, 2014; Curate, Silva, & Cunha, 2016; Lovell, 1997; Mays, 2006a; Müller, Nazarian, Koch, & Schatzker, 1990). Hip fractures were specified as those occurring above a 5-cm point underneath the lesser trochanter up until the apex of femoral head. Distal radius fractures were identified as those observed at the distal and metaphyseal areas of the radius. Proximal humerus fractures were defined as those that occurred from the apex of the humeral head up until the surgical neck. A semiquantitative evaluation (the method of Genant, Wu, & Vankuijk [1993] modified by Curate et al., 2016) was applied to vertebral compression fractures.

Descriptive statistics including group means, standard deviation (SD) and 95% confidence intervals (95% CI) were estimated for each variable studied. Normal distribution for quantitative variables was evaluated through skewness and kurtosis. As such, with values of|Ku| < 2 and|Sk| < 2, it was assumed that a violation of normality was not an issue. Homoscedasticity was assessed with a Levene's test. A Student's t test was employed to consider the null hypothesis that the means of two groups were equal. Linear Pearson correlation was used to evaluate a possible linear relationship between two quantitative variables. Logistic regression (stepwise variable selection; Forward Conditional method) was applied to evaluate the relationship between an outcome variable (presence vs. absence of fractures) and a set of explanatory variables (age [at death], sex, and MCI). Local polynomial regression fitting smoothing was used to graphically summarize nonlinear empirical relationships between variables (Cleveland, 1979). A subsample of 25 metacarpals was analysed in two consecutive days to assess intra-observer error. Inter-observer error was also evaluated in the same metacarpals. Both measurement errors were estimated with the relative technical error of measurement (rTEM, Ulijaszek & Kerr, 1999), and rTEM values less than 5% were considered precise.

All statistical and graphical analyses were performed with R programming language (Chang & Wickham, 2018; R Development Core Team, 2018) and IBM SPSS v. 20.0.

3 | RESULTS

3.1 | Metacarpal cortical bone loss

Measurement error for both cortical measurements was always less than 5% (Table S2).

Descriptive and test statistics are summarized in Tables 1, 2, 3, and S3. Diaphysis total width (DTW) and metacarpal cortical index (MCI) are significantly larger in men. Medullary width (MW) is larger in women but the differences are not statistically significant. However, MW is significantly larger in older women (individuals with more than 60 years of age) when compared with age-matched men (Table S3).

MW and MCI in women are linearly correlated with age at death (Pearson's $r_{\mathrm{MW*age}}$: 0.425; p < 0.001/Pearson's $r_{\mathrm{MCI*age}}$: −0.497; p < 0.001). Both parameters exhibit a moderate significant bivariate

TABLE 1 Mean values of DTW (in mm) according to sex and age class (CISC)

Age class	Females				Males			
	Mean	*SD*	95% CI	*N*	*Mean*	*SD*	95% CI	*N*
20–29	7.14	0.67	6.84, 7.45	22	7.93	0.78	7.54, 8.32	19
30–39	7.28	0.63	7.01, 7.55	26	7.95	0.80	7.64, 8.26	28
40–49	6.93	0.62	6.66, 7.21	23	8.11	0.80	7.78, 8.44	26
50–59	7.16	0.43	6.99, 7.34	28	8.03	0.63	7.76, 8.30	25
60–69	7.03	0.77	6.60, 7.45	16	7.97	0.63	7.69, 8.25	22
70–79	7.27	0.56	7.00, 7.54	21	7.98	0.72	7.65, 8.32	21
80+	7.17	0.74	6.80, 7.54	18	8.29	1.21	7.16, 9.41	7
Total	7.14	0.62	7.04, 7.25	154	8.01	0.75	7.89, 8.14	148

Note. CISC: Coimbra Identified Skeletal Collection; DTW: diaphysis total width.

TABLE 2 Mean values of MW (in mm) according to sex and age class (CISC)

Age class	Females				Males			
	Mean	*SD*	95% CI	*N*	*Mean*	*SD*	95% CI	*N*
20–29	3.45	0.96	3.01, 3.89	22	3.77	0.99	3.27, 4.27	19
30–39	3.62	0.95	3.21, 4.04	26	3.79	1.18	3.33, 4.25	28
40–49	3.09	0.91	2.69, 3.48	23	4.00	1.09	3.55, 4.45	26
50–59	3.78	0.64	3.53, 4.04	28	3.84	1.32	3.28, 4.40	25
60–69	4.36	0.87	3.88, 4.85	16	3.75	1.00	3.31, 4.20	22
70–79	4.14	0.63	3.84, 4.44	21	3.81	0.83	3.42, 4.20	21
80+	4.67	1.06	4.14, 5.20	18	4.68	1.10	3.66, 5.70	7
Total	3.82	0.98	3.66, 3.98	154	3.87	1.09	3.69, 4.05	148

Note. CISC: Coimbra Identified Skeletal Collection; DTW: diaphysis total width.

association with age at death (Figures 1 and 2). DTW is not correlated with age at death (Pearson's $r_{DTW*age}$: 0.002; $p = 0.772$). Cortical bone net loss between the first adult (20–29 years) and the seventh (80+ years) decades is 32.6%, with an average loss of 4.6% per decade. The pattern of net loss is irregular, with marginal variation in the first years of adulthood. Between the fifth and sixth decades, net cortical loss intensifies—reaching 15.6%. Periosteal apposition (using DTW as surrogate) is negligible, whereas endocortical loss (with MW functioning as proxy) increases by 35.4%. Cortical bone parameters are not associated with age at death in men (Pearson's $r_{DTW*age}$: 0.043; $p = 0.605$/ Pearson's r_{MW*age}: 0.050; $p = 0.554$/Pearson's $r_{MCI*age}$: −0.036; $p = 0.665$; Figures 3 and S1).

3.2 | Fragility fractures

The prevalence of fragility fractures of any type (hip, vertebral bodies, distal radius, and proximal humerus) in the overall sample is 14.9% (45/302; Table 4). The prevalence is similar for men (15.5%; 23/148) and women (14.3%; 22/154; Table S4). The overwhelming majority of fractures among women was observed in individuals older than 50 years (95.5%; 21/22), especially after the seventh decade of life (68.2%; 15/22). In the group of males, 69.6% (16/23) of the fractures were observed in individuals older than 50 years, with the remaining 30.4% (7/23) recorded at younger ages. On average, men with a fragility fracture are older (*M* = 58.5; *SD* = 17.1 years) than those without (*M* = 49.5 years; *SD* = 17.6; Student's *t* = −2.254; *df* = 146; $p = 0.026$), with a matching tendency—even if more evident—among women (fractured: *M* = 70.7 years; *SD* = 13.7/nonfractured: *M* = 49.6 years; *SD* = 19.8; Student's *t* = −5.056; *df* = 152; $p < 0.001$).

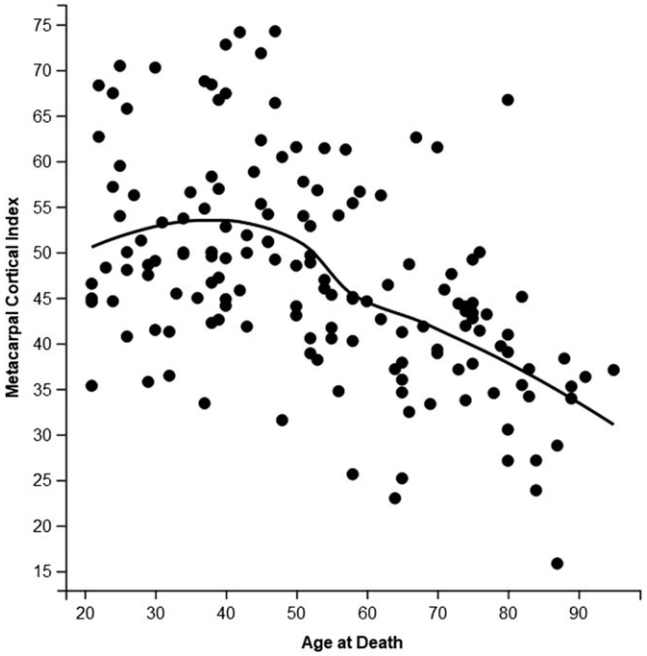

FIGURE 1 Local polynomial regression fitting smoothing for metacarpal cortical index and age at death in (females, Coimbra Identified Skeletal Collection sample)

Women with a fragility fracture of any type tend to possess a larger medullary width (fractured: *M* = 4.41; *SD* = 0.86/ nonfractured: *M* = 3.72; *SD* = 0.97; Student's *t* = −3.110; *df* = 152; $p = 0.002$) and a reduced metacarpal cortical index (fractured: *M* = 38.97; *SD* = 9.51/ nonfractured: *M* = 48.60; *SD* = 11.17; Student's *t* = 3.814; *df* = 152; $p < 0.001$). Men with a fragility fracture exhibit a larger diaphysis width (fractured: *M* = 8.41; *SD* = 0.74/nonfractured: *M* = 7.95; *SD* = 0.74; Student's *t* = −2.700; *df* = 146; $p = 0.008$). In the logistic regression (LR) model (overall sample,i.e., both sexes combined), only the variable «age» (β = 0.046; Wald = 21.769; $p < 0.001$; odds ratio = 1.047) exerted a significant effect on the probability of exhibiting a fragility fracture of any type.

Vertebral compression fractures (Figure 4) are the most common in the CISC overall sample (11.9%; 36/302), followed by distal radius (3.6%; 11/302), hip (1.7%; 5/302), and proximal humerus fractures

TABLE 3 Mean values of MCI according to sex and age class (CISC)

Age class	Females				Males			
	Mean	*SD*	95% CI	*N*	*Mean*	*SD*	95% CI	*N*
20–29	52.16	10.17	47.65, 56.67	22	52.84	12.21	46.95, 58.73	19
30–39	51.06	9.69	47.15, 54.97	26	52.66	12.71	47.73, 57.59	28
40–49	55.71	11.42	50.76, 60.65	23	50.28	11.46	45.65, 54.91	26
50–59	47.66	8.76	44.26, 51.05	28	53.16	13.74	47.48, 58.83	25
60–69	40.23	10.29	34.75, 45.72	16	52.88	11.33	47.85, 57.91	22
70–79	43.05	6.03	40.30, 45.80	21	52.66	11.17	47.57, 57.75	21
80+	35.14	10.45	29.95, 40.34	18	43.94	6.54	37.89, 50.00	7
Total	47.21	11.43	45.39, 49.03	154	52.08	11.96	50.12, 54.04	148

Note. CISC: Coimbra Identified Skeletal Collection; DTW: diaphysis total width.

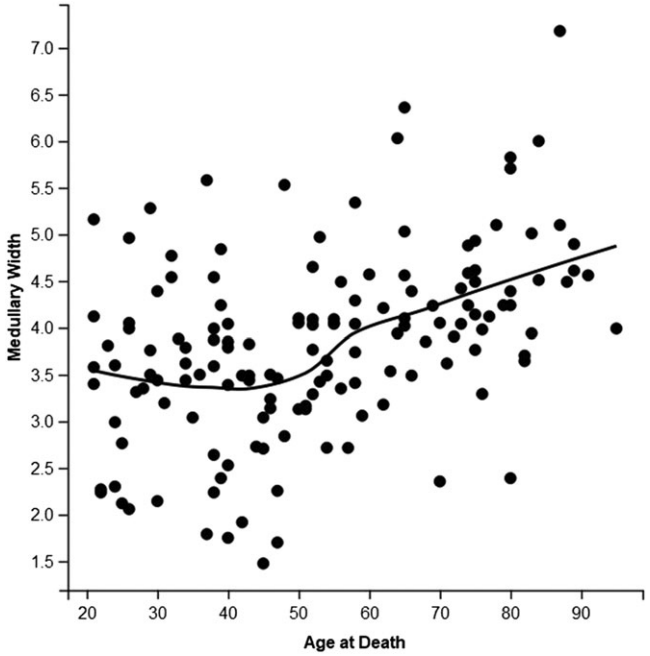

FIGURE 2 Local polynomial regression fitting smoothing for medullary width (mm) and age at death (females, Coimbra Identified Skeletal Collection sample)

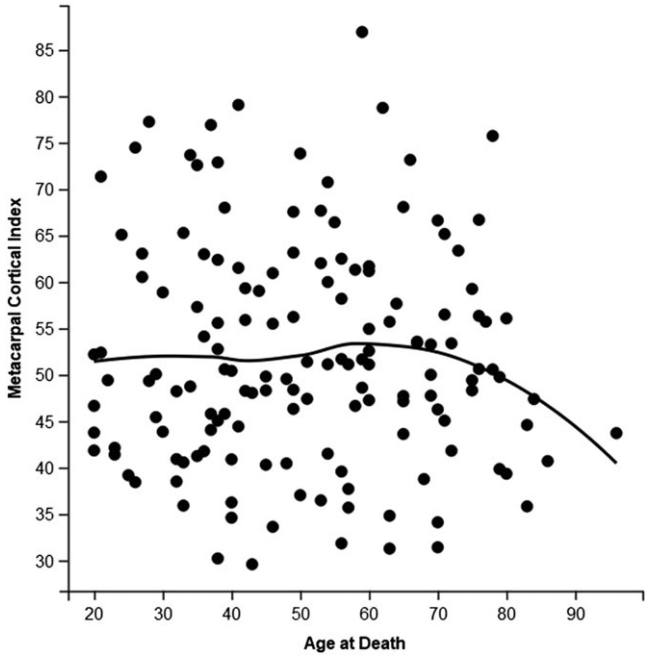

FIGURE 3 Local polynomial regression fitting smoothing for metacarpal cortical index and age at death (males, Coimbra Identified Skeletal Collection sample)

(1.3%; 4/302). In the females' group, vertebral compression fractures are also the most prevalent (10.4%; 16/154), trailed by distal radius (4.5%; 7/154), hip (1.9%; 3/154), and proximal humerus fractures (1.9%; 3/154). Vertebral fractures are also the more frequent in men (13.5%; 20/148), followed by distal radius (2.7%; 4/148), hip (1.4%; 2/148), and proximal humerus fractures (0.7%; 1/148). Differences in prevalence between sexes are not significant.

TABLE 4 Prevalence of fragility fractures (hip, distal radius, proximal humerus, and vertebrae) in the CISC sample, according to sex and age class

Age class	Females			Males		
	%	*n*	*N*	%	*n*	*N*
20–29	-	-	22	-	-	19
30–39	3.8	1	26	14.3	4	28
40–49	-	-	23	11.5	3	26
50–59	17.9	5	28	17.4	4	25
60–69	6.2	1	16	22.7	5	22
70–79	33.3	7	21	19.0	4	21
80+	44.4	8	18	42.9	3	7
Total	14.3	22	154	15.5	23	148

Note. *N*: number of individuals in each age/sex categories; *n*: number of individuals with fractures; %: prevalence of fragility fractures; CISC: Coimbra Identified Skeletal Collection; DTW: diaphysis total width.

FIGURE 4 Vertebral compression fracture in the fourth lumbar vertebra, grade 3, wedge (female, 58 years, MCI = 25.63, Z-score = −2.51) [Colour figure can be viewed at wileyonlinelibrary.com]

Women with vertebral compression fractures are significantly older (M = 70.63 years; SD = 14.13) than women without this type of fracture (M = 50.54 years; SD = 19.03; Student's t = −4.087; df = 152; p < 0.001; Table S5). MW is larger in women with a vertebral fracture (fractured: M = 4.48; SD = 0.92/nonfractured: M = 3.74; SD = 0.97; Student's t = −2.924; df = 152; p = 0.004), whereas MCI is significantly lower in women with a compression fracture of the vertebral body (fractured: M = 37.95 years; SD = 10.17/nonfractured: M = 48.30 years; SD = 11.11; Student's t = 3.555; df = 152; p < 0.001). In the males' group, individuals with vertebral fractures are slightly older (fractured: M = 56.25 years; SD = 16.74/nonfractured = 50.09; SD = 17.80), but the difference is not significant (Student's t = −1.450; df = 146; p = 0.149). DTW in men with a vertebral compression fracture is significantly larger (fractured: M = 8.39; SD = 0.61/nonfractured: M = 7.96; SD = 0.76; Student's t = −2.332; df = 146; p = 0.021). Logistic regression (overall sample) suggests that only «age» influenced the probability of suffering a vertebral compression fracture (β = 0.037; Wald = 12.829; p < 0.001; odds ratio = 1.037).

Descriptive statistics for fractures of the hip, distal radius, and proximal humerus are summarized in Tables S4, S6, S7, and S8. All distal radius fractures were observed in individuals with an age at death exceeding 50 years, and all hip and proximal humerus fractures (Figures 5 and 6) were recorded in individuals older than 70 years. For these types of fracture, no statistical analysis was undertaken due to the small sample size.

4 | DISCUSSION

4.1 | Metacarpal cortical bone loss

In the CISC sample, sexual differences in metacarpal cortical parameters result from gendered disparities in the rate and pattern of bone loss and also bone dimensions (Samuel, Baran, Wei, & Davis, 2009; Seeman, 2013). On average, men have larger bones, enduring a longer period of skeletal maturation (Doyle, Lazenby, & Pfeiffer, 2011; Seeman, 2002, 2008). Androgen increases periosteal bone formation, stimulating the enlargement of diaphyseal diameters (Seeman, 2002). In women, oestrogen production increases after puberty, possibly constraining periosteal bone formation (Seeman, 2008; Gosman, Stout, & Larsen, 2011). Bone growth is also regulated by mechanical loading and nutrition, among others, and the impact on bone size might be gender-specific (Gilsanz et al., 1997; Gosman et al., 2011; Nieves et al., 2004). Cortical skeletal surfaces influenced by sex hormones are very responsive to mechanical loads (Gosman et al., 2011), especially the endocortical surface (Birkhold et al., 2016). Men in the CISC sample were mostly manual workers, with strenuous workloads (e.g., railroader or farmer), but women also faced a lifestyle that encompassed demanding physical work (Cunha & Umbelino, 1995). The scarcity of animal proteins and dairy products during growth is well-known for the Coimbra underprivileged classes in the early 20th century (Lopes, 1999; Pereira, 1975) and affected both sexes—but probably more young women (Pereira, 1975).

FIGURE 5 Hip fracture, intracapsular, with cervical resorption (male, 78 years, MCI = 50.58, Z-score = −0.19) [Colour figure can be viewed at wileyonlinelibrary.com]

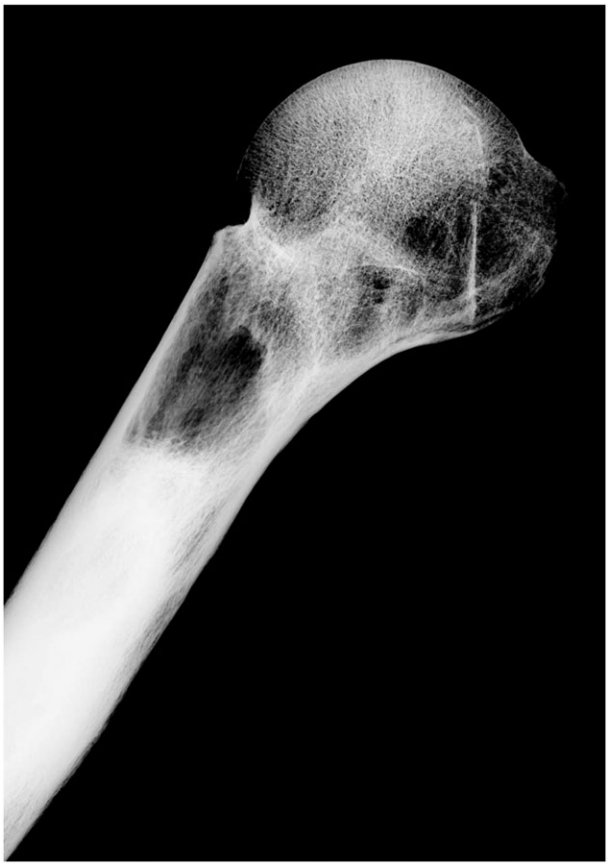

FIGURE 6 Fracture of the right proximal humerus, surgical neck, severe angulation (X-ray, female, 73 years, MCI = 33.74, Z-score = −1.54)

In this sample, MW and MCI are similar in both sexes during the first decades of adult life. However, after the fifth decade (60–69 years), the differences become obvious, with net cortical loss in women reaching its peak between the fifth and sixth decades. Oestrogen withdrawal around menopause increases bone remodelling, with less bone being formed, and more resorbed at the basic multicellular units (Khosla, 2013; Seeman, 2008). Menopause age is not known for the women in the CISC sample, but the average age of menopause in past populations most likely varied between 45 and 50 years (Post, 1971). As such, menopausal hormonal changes in women are probably a major cause for the observed sexual differences in MW and MCI. In the CISC, a radiogrammetric study in the femur yielded similar results (Curate & Cunha, 2017). Sexual differences regarding cortical bone loss have been expressed in studies involving both modern (e.g., Barnett & Nordin, 1960; Ginsburg, Kobyliansky, Malkin, & Rudan, 2001; Karasik, Ginsburg, Livshits, Pavlovsky, & Kobyliansky, 2000; Virtamä & Helelä, 1969) and archeological samples (e.g., Agarwal, Glencross, & Beauchesne, 2011; Carlson, Armelagos, & Gerven, 1976; Cho & Stout, 2011; Dewey, Armelagos, & Bartley, 1969; Drusini, Bredariol, Carrara, & Bonati, 2000; Glencross & Agarwal, 2011; Ives, 2007; Mays et al., 1998; Umbelino et al., 2016). Other paleopathological studies found no differences between sexes (e.g., Beauchesne & Agarwal, 2014; Beauchesne & Agarwal, 2017; Mays, 1996).

Age-related changes in the cortical bone are complex but, in general, the cortical bone becomes weaker with age—mainly due to increased endocortical resorption and cortical porosity (Buenzil et al.,

2013; Zebaze & Seeman, 2015). Cortical thinning with age is the consequence of increased resorption depth, reflecting the deeper penetration by bone multicellular units (Han, Palnitkar, Rao, Parfitt, & Nelson, 1996). In this study, cortical bone changes with age are only significant among females—namely, medullary width and cortical index. The cortical bone is maintained during the first decades of life (the same pattern was observed for femoral the cortical bone and BMD at the proximal femur, see Curate & Cunha, 2017; Curate & Tavares, 2018), and an acceleration in bone loss is observed around the fifth decade. Metacarpal medullary cavity diameter increases during ageing due to an imbalance between endosteal bone resorption and formation that eventually prompts bone loss at the endocortical envelope (Boskey & Coleman, 2010). Endosteal bone remodelling increases considerably in perimenopausal and early postmenopausal women and slows down in older women (Clarke, 2008). Metacarpal cortical bone loss in women from the CISC reproduces the general pattern of bone loss with ageing, as observed in the same collection through other methods (Bergot et al., 2009; Curate et al., 2013; Curate & Cunha, 2017). DTW, which functions as a proxy for periosteal apposition and is often viewed as a response adaptation to preserve resistance to bending (Lazenby, 1990), does not increase with age. It is noteworthy that DTW measured in the femur enlarges with age, probably reflecting the fact that the femur is a weight-bearing bone, susceptible to augmented biomechanical loading (Curate & Cunha, 2017).

Men seem to preserve the cortical bone at the second metacarpal through the ageing process—although MCI seems to decrease in older men (sampling bias may have hampered statistical significance because there are only seven males in the oldest age cohort). Bone loss usually occurs with ageing in both women and men, but age-related bone loss occurs much later in men (Khosla, Amin, & Orwoll, 2008). Of course, men do not experience an abrupt loss of gonadal sex steroid secretion (Khosla, 2013). Moreover, men of the CISC were involved in highly demanding activities (not unlike women, though) and possibly benefited from better nutrition (Pereira, 1975). The differential allocation of food according to age and sex, especially during growth, can affect bone health (Cho & Stout, 2011), and although this practice has not been directly confirmed in the CISC collection, the few individuals that died from diseases directly associated with malnutrition were women (Santos, 1995). Also, a socio-economic enquiry conducted in the region of Coimbra in 1906 showed that food rations for women were both quantitatively and qualitatively inferior (Pereira, 1975). In skeletal samples, the cortical bone has been shown to decrease with age in both males and females (Beauchesne & Agarwal, 2014; Beresheim, Pfeiffer, Grynpas, & Alblas, 2018; Ives, 2007; Mays, 2015) or only in females (Mays, 1996; Umbelino et al., 2016). Other studies at the CISC also suggest that cortical bone loss in males is negligible (Bergot et al., 2009; Curate & Cunha, 2017). However, bone mineral density measured through DXA significantly decreased with age in males (Curate et al., 2013).

4.2 | Fragility fractures

The aetiology of osteoporotic fractures is complex, but old age, sex, and bone fragility are major risk factors (Johansson, Kanis, Oden, Johnell, & McCloskey, 2009; Ström et al., 2011). In univariable statistical analysis, MW and MCI in females and DTW in males were associated with fractures. Also, the second metacarpal cortical index, sex and age (at death) were modelled as risk factors for fracture. Logistic regression suggested that only age influenced the probability of exhibiting an osteoporotic fracture of any type or the probability of displaying a vertebral compression fracture. The LR model implies that MCI in a multivariable analysis is not a statistically significant independent risk factor for osteoporotic fractures. These results must be interpreted with caution as they may be, at least to a degree, a consequence of the lumping of different types of osteoporotic fracture—of course, this is not the case for vertebral compression fractures. Also, radiogrammetry is insensitive to early bone loss, and metacarpal radiogrammetry does not assess cortical bone mass in the typical sites of osteoporotic fracture (Bonnick, 2010). Finally, bone mass only correlates to a certain degree with the risk of fracture, and other factors, such as bone quality or the propensity to falls, are involved (Grynpas, 2003).

Osteoporotic fractures are usually more prevalent in women (Alvarez-Nebreda, Jiménez, Rodríguez, & Serra, 2008; Ström et al., 2011), resulting from differences in areal BMD, bone size, and geometry (Seeman, 2008). Nonetheless, overall fracture prevalence in both sexes from the CISC sample is very similar. Prevalence per type of fracture shows that only vertebral fractures are more common in men, in agreement with some epidemiological studies that indicate a similar or higher prevalence in men (e.g., Kudlacek, Schneider, Resch, & Freudenthaler, 2000; Kwok, Gong, & Wang, 2013). A substantial number of vertebral fractures in men affected younger individuals, hinting at an association with occupational hazards and not with bone loss (Zebaze & Seeman, 2003). As previously mentioned, most of the men in the CISC sample were engaged in physically demanding jobs, including agricultural and industrial activities, that increased the exposure to occupational hazards (Cunha & Umbelino, 1995). Interestingly, the only young woman that suffered a vertebral fracture died due to dystocic labour (Curate & Tavares, 2018). On rare occasions, pregnancy-associated osteoporosis can cause vertebral compression fractures (Krishnakumar, Kumar, & Kuzhimattam, 2016), but this woman showed normal BMD values (Curate, 2011).

Age is an independent risk factor for fracture, reflecting the effects of other factors related with ageing, including secondary hyperparathyroidism, sarcopenia, motor performance deficits, cognitive decline, and liability to falls (Durão, Pedrosa, Curate, & Cunha, 2018; Krege et al., 2013). Cortical bone properties are also directly affected by age-related changes (Boskey & Coleman, 2010). Overall prevalence of osteoporotic fractures increases with age, with a similar pattern for each type of fracture. Notwithstanding, a substantial number of vertebral compression fractures in men was observed in younger individuals and probably were not fragility fractures. In archeological contexts, fragility fractures of any type are usually associated with older individuals (Curate, Assis, Lopes, & Silva, 2011; Curate, Lopes, & Cunha, 2009; Ives, Mant, de la Cova, & Brickley, 2017; Lovell, 2016; Mays, 2006b; Umbelino et al., 2016).

Both cortical thinning and trabecular bone loss influence bone fragility but at some skeletal sites of interest—such as the femoral neck—the cortical bone and its geometric and material characteristics seem

the primary determinants of bone strength (Holzer et al., 2009). Cortical parameters (MCI and MW in females and DTW in males) were significant factors in univariable analysis. Notwithstanding, in the logistic regression model, the cortical index of the second metacarpal do not seem to influence the risk of osteoporotic fracture (be it all types of fractures evaluated together or just vertebral compression fractures). Digital X-ray radiogrammetry assesses osteoporotic fracture risk in living populations (Bach-Mortensen et al., 2006; Haugeberg et al., 2004), and Mays (1996) observed an association between low metacarpal cortical index and fractures in females from the medieval site of Wharram Percy (UK). In other archeological samples, that possible relation was not observed (Mays, 2000; Mays, 2006b). The occurrence of «classical» osteoropotic fractures (e.g., vertebral compression fractures and hip fractures) in the archeological record has sometimes being interpreted as a consequence of etiological factors other than bone mass (Antunes-Ferreira, Prates, & Curate, 2018; Umbelino et al., 2016). In another CISC sample, women with a densitometric diagnosis of osteoporosis had a much higher probability of showing an osteoporotic fracture (Curate et al., 2013).

5 | FINAL REMARKS

Metacarpal cortical bone loss patterns in a sample from a Portuguese reference skeletal collection are complex, developing differently along sex and age categories. Endocortical bone loss increases with age in women, particularly in presumed peri- and postmenopausal women, whereas it is unremarkable in men. There was no accretion of bone in the outer diameter of the second metacarpal, in contrast to what was observed in the femur. Cortical parameters of the second metacarpal in men remain essentially unaltered until late in life, with bone strength preserved. The overall prevalence of fragility fractures is apparently influenced by age, whereas metacarpal cortical index does not seem to be an independent risk factor. This investigation presents a few shortcomings, namely, the cross-sectional nature of the data and the dependence on mediolateral axis measurements only for the evaluation of the cortical bone.

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CONFLICT OF INTEREST

The authors state that they do not have any conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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