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Sex- and site-specific, age-related changes in bone density – a Terry collection study

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With 9 figures and 4 tables

Abstract: As modern populations are living longer, age-related health issues have become more common. One growing concern is the age-related bone density loss that increases the individual's risk for fractures, which unfortunately seems to disproportionately afflict women. These fractures are not only detrimental to the individuals' lives but also come with a great economic burden to the societies. Although age-related bone loss is a normal phenomenon, studies on archaeological individuals have demonstrated that the pattern how this occurs has experienced changes due to our changing lifestyles. Hence, to add to our understanding of secular trends in age-related bone loss, we studied age- and sex-related differences in vertebral and femoral bone densities of a recent past population of late 19th and early 20th century Americans. We used a sample of 114 individuals (55 males, 59 females) from the Robert J. Terry Anatomical Skeletal Collection. Peripheral quantitative computed tomography (pQCT) was used to scan the dry bones. We took one scan from the 4th lumbar vertebra and three scans from the femur. The associations between the age, sex and bone density were analyzed. We were able to detect age-related bone loss in both vertebra and femur. It was observed that men tended to lose more bone density on the vertebra, whereas bone loss in women was more pronounced in the femur. We speculate that differences to modern and earlier archaeological populations are related to the major lifestyle differences between the periods.

Keywords: bone density loss; age-related changes; lumbar vertebra; femur; Terry Collection

Introduction

As the number of people reaching older age is increasing so are the age-related health issues. One of these is the age-related bone density loss, often accompanied by osteoporosis, a disease that causes excessive bone loss. Bone loss increases the vulnerability to bone fractures that are not only a heavy economic burden on healthcare systems (Riggs & Melton III 1995) but often lead to a negative impact on people's quality of life (Lips et al. 1999; Fechtenbaum et al. 2005) and can even cause disability and increased mortality (Ensrud et al. 2000; Hasserius et al. 2003).

Bone fractures in older age are common among both sexes (Lunt et al. 1997; O'Neill & The European Prospective Osteoporosis Study (EPOS) Group 2002). However, depending on the definition of a "vertebral fracture", women tend to exhibit a two to three-fold greater incidence of fractures than men (Cummings & Melton 2002; O'Neill & The European Prospective Osteoporosis Study (EPOS) Group 2002). Similarly, women also exhibit twice as many hip fractures as men (Cummings & Melton 2002). Although the differences in bone density are only moderate in younger age (Ebbesen et al. 1999; Duan et al. 2001a; Riggs et al. 2004; Bouxsein & Karasik 2006; Oppenheimer-Velez et al. 2018), age-related changes tend to increase the sex differences in later years. The sex differences have mainly been associated with a greater net-bone density loss that women experience after menopause and their overall smaller bones compared to men (Gilsanz et al. 1994; Duan et al. 2001b; Bruno et al. 2014). Men appear to have a smaller net-bone loss than women due to a larger periosteal growth during aging, that is able to compensate the bone loss (Duan, et al. 2001a; Duan et al. 2001b;

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Seeman 2001). Hence, it has been suggested that men's bone strength decreases less than women during aging (Ruff & Hayes 1988; Duan et al. 2001a; Lauretani et al. 2008).

Previous quantitative computed tomography (QCT) and peripheral QCT (pQCT) studies on vertebral density have indicated that women have either slightly higher or similar total and trabecular densities in younger age compared to men (Ebbesen et al. 1999; Riggs et al. 2004; Bouxsein & Karasik 2006; Oppenheimer-Velez et al. 2018) but tend to lose more density especially after menopause, causing older women to have lower bone densities than older men (Riggs et al. 2004; Bouxsein & Karasik 2006; Hayashi et al. 2011; Oppenheimer-Velez et al. 2018). Similarly, in the femur, the volumetric density of the neck and midshaft has been found to be comparable between sexes in the younger age and even higher in women in case of the neck (Duan et al. 2003; Center et al. 2004; Wang et al. 2005; Peacock et al. 2009). In the older age, a more pronounced difference between the sexes can be found in the mid-shaft density (Taaffe et al. 2003), but no significant difference in the femoral neck density seems to emerge (Center et al. 2004).

Interestingly studies on archaeological samples indicated that the pattern of bone loss might not always have been the same as the one observed in the current post-industrialized societies (Lees et al. 1993; Ekenman et al. 1995; Mays 1996; Mays 2000; Mays 2001; Agarwal et al. 2004; Mays 2006; Mays et al. 2006; Agarwal & Grynpas 2009; Agarwal 2012; Beauchesne & Agarwal 2017). For example, Agarwal (2012) found difference in bone loss between rural and urban sites. In rural context both men and women lost bone in younger but not older age. In contrast, in urban setting women tended to lose more density than men similarly to the modern population. Mays (1996; 2000; 2001; 2006) on the other hand, has reported that both earlier medieval and later industrialized women experienced cortical bone loss, whereas only industrialized men were found to show signs of bone loss. These results would seem to indicate that large changes in lifestyles and living environment due to urbanization and industrialization could have influenced the bone density and its age-related loss. This is also supported by research comparing hunter-gatherer, horticultural and industrialized populations that indicated differences in the bone density between the more active and sedentary populations (Chirchir et al. 2017).

One of the largest lifestyle changes in the recent past is due the industrialization which both increasingly draw people to urban environments and facilitated changes in our means to provide to ourselves (Blumin 2006; Barca & Bridge 2015; Atack et al. 2022). As such this is an important period as it could be seen as transformational point between the early urbanization to the modern urban lifestyle. Apart from few archaeological studies offering some insight in bone density of this period, the subject is still relatively scarcely studied. To add to our understanding how the industrialization and urbanization during 20th century has affected the age-related bone density loss, we studied a well-preserved skeletal collection of 19th and 20th century European descent Americans. We are not aware that Terry collection would have been utilized on the subject before. Hence, it can offer us new information on population that lived at the height of industrialization. We chose the pQCT as method, as it has been used in few earlier studies of archaeological individuals and skeletal collection with promising results (Suby et al. 2009; Agarwal 2012; Chirchir et al. 2015; Chirchir et al. 2017).

Since lifestyle (e.g. physical activity and diet) have been demonstrated to affect bone density loss (Dawson-Hughes et al. 1997; Puntila et al. 2001; Vuillemin et al. 2001; Devine et al. 2004; Di Daniele et al. 2004; Daly et al. 2008; Chastin et al. 2014), it is beneficial to see how the changes in lifestyle in the last hundred years may have affected bones' aging process. In addition, our previous study on the age-related trends in the vertebral dimensions on 119 individuals from the Terry skeletal collection found no convincing evidence of a great increase in dimensions during aging (Junno et al. 2015), giving us grounds to consider that the potential age-related differences in this population may be more prominent in bone mineral properties than geometry.

As the period in this study encased a great increase in urbanisation, we are expecting that the results may show age-related bone loss trends that are closer to those observed in the contemporary populations, but might still partly reflect past conditions. Hence, we hypothesize to find at least partly similar age-related changes in bone density to those that have been reported by the previous studies on contemporary populations, based on the earlier studies of the past populations that have indicated similar bone loss trends in urban, industrialized population and modern population compared to agricultural populations (Mays 2000; Mays 2001; Agarwal 2012). These modern age-related trends include 1) similar bone density between sexes in younger age, 2) the greater bone loss in females in both sites, and 3) the femoral shaft is likely to loss least amount of density (Hannan et al. 1992; Yu et al. 1999; Riggs et al. 2004; Marshall et al. 2006; Sigurdsson et al. 2006; Lang et al. 2012; Oppenheimer-Velez et al. 2018).

Material

The present sample consisted of 114 human skeletons from the anatomical Terry Collection, originally included an industrial working-class population of an Anglo-American origin from the late 19th and early 20th century (Hunt & Albanese 2005). Adult cadavers with a broad age spectrum (24–77 years) were selected. Individuals with visible pathologies were excluded. We are utilizing the same sample as our earlier study (Junno et al. 2015), except we left five individuals out as they were missing at least one density value. Age at death, sex, and occupation (if known) were obtained from the Terry Collection database.

Methods

Computed tomography scanning

pQCT scans of the fourth lumbar vertebra (L4), femoral neck, femoral head, and the femoral diaphysis of each specimen were obtained using a Stratec XCT Research SA scanner (Stratec Medizintechnik GmbH, Pforzheim, Germany) which is an automated system for the measurement of bone density in bone samples (Ferretti 1999). Scans were analyzed using the manufacturer's software version 6.20 with built-in algorithms for converting the CT scan into quantitative bone density measures (Augat et al. 1998). Slice thickness and pixel size were set at 0.7 mm and 100 µm, respectively. A hydroxyapatite phantom was used with daily quality assurance (measurement error < 1 %).

Specific sites of the scans are demonstrated in Figs 1 and 2. As regards the vertebrae, a frontal scan was performed on the middle part of the corpus of L4. The site was chosen due to the fact that human vertebrae are primarily loaded in the longitudinal direction (Ferguson & Steffen 2003; Adams & Dolan 2005). Correspondingly, one slice (perpendicular to the diaphysis) was obtained from the middle part of the femoral diaphysis, the second slice was from the femoral neck, and third from the femoral head which was scanned perpendicular to the head-neck axis, midway between the lateral border of the articular surface and the medial extent of the articular surface along the head-neck axis.

For each scan, the appropriate region of interest (ROI) was detected automatically by the software. All the vertebral and femoral densities (mg/cm^3) were obtained from the output of the pQCT software using the method described by Chirchir et al. (2017).

Statistical analysis

The data was analyzed using the SPSS software (IBM, Armonk, NY, USA) version 26. Two age groups, < and ≥ 50 years were created based on the specimens' known ages at death. We compared the bone densities across the groups in terms of eight outcome variables: (1) vertebral total density (VtotD), (2) vertebral trabecular density (VtraD), (3) femoral head total density (FHtotD), (4) femoral head trabecular density (FHtraD), (5) femoral neck cortical density (FNcrtD) and (6) femoral shaft cortical density (FcrtD). The cut-off was set at 50 years since it provided the most even age categories among the sample (young: n = 59, old: n = 55) and seems to be an important cut-off after which the deterioration of bone quality markedly increases (Eastell & Lambert 2002; Felsenberg et al. 2002; Bergström et al. 2008; Compston et al. 2009).

First, the connection of the vertebral and femoral densities to one another, age, and age group was tested using bivariate correlation analysis. Differences between the age groups were then analyzed with linear regression. An independent sample t-test was used to study sex differences in bone densities. p-values of < 0.05 were considered statistically significant.

In a supplementary analysis, three age groups (< 40, 40–50, > 50 years) were constructed and compared using analysis of variance (ANOVA) with Scheffe's post hoc test.

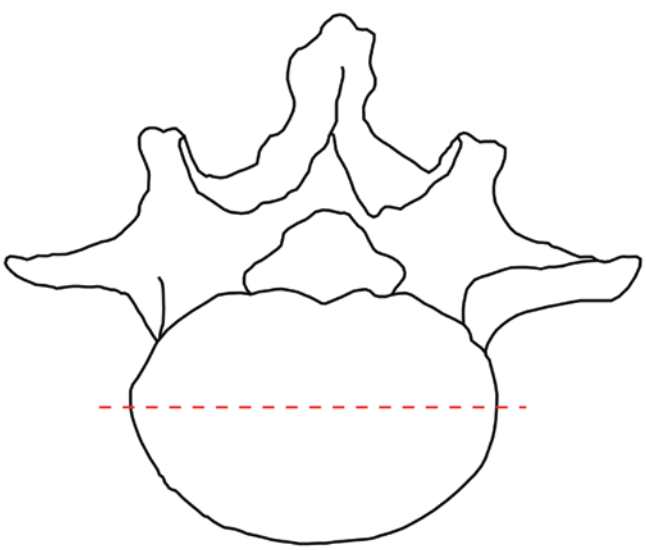

Fig. 1. Illustrates the specific site on L4 where the pQCT scan was taken.

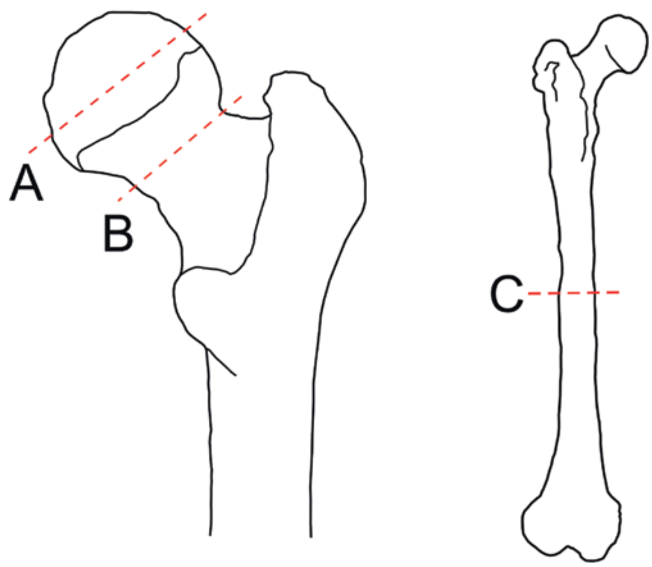

Fig. 2. Demonstrates the specific sites on the femur where the pQCT scans were taken. **(A)** illustrates the scan taken from the head, **(B)** the neck, and **(C)** the shaft.

Results

The means of the sex and age groups and the differences between them are shown in Table 1 and Figs 3–8 illustrate the changes in the densities during ageing for both sexes. Slight to moderate age-related bone loss was detected in all the bone sites for the pooled sex sample. The greatest difference between age groups in the pooled sample was in the VtraD (–17 %). For the men, the greatest difference was also found in the VtraD (–20 %) and after that in the VtotD (–15 %). The men´s femoral densities had an almost non-existent change between the age groups (between –2 % and –5 %). The women, on the other hand, demonstrated largest difference between the age groups in the FHtotD (–20 %) and the FHtraD (–20 %). Rest of the vertebral and femoral densities experienced moderated decreases between age groups (between –11 % and –14 %). Differences between sexes were extremely small in the vertebra and only decreased in the older group. In the femur, the largest differences between sexes were found in the femoral head and shaft. In both, the decrease in density was greater in women and hence increasing the sex differences in the older age group.

The Pearson bivariate correlations were done using both the age as continues variant and the two age groups, < and ≥ 50 years (Table 2). They showed a statistically significant negative correlation sample between age and the VtraD (r = –0.430, with age group r = –0.427), VtotD (r = –0.386, with age group r = –0.353), FHtraD (r = –0.355, with age group r = –0.288), FHtotD (r = –0.343, with age group r = –0.285), FNcrtD (r = –0.239, with age group r = –0.245) and FcrtD (r = –0.459, with age group r = –0.423) in the pooled sample. The men´s sample showed slightly stronger negative correlation between age and VtraD (r = –0.442, with age group r = –0.479) and VtotD (r = –0.410, with age group r = –0.405) densities than women's (r = –0.414 and r = –0.354 respectively, with age group r = –0.372 and r = –0.306). However, only the women showed statistically significant negative correlations between age and the FHtraD (r = –0.547, with age group r = –0.499), FHtotD (r = –0.541, with age group r = –0.506), FNcrtD (r = –0.300, with age group r = –0.343) and FcrtD (r = –0.645, with age group r = –0.609).

The linear regression analysis (Table 3) for the pooled sample showed that the VtotD ($p < 0.001$), VtraD ($p < 0.001$), FHtotD ($p = 0.001$), FHtraD ($p = 0.001$), FNcrtD ($p = 0.007$) and FcrtD ($p < 0.001$) were smaller at the older age. For men, only the VtraD and VtotD were lower in the older age group ($p < 0.001$ and p = 0.002, respectively). For women, all the vertebral and femoral densities showed decline between the age groups ($p < 0.005$). In the independent student t-test (Table 4) only FHtotD, FHtraD and FcrtD showed statistically significant difference between sexes in the pooled ($p < 0.001$ for all) and old age ($p < 0.001$ for all) samples.

Table 1. Presents the mean bone densities in different categories (sex, age and age/sex specific groups) and shows the the changes in bone densities between age and sex groups.

	Pooled sex		Change between age groups✳	Men		Change between age groups✳	Women		Change between age groups✳	Difference between sexes (women to men)★		Pooled ages		Differences between sexes (women to men)★
	Young	Old		Young	Old		Young	Old				Men	Women	
N	59	55		28	27		30	29		Young	Old	55	59	
Density	Mean	Mean	%	Mean	Mean	%	Mean	Mean	%	%	%	Mean	Mean	%
VtotD¶ (mg/cm³)	360.1 ± 61.3	311.7 ± 67.9	–13 %	371.7 ± 64.1	317.4 ± 62.7	–15 %	349.5 ± 58.7	307.9 ± 72.6	–12 %	–6 %	–3 %	345.0 ± 68.6	329.0 ± 68.6	–5 %
VtraD† (mg/cm³)	271.1 ± 55.5	225.5 ± 40.0	–17 %	278.7 ± 61.1	223.2 ± 40.8	–20 %	264.5 ± 50.6	228.7 ± 39.5	–14 %	–5 %	+2 %	251.4 ± 58.8	246.9 ± 48.6	–2 %
FHtotD‡ (mg/cm³)	525.3 ± 99.9	461.1 ± 118.0	–12 %	538.6 ± 104.8	527.9 ± 121.7	–2 %	508.3 ± 92.8	406.0 ± 84.4	–20 %	–6 %	–30 %	533.3 ± 112.5	458.0 ± 102.0	–16 %
FHtraD✦ (mg/cm³)	796.6 ± 154.7	695.4 ± 184.5	–13 %	817.1 ± 164.1	795.0 ± 192.7	–3 %	770.3 ± 141.8	613.6 ± 135.1	–20 %	–6 %	–30 %	806.2 ± 177.4	693.3 ± 158.4	–16 %
FNcrtD✢ (mg/cm³)	415.7 ± 70.4	381.3 ± 66.6	–8 %	397.2 ± 69.7	379.1 ± 73.6	–5 %	432.1 ± 68.9	385.5 ± 60.4	–11 %	+8 %	+2 %	388.3 ± 71.5	409.2 ± 68.5	+5 %
FcrtD❖ (mg/cm³)	1057.3 ± 64.7	980.4 ± 99.0	–7 %	1075.5 ± 53.5	1048.0 ± 41.9	–3 %	1042.6 ± 70.6	917.7 ± 93.7	–12 %	–3 %	–14 %	1062.0 ± 49.7	981.2 ± 103.4	–8 %

† Vertebral trabecular density
‡ Femoral head total density
✦ Femoral head trabecular density
✢ Femoral neck cortical density
❖ Femoral shaft cortical density
✳ Calculated as change percentage
★ Calculated as reference percentage

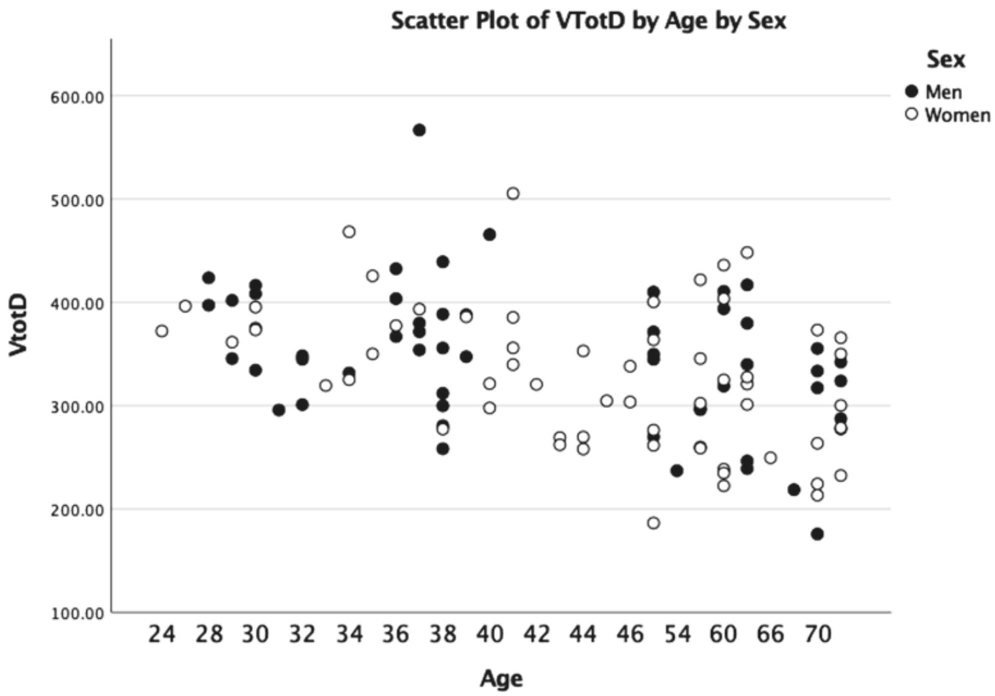

Fig. 3. Scatter plot presenting the distribution of total density according to age in the vertebra for both sexes.

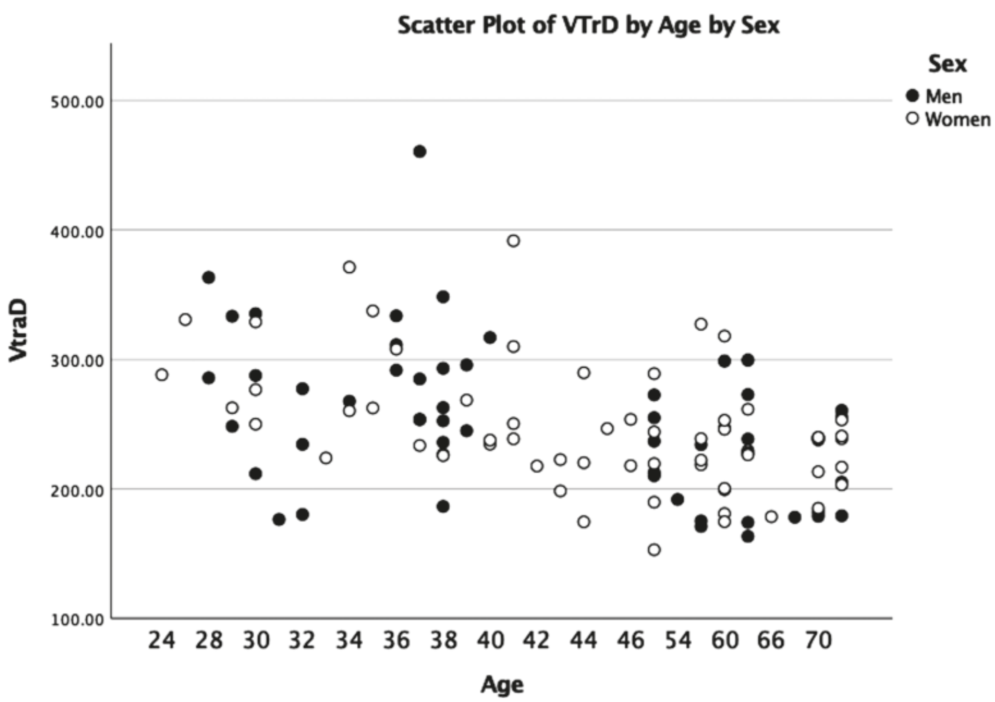

Fig. 4. Scatter plot presenting the distribution of trabecular density according to age in the vertebra for both sexes.

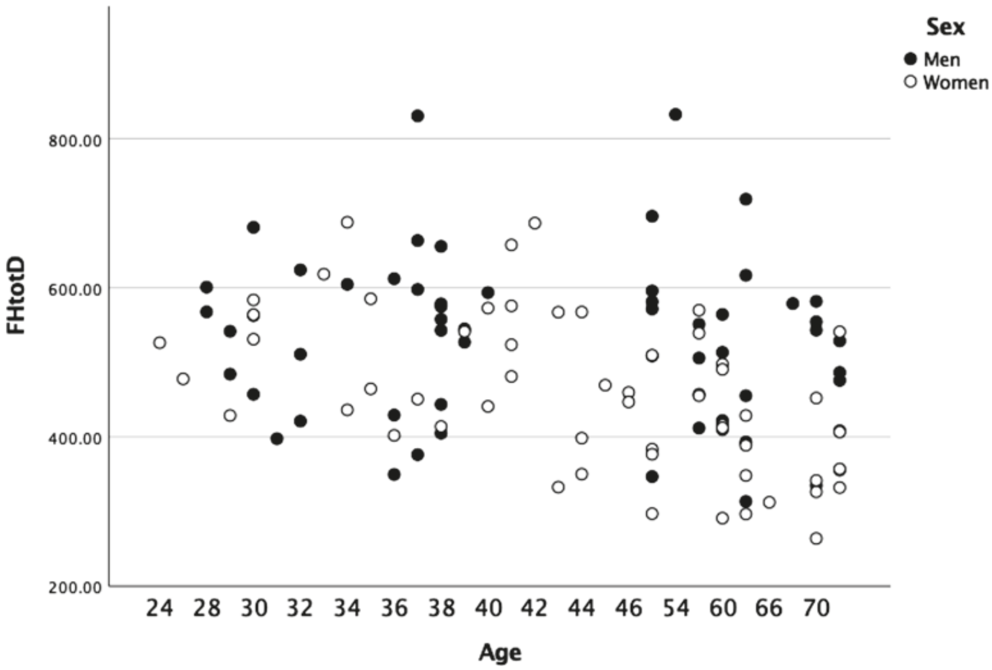

Fig. 5. Scatter plot presenting the distribution of total density according to age in the femoral head for both sexes.

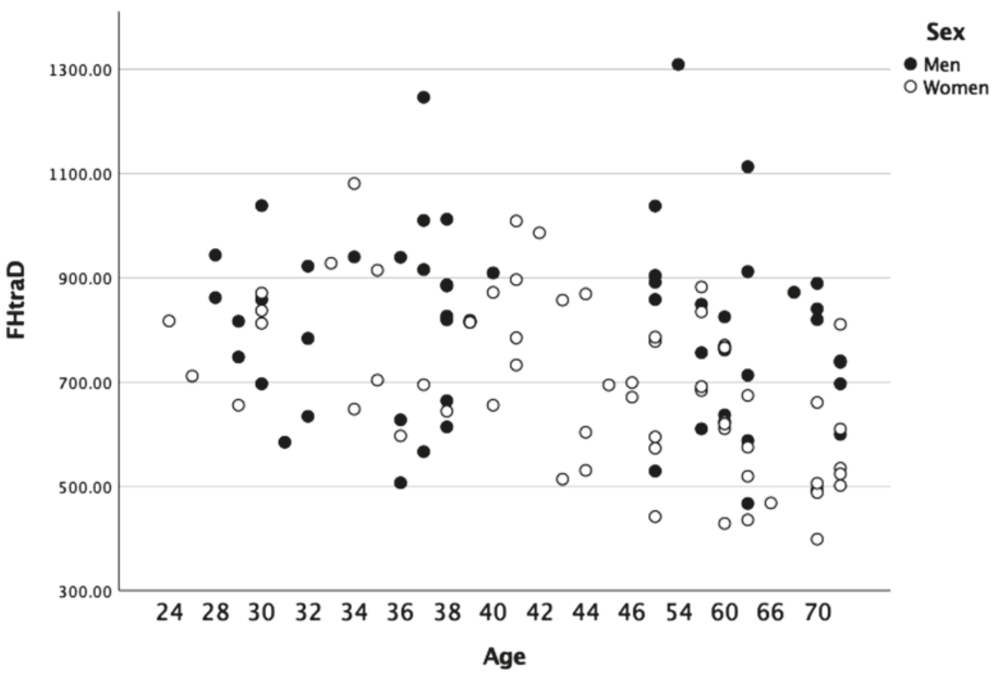

Fig. 6. Scatter plot presenting the distribution of trabecular density according to age in the femoral head for both sexes.

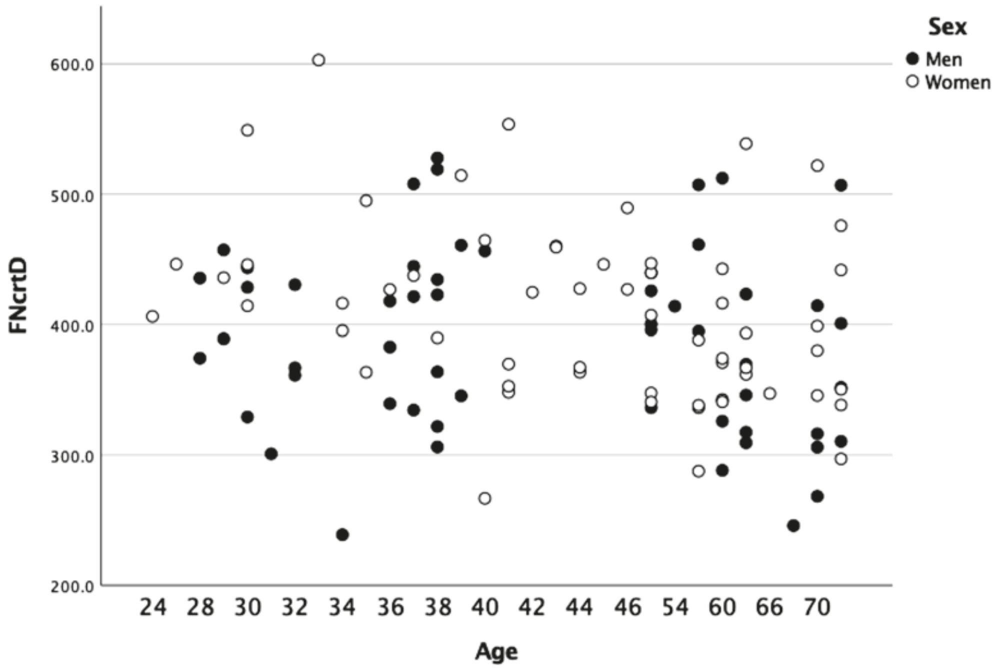

Fig. 7. Scatter plot presenting the distribution of cortical density according to age in the femoral neck for both sexes.

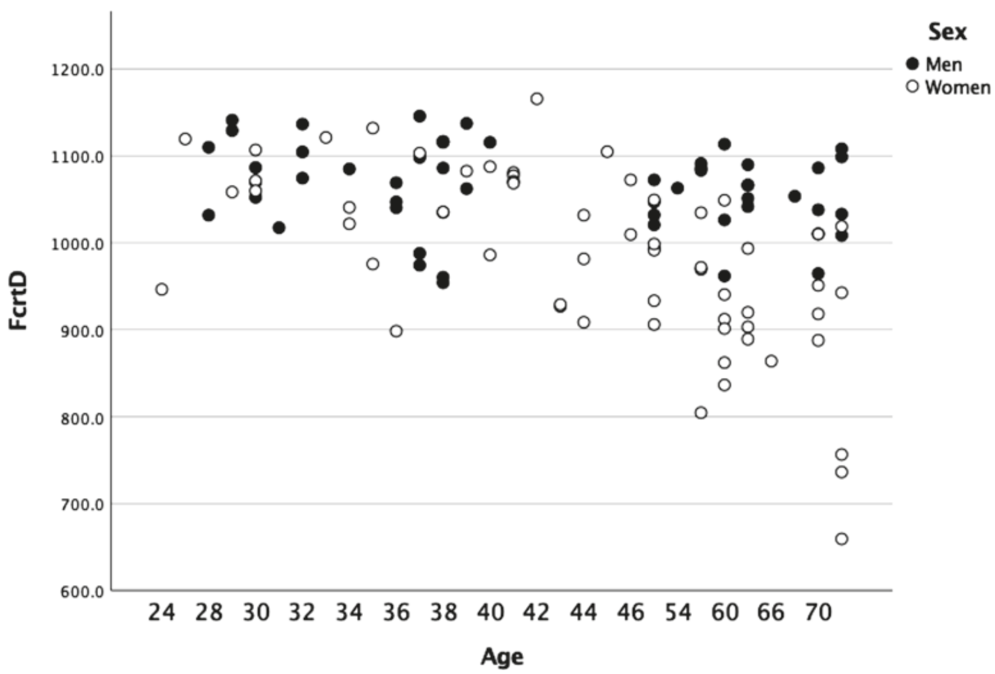

Fig. 8. Scatter plot presenting the distribution of cortical density according to age in the femoral shaft for both sexes.

Table 2. Presents the Pearson´s bivariate correlations between age or agegroup and vertebral densities and femoral densities.

	Pooled		Men		Women	
	Age	Agegroups	Age	Agegroup	Age	Agegroup
VtotD (mg/cm³)	–0.391**	–0.353**	–0.410**	–0.405**	–0.364**	–0.306*
VtraD (mg/cm³)	–0.432**	–0.427**	–0.442**	–0.479**	–0.419**	–0.372**
FHtotD (mg/cm³)	–0.343**	–0.285**	–0.150	–0.091	–0.548**	–0.506**
FHtraD (mg/cm³)	–0.355**	–0.288**	–0.172	–0.105	–0.552**	–0.499**
FNcrtD (mg/cm³)	–0.241*	–0.245**	–0.209	–0.157	–0.303*	–0.343**
FcrtD (mg/cm³)	–0.462**	–0.423**	–0.219	–0.225	–0.656**	–0.609**

* significant at the 0.05 level
** siginificant at the 0.01 level

Table 3. Presents the linear regression results for all densities in pooled sample that was adjusted for age group and sex. Shows also the results for seperated samples of men and women that are adjusted only for the age group.

	Pooled*		Men		Women	
	Lower among older[a]	*p* for age difference	Lower among older[a]	*p* for age difference	Lower among older[a]	*p* for age difference
VtotD (mg/cm³)	–48.1 (–24.2; –72.1)	< 0.001	–55.2 (–20.9; –89.4)	0.002	–41.6 (–7.2; –76.0)	0.019
VtraD (mg/cm³)	–45.5 (–27.3; –63.6)	< 0.001	–55.8 (–27.6; –84.1)	< 0.001	–35.8 (–12.1; –59.5)	0.004
FHtotD (mg/cm³)	–62.8 (–24.6; –101.0)	0.001	–20.2 (41.0; –81.5)	0.511	–102.4 (–56.1; –148.6)	< 0.001
FHtraD (mg/cm³)	–99.1 (–39.3; –158.8)	0.001	–37.1 (59.3; –133.6)	0.444	–156.6 (–84.4; –228.9)	< 0.001
FNcrtD (mg/cm³)	–34.8 (–9.6; –60.1)	0.007	–22.2 (16.4; –60.9)	0.253	–46.6 (–12.7; –80.4)	0.008
FcrtD (mg/cm³)	–79.4 (–52.3; –106.6)	< 0.001	–22.2 (4.3; –48.6)	0.099	–124.9 (–81.7; –168.1)	< 0.001

[a] Beta estimate (95 % confidence interval) according to the linear regression models
* Adjusted for sex

Table 4. Presents the differences between sexes according to the independent student t-test.

Densities	Pooled	Young	Old
	p-value	*p*-value	*p*-value
VtotD (mg/cm³)	0.216	0.177	0.664
VtraD (mg/cm³)	0.655	0.362	0.539
FHtotD (mg/cm³)	< 0.001	0.186	< 0.001
FHtraD (mg/cm³)	< 0.001	0.186	< 0.001
FNcrtD (mg/cm³)	0.114	0.069	0.623
FcrtD (mg/cm³)	< 0.001	0.075	< 0.001

Using the three age categories for ANOVA with Scheffe post hoc showed that men tended to lose density more even pace in vertebrae than women (see Supplement 1). Men showed difference in density between groups 1 and 3 whereas in women trabecular density indicated change already between groups 1 and 2. In femur, women mainly showed change in bone density in later in life between age groups 2 and 3. Only exception being femoral neck that showed more even bone loss during ageing.

Occupation

We were able to find occupation information for 77 individuals (40 men and 37 women) of the sample. The distributions of the occupations for men and women are presented in Fig. 9. We can see that a clear majority of men were laborers or day laborers, whereas almost three-quarters of women were either housewives or had housework listed as their occupation. Next category for both sexes was service or crafts work. Very few had some type of office work or

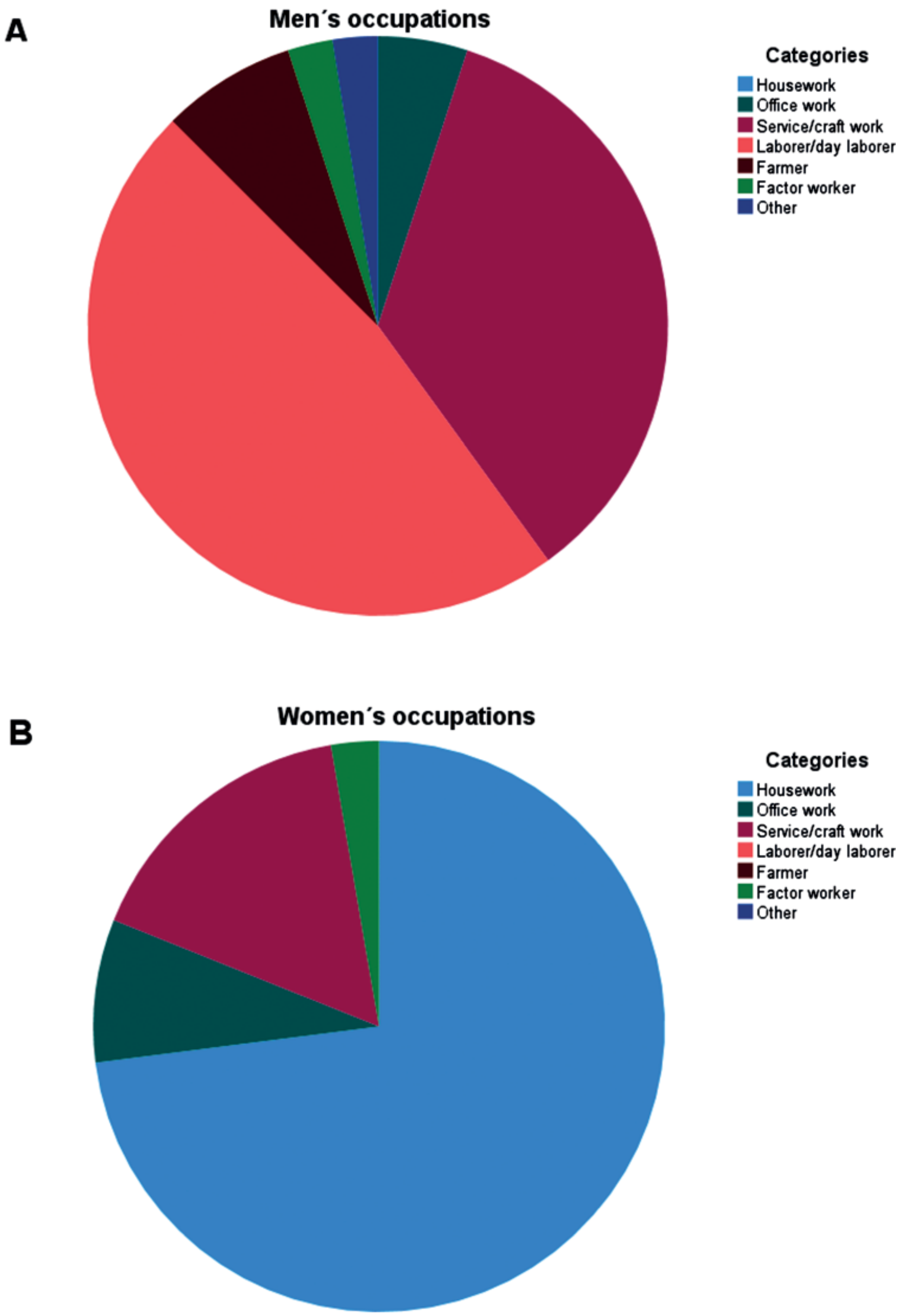

Fig. 9. Pie charts presenting the division of occupations in **(A)** men and **(B)** women.

factory work and only a couple of men were listed as farmers. There was a very clear division between the jobs done by men and women and especially women tended to mainly do housework, whether this meant in their own home or as hired hand.

Discussion

Sex- and age-related changes

In this cross-sectional study, we studied the age- and sex-specific changes in the bone densities of the vertebral body and the femoral head, neck and shaft in a recent past population of industrialized Americans. A slight decline in the bone density between the age groups (< and ≥ 50 years) was observed in all sites. However, only women showed a statistically significant decrease in femoral densities between the age groups. These results, especially for the vertebra, differ from what we could typically find in modern humans but also partly from the earlier populations.

In the contemporary populations CT based studies on the vertebrae (Ebbesen et al. 1999; Riggs et al. 2004; Bouxsein & Karasik 2006; Oppenheimer-Velez et al. 2018;) have suggested that younger aged men and women do not seem to differ in the volumetric trabecular density, which seemed to be the case also in our study. The greater bone loss in modern women compared to men is typically observed most often after the menopause (Riggs et al. 2004; Hayashi et al. 2011; Oppenheimer-Velez et al. 2018), which is in agreement with the observations in the archaeological urban population (Agarwal 2012). However, in archaeological rural populations, it has been observed that both sexes tended to experience bone loss already before an age of 50 (Agarwal et al. 2004; Agarwal & Grynpas 2009; Agarwal 2012). Also, not all studies on the contemporary populations have reported the same results. For example, Ebbesen et al. (1999) observed no sex differences in the loss of trabecular and total densities in the L3 vertebrae. Similarly, Eckstein et al. (2007) found no sex differences in bone microstructure in older individuals for the lumbar vertebrae. In our study both sexes were noted to experience age-related bone loss in vertebrae. Although we mainly studied only two age groups, our results from using three age categories did indicate possible differences in the timing of the bone lose between sexes, as men seemed to lose density more evenly than women and women experienced trabecular bone loss already before age of 50. However, we did not detect larger bone loss in women compared to men; instead, men seemed to lose slightly more density than women. In addition, no statistically significant differences in vertebral bone densities were detected between the sexes in either age group.

In femur, we found no statistically significant difference in the densities between the young adult men and women. The femoral neck showed slightly higher values for women than men, especially at the young age group, although the difference was not statistically significant. Studies on the modern populations have also reported similar results for the femoral neck (Tsai et al. 1997; Duan et al. 2003; Saeed et al. 2009). It has also been shown that women tend to lose more density in the femoral neck than men (Tsai et al. 1997; Marshall et al. 2006; Meta et al. 2006; Sigurdsson et al. 2006; Wang & Niebur 2006), which was also the case in our sample and seems to have been typical in archaeological populations (Lees et al. 1993; Mays 2006) indicating continuum in this feature despite changes in lifestyles. However, not all studies in archaeological populations have shown sex differences in bone loss (Ekenman et al. 1995).

Interestingly, although our women sample showed approximately two-fold bone loss in the femoral neck compared to men, there still was no statistically significant difference between sexes in the bone density in older age. This also seems to be the case in some of the modern populations' studies (Wang et al. 2005), although some have reported lower densities for the older women compared to the men (Tsai et al. 1997).

The bone loss was greatest in the head of the femur for the women, probably due it being the most trabecular-rich part. Previous studies have demonstrated a greater loss in trabecular-rich sites than cortical-containing sites (Beck et al. 2000; Meta et al. 2006). In contemporary human studies, age-related changes in the femoral head have been observed, but unlike in our results, no significant sex-related differences have been noted (Greenwood et al. 2018). Intriguingly, overall in the femur for women, the bone loss seemed to occur later in life than in vertebrae.

For men, density loss was low in the shaft's cortical density. This lines up with what has been reported by previous research on contemporary populations (Marshall et al. 2006). Although studies on the bone mineral density (g/cm^2) have indicated that women would lose more density in the trochanter area than men (Hannan et al. 1992; Tsai et al. 1997), it has also been shown that the cortical bone loss tends to be mild in both sexes (Marshall et al. 2006; Meta et al. 2006; Sigurdsson et al. 2006). It is therefore interesting that our sample indicated such clear sex differences in the shaft's cortical density loss.

Factors underlying the bone loss patterns

We argue that the greatest factor influencing the bone loss differences between the time periods is the level of physical activity, as in the 19th-century and even in early 20th physical activity levels were completely different from those of modern-day societies. Majority of people had an occupation that required at least some level of manual work and weekly working hours were higher than in modern days (Floud et al. 2011). The increased urbanization of the industrialized period also meant changes in occupations compared to the earlier agriculturally oriented societies.

In our sample the majority of men had been recorded as either laborers or day laborers. This label could include a variety of jobs; hence it is hard to label them as a physically demanding category per se, although most of them likely required some level of physical activity. The next most common occupations were service, and crafts works. Very few individuals were labeled as a farmer, factory, or office worker. In women, almost three-quarters were listed as housewives or had housework as their occupation. Apart from that, the next most common occupation category was services and crafts jobs. A couple of women were office workers and only one individual worked in a factory. Although less is known about the employment and retirement of the women from that time period, it is likely that working days were long and strenuous for both sexes. Retirement was not very common. Over half of the men aged 60 and above were reported to still be working in the second half of the 19th century and this did not seem to drop much before the 1930s (Ransom & Sutch 1986). As for housework, especially if it is one's own house, it is not something that one really retires from, so housewives likely continued to work until they could no longer.

Physical activity has been shown to have a mostly positive effect on bone health and hinder bone loss (Langsetmo et al. 2012; Chastin et al. 2014; Johansson et al. 2015; Strope et al. 2015). Although the results are quite varied, some studies have indicated that men might benefit from physical activity more in their femur than women (Nguyen et al. 2000; Vuillemin et al. 2001; Chastin et al. 2014; Johansson et al. 2015). Therefore, we speculate that the men in our sample could have been exposed to harder physical labor until later in life which could have benefitted them in terms of their femoral densities. Women, on the other hand, have been reported not to benefit from physical activity as much, especially regarding the lower limbs (Silman et al. 1997; Puntila et al. 2001; Gerdhem et al. 2003a; Gerdhem et al. 2003b; Gába et al. 2012; Chastin et al. 2014). Rather, some research has indicated that they might benefit more from light activities and standing jobs, especially when it comes to vertebrae (Ebrahim et al. 1997; Silman et al. 1997; Douchi et al. 2000; Puntila et al. 2001). This could indicate that although women in our sample may not have reaped the benefits from chores and activities at home in terms of their femur, it may have been beneficial to their spine. However, it is good to note that housework in 19th and 20th century was quite different than what is today. It was usually a whole day job, meaning long days standing and doing physically laborious work. Unlike with men, women's day lasted from the moment they woke up to moment they went to bed. Even the first electronic devices did not really shorten their day as time that was saved from one chore was often transferred to another (Davidson 1982; Simonton 1998). Some of the housewives could also add to the family's income by either helping with their husband's occupation or practice boarding or inn keeping (Goldin 1993). So, although it might at first glance seem that women were speared from the physically hard work by doing mainly housework this is likely not the case.

The possible beneficial effects of working habits on the women's vertebrae are also supported by results from our previous research on the age-related changes in vertebral dimensions among the same sample. The study indicated that although men did not experience a statistically significant age-related increase in the vertebral cross-sectional area, females did (Junno et al. 2015). This would mean that women experienced larger periosteal increase, maybe due to high physical strain, which could have decreased the net-loss of bone (Duan et al. 2001b). On the other hand, this could also represent site specific microstructural differences between men and women. For example, Eckstein et al. (2007) observed significant sex difference in bone microstructure in the femoral neck and shaft, but not in the lumbar vertebrae.

In addition to physical activities, there are other factors that may have affected the bone density loss. One is the calcium intake, which in modern populations has been demonstrated to have a positive influence on bone density, especially together with physical activity (Dawson-Hughes et al. 1997; Devine et al. 2004; Di Daniele et al. 2004). It has been estimated that dairy and eggs represented around 9 % of the caloric intake during the 19th century, although the proportion of expenditure that people used on non-grain products tended to increase with their wealth (Floud et al. 2011). Yet, in the frame of this study it is difficult to estimate how large an effect this could have had on this population.

As regards the bone loss experienced by the women, one might need to consider the changes that may have affected the hormonal influence of the bone loss, such as the age of menarche, the age of menopause, the number of years of menstruation, the number of children and duration of nursing. All of these have been noted to have some kind of an effect on bone density (Fehily et al. 1992; Vico et al. 1992; Fox et al. 1993; Kritz-Silverstein & Barrett-Connor 1993; Ito et al. 1995; Galuska & Sowers 1999; Ho & Kung 2005; Streeten et al. 2005; Chevalley et al. 2008; Crandall et al. 2017; Lee 2019; Seo et al. 2021). For example, a younger age at menarche, an older age at menopause, and a longer period of menstruation have been shown to have positive effects on bone density (Fox et al. 1993; Kritz-Silverstein & Barrett-Connor 1993; Ito et al. 1995; Galuska & Sowers 1999; Chevalley et al. 2008; Sioka et al. 2010). This is a positive note for modern women since temporal trends seem to be an advantage for all three concepts (Gottschalk et al. 2020). However, again, in the frame of this study it is not possible to consider in detail the influence of these on bone density.

Strengths and weaknesses

The strength of our study is the large sample size of individuals from the well-kept and documented collection that included individuals of different ages. On the other hand, the collection itself might also be a source of bias. Since Terry's skeletal collection consists of individuals mainly from the latter half of 19th century and early 20th century, reaching the age of 60 years, likely meant you were healthier and more robust than your average peer. This could mean that we are comparing weaker individuals (the ones who died at a younger age) to stronger (the ones that lived until old age). Hence, the bone densities in the younger group could have been lower than average or higher than average in the older group. However, we believe that the bias would decrease the age differences rather than increase them. We also acknowledge that we did observe an age-related bone loss in our sample, but it could be less than what would have been observed in a longitudinal study.

Conclusions

We found age-related changes in the lumbar vertebra and three sites in the femur: head, neck, and shaft. The greatest loss of bone density occurred in the most trabecular-rich parts: the vertebral body and femoral head. There were also great differences in bone loss patterns between the sexes. Men lost most density in the lumbar vertebrae whereas women in the femoral head. The loss of cortical density in the femoral neck and shaft was minuscule in men but statistically significant in women. As men have been typically observed to lose less bone density in vertebrae compared to women in contemporary populations, it was unexpected that men lost more density than women. We suggest that these patterns could reflect differences in lifestyle over the time, with men likely required to work late in life which could have benefitted the bone density of lower limbs. Women's vertebrae instead could have benefitted from the slightly lighter activities and long periods of time spent standing while working at home.

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Competing interests

The authors declare no competing interests.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supplement 1. Table presenting the results for ANOVA with Scheffe post hoc for three age categories.

	Group	Age group	N	VtotD	VtraD	FHtotD	FHtraD	FNcrtD	FcrtD
Men	1	< 40	28	367.7	276.4	541.0	820.7	396.8	1071.0
	2	40–50	6	368.7	250.8	564.4	855.1	409.2	1054.4
	3	> 50	21	308.0	218.3	514.1	773.0	371.1	1047.0
		$p < 0.005$		1 vs 3	1 vs 3	NA	NA	NA	NA
Women	1	< 40	15	373.2	282.0	514.4	782.1	449.4	1051.6
	2	40–50	20	318.7	240.1	480.6	727.5	410.2	1019.1
	3	> 50	24	310.0	230.7	404.0	609.2	383.3	905.6
		$p < 0.005$		1 vs 3	1 vs 2	2 vs 3	2 vs 3	1 vs 3	2 vs 3