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TABLE DES MATIÈRES / INHOUDSTAFEL

Erratum

Concerning Emmanuel GILISSEN & Rosine ORBAN, Bone mineral density in femora of documented age at death from Schoten (Belgium, 19th-20th century). Anthropologica et Præhistorica, 131/2020 (2022) : 161-175. https://doi.org/10.57937/ap.2022.007

We apologize for a reference error in the legends of two tables; in the legend of tables 7 and 8, page 172, please read “(see table 6 for the equations)” instead of “(see table 8 for the equations)”.

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Bone mineral density in femora of documented age at death from Schoten (Belgium, 19th-20th century)

Emmanuel GILISSEN & Rosine ORBAN

Abstract

The proportion of older age groups in Western human populations is growing. It is therefore of utmost importance to understand the factors associated with diseases and disabilities due to aging but also to know how these factors are changing in these industrialized populations whose lifestyle and conditions are changing. Among these factors, osteoporosis, often considered absent or rare in pre-industrial populations, is associated with sedentary lifestyle in modern populations. The relationship between decreased bone mass, age, and increased risk of femoral neck fracture is well documented. In this study, we attempted to identify possible secular trends in bone mineral content related to aging in a series of 51 adult skeletons of known age and sex (27 males and 24 females born between 1837 and 1916). All individuals constituting this series were buried in 1930 and 1931 in the old cemetery of Schoten, in the suburbs of Antwerp, Belgium, and were exhumed in 1946. Our results indicate a degradation of bone mineral density during aging that is comparable to that of current Western reference populations. Females appear to have bone health above the current average until the age of 50 years. These results illustrate the variability of bone mineral density between different populations and within human populations over time.

Keywords: Schoten population, bone mineral density (BMD), DXA system, aging, osteoporosis.

Résumé

L'accroissement des groupes de tranche d'âge élevée au sein des populations humaines occidentales change rapidement. Il est donc de la plus grande importance de comprendre les facteurs liés aux maladies et handicaps dus au vieillissement mais aussi de savoir comment se modifient ces facteurs au sein de ces populations industrialisées dont le mode et les conditions de vie changent très rapidement. Parmi ces facteurs, l'ostéoporose, souvent considérée comme absente ou rare dans les populations préindustrielles, est associée à la sédentarité dans les populations modernes. La relation entre diminution de masse osseuse, âge, et augmentation des risques de fracture au niveau du col du fémur est bien documentée. Dans cette étude, nous avons tenté de cerner les possibles changements séculaires (secular trends) du contenu minéral osseux en rapport avec le vieillissement sur une série de 51 squelettes adultes d'âge et de sexe connus (27 hommes et 24 femmes nés entre 1837 et 1916). Tous les individus constituant cette série ont été inhumés en 1930 et 1931 dans l'ancien cimetière de Schoten, dans la banlieue d'Anvers (Belgique), et furent exhumés en 1946. Nos résultats indiquent une dégradation de la densité minérale osseuse lors du vieillissement comparable à celle de populations occidentales actuelles de référence. Les sujets féminins semblent toutefois présenter une santé osseuse au-dessus de la moyenne actuelle jusque l'âge de 50 ans. Ces résultats illustrent la variabilité de la densité minérale osseuse entre différentes populations et au sein des populations humaines au cours du temps.

Mots-clés : *population de Schoten, densité minérale osseuse (DMO), système DXA, vieillissement, ostéoporose.*

1. INTRODUCTION

In a survey written in 2003, Hebert *et al.* made a striking assessment of the rates of change in the proportions of age groups in Western societies; by 2050, due to the rapid growth of the oldest age groups of the US population, the number who are 85 years and older will more than quadruple to 8.0 million, the number who are 75 to 84 years old will double to 4.8 million, the number who are 65 to 74 years old will remain fairly constant at 0.3 to 0.5 million (HEBERT *et al.*, 2003). Although specific regional circumstances could make important differences, the 2019 Revision of World Population Prospects foresees that the world's number of persons aged 65 or over in 2019 should increase from 702.9 million to 1548.9 million in 2050, a percentage change of 120 % (UNITED NATIONS, 2019). A corollary question then arises, with the dramatic changes that occurred in our way of life

since several decades, do we still age the same as before? More specifically, is it possible to observe secular trends in age-related biological parameters in Western European societies? Among these parameters, the bone mineral density (BMD) of the total hip decreases with age. Bone density is an important biological aging parameter because it can help to predict the risk of getting a fracture. In particular, the contribution of post-menopausal bone loss to age-related bone loss causes females to become typically more susceptible to risk of osteoporosis-related fracture compared to males (STINI, 2003; BRICKLEY & IVES, 2008), a striking feature in northern European societies. Moreover, besides gender differences, not all populations show the same bone architecture, bone mineral density or fragility (NELSON &MEGYESI, 2004; RUFFING *et al.*, 2006; ARAUJO *et al.*, 2007; LOOKER *et al.*, 2009; NAM *et al.*, 2010; WANG & SEEMAN, 2012). Age-related bone changes thus exhibit population-related variability in terms of incidence or degree (WALKER *et al.*, 2012; MOLLESON & ORBAN, 2019).

Besides aging and ethnicity, multiple factors are associated with bone mineral density both in men and women, including body size and body composition (body mass index), hematological parameters, hormonal status, use of oral contraceptive, number of pregnancies, genetic factors such as family history of osteoporosis, diet (calcium intake), frequency and duration of exercise, and occurrence of fracture or prior fracture. Body composition, lifestyle and socioeconomic status factors contribute differently to bone mineral density in ethnic groups (GUR *et al.*, 2003; RUFFING *et al.*, 2006, 2007; RAUTAVA *et al.*, 2007; MORIN *et al.*, 2009; SCHOLTISSEN *et al.*, 2009; BOW *et al.*, 2011; WEI *et al.*, 2011; CHANTLER *et al.*, 2012) and the influence of climate has been suggested (ROZMAN *et al.*, 2003).

Two types of methods are used to evaluate bone senescence. On the one hand, the measurement of anatomical variations of aging represented by morphometrics, and on the other hand, the measurements of bone mass and density, the most common of which are X-ray absorptiometry (LAVAL-JEANTET *et al.*, 1995). Molleson and Orban (2019) used the first set of methods to assess the correlates of age-related effects of bone remodeling and thinning, the cross-sectional geometry of long-bones indeed appears to be a good indicator of the influential mechanical forces and a reasonable reflection of habitual activities (PEARSON & LIEBERMAN, 2004).

As a follow-up of Molleson and Orban (2019) we also turned our attention to the same small collection of known age individuals from the well documented skeletal sample derived from Schoten, a village in the outer suburbs of Antwerp, Belgium. The objective of this study is to illustrate the dynamics of bone mineral density status at the femoral region in men and women in this population sample and to compare it to current norms. The limitations of the Schoten collection are detailed in Orban *et al.* (2011). The collection is small compared to other European osteological collections containing specimens of known (or estimated) age and sex and covering the period between 11th and 16th centuries AD (Wharram Percy burials, North Yorkshire, England, MAYS *et al.*, 2007) or between 18th and 19th centuries AD (Christ Church Spitalfields, London, England, MOLLESON & COX, 1993). A study of this material is however of high interest for population health history (WALKER, 2000); from the 9 collection detailed in Orban *et al.* (2011), only 4 (including Schoten) are from Northern Europe. It should however be kept in mind that a study of this collection stands between a clinical case study (MOLLESON & ORBAN, 2019) and a population survey. The results of our femoral bone mineral density measurements are presented herewith below.

2. MATERIAL

The Schoten series consists in 48 adult skeletons (26 males and 22 females) and 3 juveniles (one 19 year old male, one 19 year old female and one 15 year old female). Details on the subjects, age ranges, gender distribution and the socioeconomic context of Schoten in the 19th-20th centuries are provided by Orban *et al.* (2011) and Molleson and Orban (2019). Year of birth, sex and place of birth, but not the names, of each subject are documented. The registers do not include the causes of death. Briefly, the

subjects, born between 1837 and 1916 within a radius of 50 km around Schoten, a suburb of Antwerp, Belgium, had died in 1930 (5) and 1931 (46) and were buried in the former cemetery at Schoten. The last burial in the old cemetery took place on 24th June 1931, after which there were burials only in family plots. A new cemetery became operational from 29th June 1931. In 1946 the old cemetery was excavated (ORBAN *et al.*, 2011; further details about Schoten cemeteries in CHABOT & CAMP, 2000) and the human remains were exhumed by the staff of the Anthropology section under the supervision of Dr. Twiesselman, head of section, Anthropology and Prehistory Section of the Royal Belgian Institute of Natural Sciences (RBINS), Brussels, Belgium, under existing Belgian legislation (ORBAN *et al.*, 2011; MOLLESON & ORBAN, 2019).

The context and the historical background of the acquisition of the Collection by the RBINS, the health status, the occupations and the social situation of the people of Schoten have been described by Orban *et al.* (2011), which also includes morphological analysis, considering the potentiality of the collection as a reference. It also provides a short report on bone mineral density from Gilissen *et al.* (2006). Storage is by anatomical part in large wooden drawers, with fitted glass topped lids. The bones have been chemically treated, most probably shellac flakes dissolved in alcohol (ORBAN *et al.*, 2011). The age range distribution of the subjects is given on Figure 1 of Molleson and Orban (2019). It could be here reminded that the distribution of the individual ages at death is peculiar, with an over-representation of old individuals; 12 are older than 80 years (27 % of the sample), 16 are between 61 and 80 years old, 13 are between 41 and 60 years old, 7 are between 21 and 40 years old, and only 3 are under 20 years old. This distribution strongly differs from the important Spitalfields collection of identified skeletons (MOLLESON & COX, 1993) where only 6 % of the individuals are over 80 years old.

3. METHODS

Dual energy x-ray absorptiometry and radiogrammetry are probably the most widely used techniques to study bone loss in past populations (CURATE, 2014). The method for measuring bone mineral density (BMD) used here is the Dual Energy X-ray Absorptiometry (DEXA or DXA). This technique measures the attenuation of an incident X-ray beam by the crossed tissues, which is a function of the density of these tissues. An image, in orthogonal projection with respect to the surface scanning, is reconstructed from the measured absorptions and is used to select the region of interest for measurement (Fig. 1). Absorption through the radiographed bone is used to evaluate the bone mineral content (BMC), which affects the attenuation of the radioactive beam. More precisely, DXA calculates the amount of hydroxyapatite in bone, expressing it in grams of mineral per area unit (Tab. 1, Fig. 2). Absorptiometry therefore calculates the mass in a cross-sectional area of the bone rather than a mass per unit volume (FREITAG & BARZEL, 2002). The result of the measurement is a total bone mass of the bone region of interest expressed

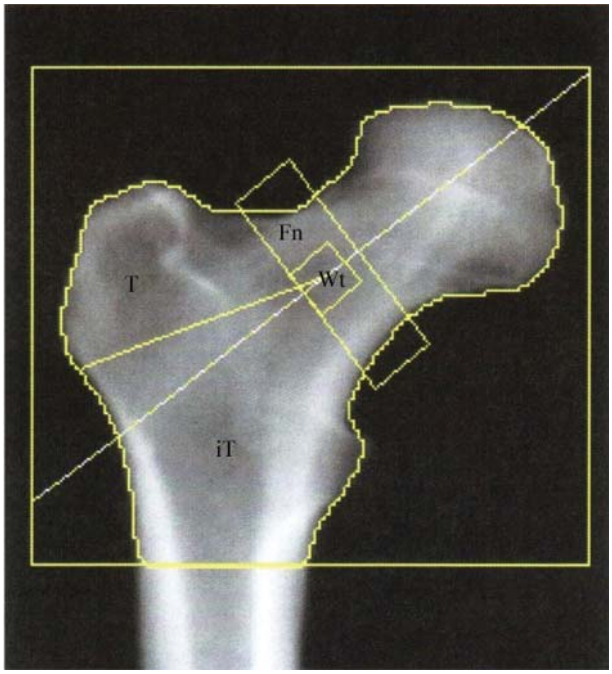

Fig. 1 – Femoral proximal region image, in orthogonal projection with respect to the surface scanning, used to select the region of interest for measurement. The regions of interest that were evaluated for bone mineral density in this study correspond to the yellow contours: T, trochanter; iT, intertrochanter; Fn, femoral neck (rectangle); Wt, Ward's triangle (square). The total region covers the trochanter, the intertrochanter and the femoral neck.

DXA results summary							
Region	*Area (cm^2)*	*BMC (g)*	*BMD (g/cm^2)*	*T-Score*	*PR (%)*	*Z-Score*	*AM (%)*
Femoral neck	5.25	4.8	0.914	0.6	108	0.9	112
Trochanter	13.08	10.45	0.799	1	114	1.1	115
Intertrochanter	22.69	28.49	1.256	1	114	1.1	115
Total	*41.02*	*43.74*	*1.066*	*1*	*113*	*1.2*	*116*
Ward's triangle	1.29	1.07	0.83	0.8	113	1.4	125

Tab. 1 – DXA report for the left femoral bone in an adult female from the Schoten series. The regions of interest are illustrated in Fig. 1. Basic results and the WHO classification for this individual indicate normality (no increased fracture risk). ROI surface area in cm^2; BMC, bone mineral content (g); BMD, bone mineral density (g/cm^2); T-score and Z-score (see methods). PR and AM are not used in this study. See Fig. 2 for a plot of the total region value.

in grams of hydroxyapatite or a surface mass in grams per cm^2 corresponding to the ratio of the bone mass to the surface of the projected image (LAVAL-JEANTET *et al.*, 1995)

Studies of BMD in the lumbar spine are probably the most common in clinical context and have provided significant results in anthropological studies (BOUCHEZ *et al.*, 2011). The proximal femur also provides robust results that are independent of the DEXA analysis system (FAN *et al.*, 2010), making studies comparison easier. The femur preserves generally better than the lumbar spine in archaeological contexts and its positioning in the densitometer is much simpler. To determine bone mineral density in the Schoten referral population, we analysed the proximal left femur from each individual with a standard densitometer manufactured by Hologic (Hologic QDR-2000 series bone densitometer, Hologic, Bedford MA, USA). The bone was placed anterior-surface uppermost, so that the femoral neck lay flat, and the diaphysis was oriented parallel to the axis of the scanner following the protocol of Mays *et al.* (2006). Measurements were made at multiple skeletal sites including femoral neck, Ward's triangle, trochanter, intertrochanteric region, and total hip (the latter corresponds to the femoral proximal metaphysis and does not include the femoral head) (Fig. 1).

As soft tissue equivalent, investigators have used various products such as flour or ethanol gel. Most authors use water (LEES *et al.*, 1993; FULPIN *et al.*, 2001) or dry rice (Mays *et al.*, 1998, 2006). Bones were placed in a plastic box containing dry rice as a soft-tissue substitute. We avoided additional product manipulation in our analysis, the data acquisition was made as consistent as possible. It must be here mentioned that clinical work confirms that the reliability of DEXA

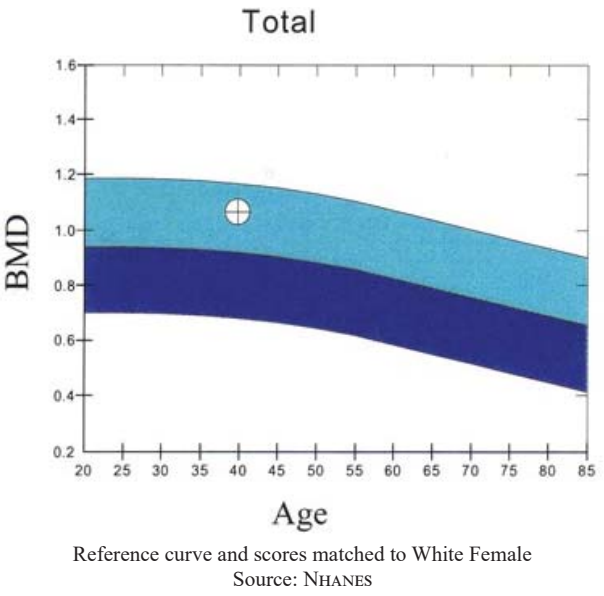

Fig. 2 – This plot shows the bone mineral density value at total proximal femoral region (see Fig. 1) against the age-related normal range in an adult female. The reference database for the plot is from NHANES. See table 1 for the values. BMD, bone mineral density.

measurements is not influenced by whether or not the bone is covered by soft tissue (Dr. Eric Laurent, personal communication).

Bone mineral density is expressed as a T score, i.e., the number of standard deviations (SD) from the young normal adult mean (a T score of zero) or as a Z score, i.e., the number of standard deviations from the age-matched mean. Bone mineral density is used to determine bone quantity, a correlate of the risk of osteoporosis and its precursor osteopenia (decrease in bone tissue without risk of fracture) (see BRICKLEY & IVES, 2008, for a review). T scores between -1 and -2.5 indicate low bone mass or osteopenia. T scores below -2.5 SD indicate osteoporosis (World Health Organization, http://courses.washington.edu/bonephys/index.html). For the diagnosis of osteoporosis, Lewiecki *et al*. (2004) recommend to consider the lowest T-score of the neck of the femur or the total hip. Table 1 and Figure 2 show an example of a summary of DEXA results for a bone region of interest (total proximal femoral region) in an adult female from the Schoten series, together with a World Health Organization (WHO) classification diagnosis. The reference database is from the National Health and Nutrition Examination Survey (NHANES) available in 2003 and was provided by L. Gantois (Institut Jules Bordet, Brussels).

4. RESULTS

No femoral fractures were identified in any of the subjects. Figures 3-12 show plots of bone mineral density (g/cm^2) (BMD) of the different femoral regions of interest (Fig. 1) as a function of age (years) in female and male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, represented here by means and standard deviations). The raw data are available under request to the authors.

Table 2 presents bone mineral density values correlation matrix for the femoral regions of interest. The data are for the female and the male subjects

	Femoral neck	*Ward's triangle*	*Trochanter*	*Inter-trochanter*
Females				
Femoral neck	1			
Ward's triangle	0.939	1		
Trochanter	0.938	0.902	1	
Inter-trochanter	0.97	0.895	0.943	1
Males				
Femoral neck	1			
Ward's triangle	0.93	1		
Trochanter	0.786	0.821	1	
Inter-trochanter	0.883	0.818	0.949	1

Tab. 2 – Bone mineral density values correlation matrix for the femoral regions of interest. Data from the Schoten population, female and male subjects.

	Total number	*Normal*	*Osteopenia*	*Osteoporosis*
Female age				
<20 yr	2	2	0	0
21-40 yr	1	1	0	0
41-60 yr	6	5	1	0
61-80 yr	6	1	3	2
>80 yr	9	0	7	2
Male age				
<20 yr	1	1	0	0
21-40 yr	6	4	2	0
41-60 yr	7	7	0	0
61-80 yr	10	6	4	0
>80 yr	3	1	2	0

Tab. 3 – Diagnosis based on femoral bone mineral density values for the Schoten population, female and male subjects. WHO classification diagnosis.

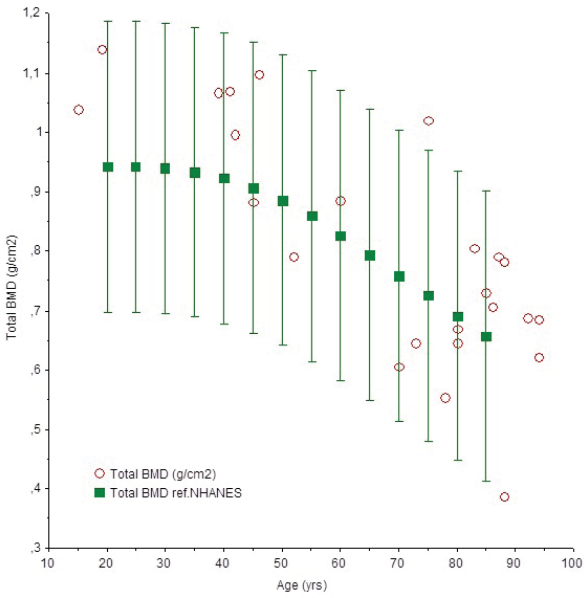

Fig. 3 – Bone mineral density (g/cm^2) of the total femoral proximal region (Fig. 1) as a function of age (yrs) in female subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

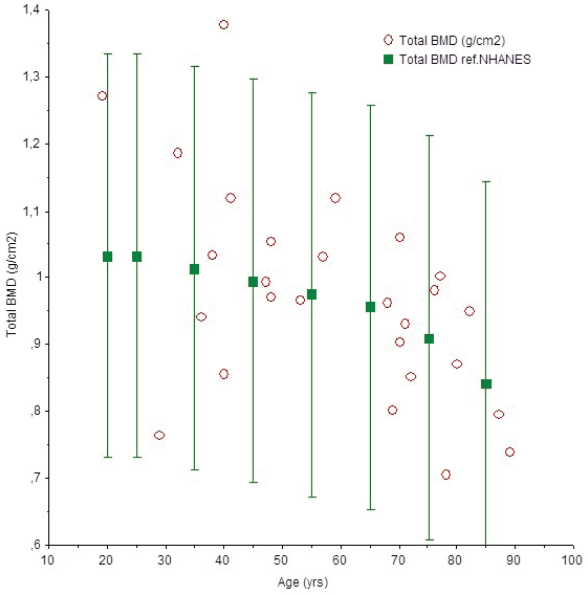

Fig. 4 – Bone mineral density (g/cm^2) of the total femoral proximal region (Fig. 1) as a function of age (yrs) in male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

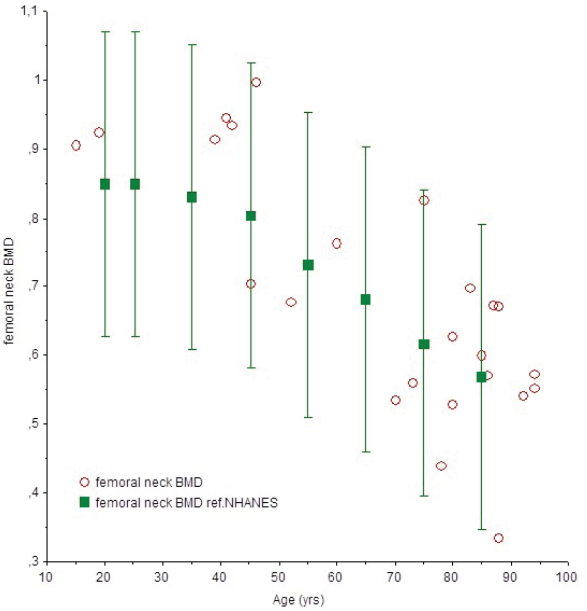

Fig. 5 – Bone mineral density (g/cm^2) of the femoral neck (Fig. 1) as a function of age (yrs) in female subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

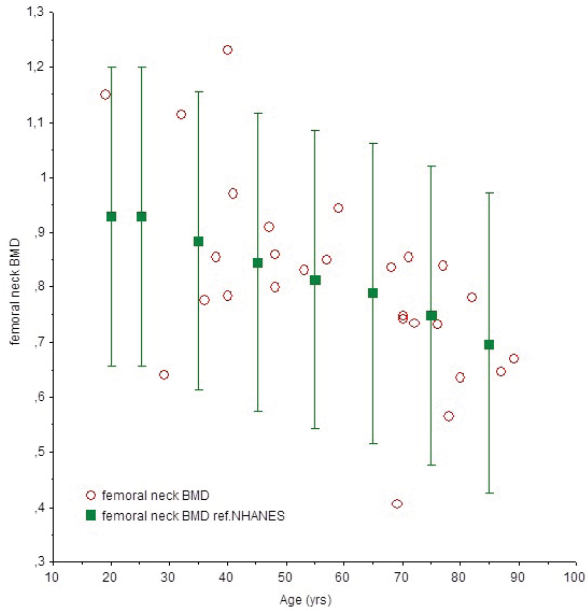

Fig. 6 – Bone mineral density (g/cm^2) of the femoral neck (Fig. 1) as a function of age (yrs) in male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

of the Schoten population. Table 3 proposes diagnosis of osteopenia or osteoporosis based on femoral bone mineral density values for the female and male subjects of the Schoten population.

5. DISCUSSION

5.1. The Schoten sample in the context of the modern population reference sample

Although the juvenile age group is small (N = 3) in Schoten, this collection is rich in elderly individuals, more than octogenarians. Due to the archaeological nature of such material, sample sizes will almost always be smaller than those in epidemiological studies on living subjects, with a consequent lack of statistical power when investigating health status of past populations (MAYS *et al.*, 2006). Such studies however are of interest in determining whether some of the differences between populations that is observed in BMD today also existed in past European populations (MAYS *et al.*, 2006). Moreover, careful examination of archaeological material from Medieval population samples of Trondheim (Norway) and Wharram Percy (England) led MAYS *et al.* (2006) to the conclusion that the BMD values in both sets are likely representative of in vivo values, rather than being artifacts of diagenesis. This conclusion can certainly be applied to the material studied here and for which details on postmortem preservation can be found in Orban *et al.* (2011) and Molleson and Orban (2019). In addition, there is a body of evidence (both direct and indirect) suggesting that diagenesis affects bone mineral content only marginally (reviewed in CURATE, 2014).

The peculiar age distribution of the Schoten sample makes it possible to address the emergence of new epidemiological problems such as osteoporosis, which is becoming increasingly common as a result of the aging of socioeconomically advantaged populations (ORBAN *et al.*, 2011). As concluded by Cauley (2011), across ethnic and racial groups, more women experience fractures than the combined number of women who experience breast cancer, myocardial infarction, and coronary death in 1 year. Prevention efforts should certainly include the study of secular trend in bone biology among various human populations. In addition, few studies examined bone mineral density of the femoral region in ancient skeletal remains, probably because of the usual paucity of this material. Studies on metacarpal bones are for instance more numerous (MAYS, 1996, 2000, 2001, 2006).

Overall, Schoten male and female subjects tend to have good to excellent bone densitometry, entirely within the range of current reference population (NHANES), especially those aged over sixty five, who appears to be well distributed around the mean (see also GILISSEN *et al.*, 2006; ORBAN *et al.*, 2011; MOLLESON & ORBAN, 2019). Although the juvenile age group is represented by 2 female and 1 male subject in our sample, it is interesting to observe that peak bone mineral density appears to be fully attained at the time of late adolescence, as in the current populations. Peak bone mineral density at the femoral neck is reached at 12 years (before 16 years) in white (Caucasian) men and women. (HENRY *et al.*, 2004; BERENSON *et al.*, 2009). Despite the paucity of the data, peak BMD at skeletal maturity is worth considering because it may be the single most important factor in the development of osteoporosis (HERNANDEZ *et al.*, 2003).

Some specific observations can be made. In contrast with the observations of Srinivasan *et al.* (2012) on a cohort of young and old men and women from Rochester, MN, USA, where femoral strength tended to be relatively similar across the sexes, bone mineral density values in Schoten female subjects until the age of 50 years appears to be higher than the average values in today's reference population. In general, female individuals indeed appear to be mostly within the upper range (above the mean) of the NHANES reference population, with male subjects more evenly distributed around the mean (Figs. 3-12). As stated above, our sample is too limited, especially in juvenile subjects, to draw any firm conclusion. However, this observation is consistent with Molleson and Orban (2019), who scored Schoten femoral radiographs according to the criteria of Acsádi and Nemeskéri (1970) and observed a slow rate of aging for the sample. This is furthermore consistent with the analysis of

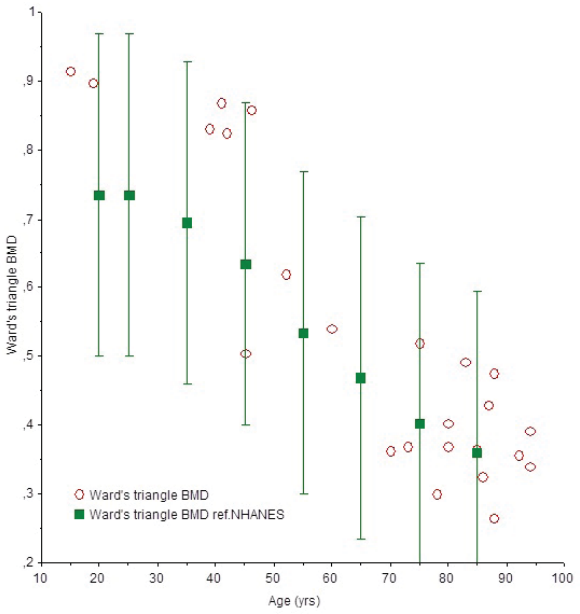

Fig. 7 – Bone mineral density (g/cm^2) of the Ward's triangle (Fig. 1) as a function of age (yrs) in female subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

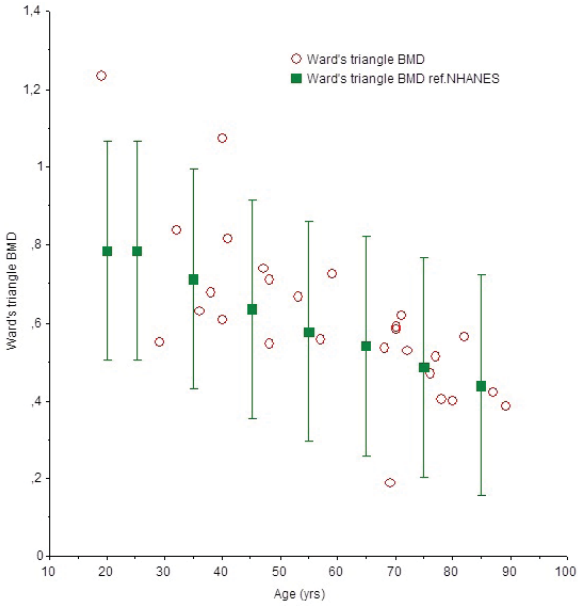

Fig. 8 – Bone mineral density (g/cm^2) of the Ward's triangle (Fig. 1) as a function of age (yrs) in male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

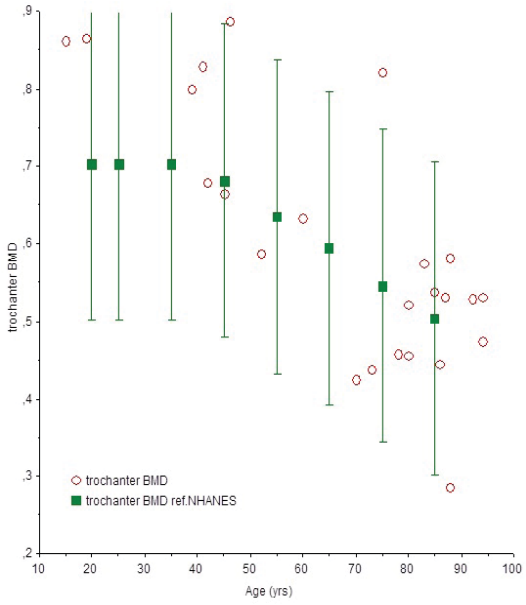

Fig. 9 – Bone mineral density (g/cm^2) of the trochanter (Fig. 1) as a function of age (yrs) in female subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

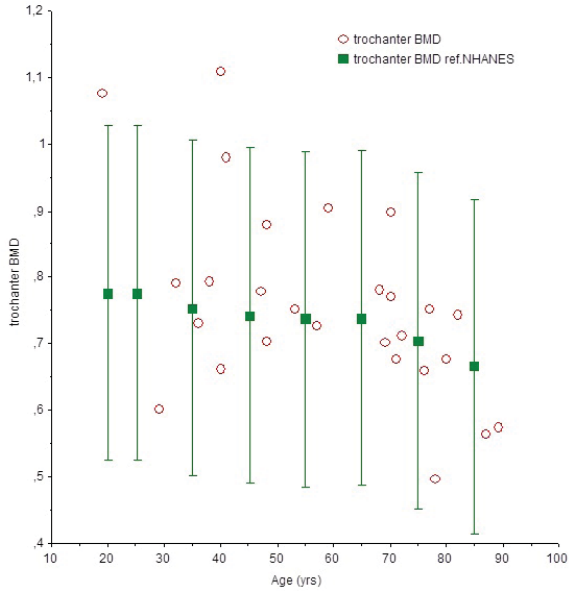

Fig. 10 – Bone mineral density (g/cm^2) of the trochanter (Fig. 1) as a function of age (yrs) in male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

the femoral cortex, where thinning was detected only in a few individuals, mostly women, aged 65 or more (MOLLESON & ORBAN, 2019) and suggests that rates of bone loss were slower in this women sample when compared to a modern reference. Lifestyle may be a correlated factor that contributed to this good health status in younger individuals, especially women.

This view is however not supported by other results. For instance, at medieval Wharram Percy, England (a homogeneous, rural peasant population, 11th-16th centuries AD), there was also significant age-related loss of bone substance in the femur but the degree of loss was no less than, and perhaps even exceeded, that seen in recent subjects. This latter finding suggests that when considering age-related bone loss, lifestyle factors may be less important than is generally believed in influencing the severity of osteoporosis (MAYS, 1996; MAYS *et al.*, 1998). It should be noted that in the Schoten sample, despite the apparent good bone health of the younger female subjects, 4 female subjects older than 60 years can be diagnosed with osteoporosis.

Moreover, although bone mineral density values in aged males and females are in the range of reference (NHANES) population, the variability for the values of bone mineral densities for the various femoral regions of interest appears to be higher in males than in females for every age range. This is consistent with the situation for current populations, considering the NHANES reference database (Tab. 4); the larger variability of Schoten male bone mineral density values entirely covers or even exceed the standard deviations calculated from the NHANES reference database. The Schoten female bone mineral density values cover a narrower spectrum of variation at all sites of measurement. This trend is expressed by better correlations between the bone mineral densities of the different femoral regions of interest in female than in male subjects (Tab. 2).

Considering the diagnosis of osteopenia and osteoporosis (Tab. 3), sex differences can clearly be observed. This concords with recent studies on sex differences in bone architecture, which indicate that a number of biomechanical variables leads to increased bone strength in males compared with females (NELSON & MEGYESI, 2004). In the case of female subjects, there is an influence of the number of pregnancies on bone mineral density in postmenopausal women (GUR *et al.*, 2003). This relationships varies between age groups and between skeletal sites and we have no data to further analyse the role of this parameter. For the diagnosis of osteoporosis more specifically, Aoki *et al.* (2000) consider that bone mineral density measurements are significantly more sensitive at the Ward's triangle than at the femoral neck, trochanter, intertrochanteric region, and total hip sites. This appears to be confirmed by the Schoten sample analysis. Interestingly, it is the Ward's triangle (and trochanter) bone mineral densities, but not the femoral neck bone mineral density, that show a significant negative correlations with the number of pregnancies in postmenopausal women (GUR *et al.*, 2003). At Ward's triangle, bone mineral density values decrease at a higher rate with age than at other regions of interest, as it is illustrated by Figure 7. Actually, the NHANES reference database shows this trend and the Schoten female subject data, for which 4 cases of osteoporosis can be diagnosed, are within the range of the reference database values. This observation indicates that more research on bone mineral density at different bone sites is necessary on the Schoten sample to reach any firm conclusions. The conditions of biomechanical functioning of the bone govern remodeling. Each bone site is therefore specific and this singularity, due to their structure (spongious bone or cortical bone) or to their location in the skeleton as a whole, prohibits generalizing from local data on overall mineral content (LAVAL-JEANTET *et al.*, 1995).

	Female		*Male*
Total	0.122	<	0.151
Femoral neck	0.111	<	0.136
Ward's triangle	0.117	<	0.141
Trochanter	0.101	<	0.126
Inter-trochanter	0.155	<	0.181

Tab. 4 – Standard deviations of bone mineral densities for the femoral regions of interest. Data from the reference database NHANES of white caucasian polulation subjects 20-85 year old.

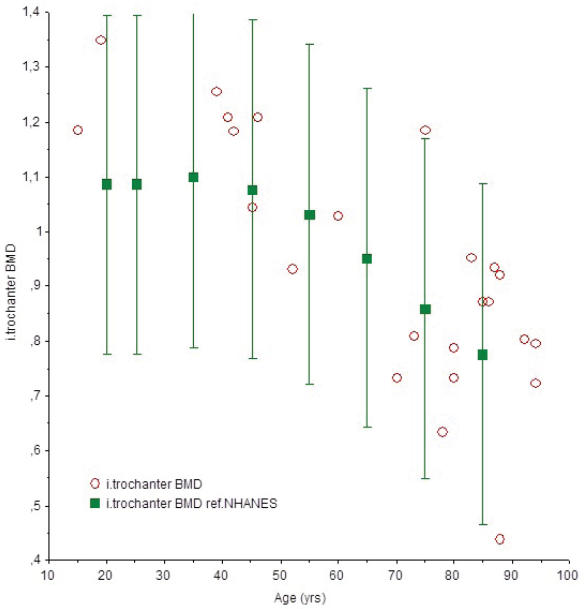

Fig. 11 – Bone mineral density (g/cm^2) of the inter-trochanter (Fig. 1) as a function of age (yrs) in female subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

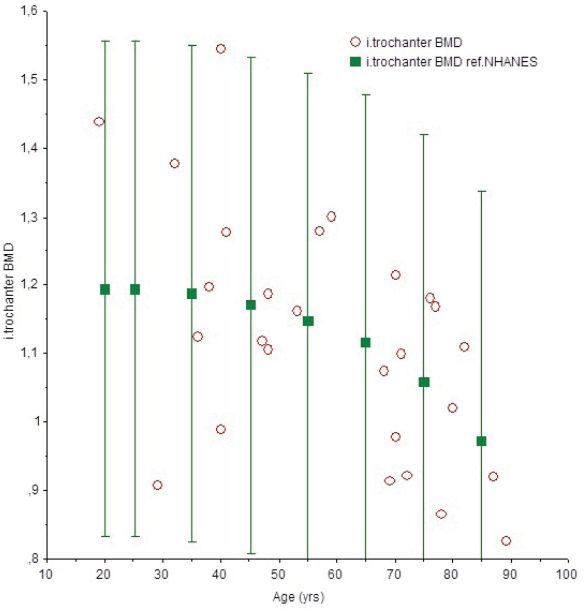

Fig. 12 – Bone mineral density (g/cm^2) of the inter-trochanter (Fig. 1) as a function of age (yrs) in male subjects from the Schoten collection (circles) together with reference group data of the same age and sex (squares, NHANES reference group, means and standard deviations). X-ray: L. Gantois & M. Lemort (J. Bordet Institute, Brussels).

The people of Schoten, born in the 19th century before mechanized transport was generally available, remained active throughout their lives and considering cross-sectional cortical thickness in femora, the rate of aging appears to have been much slower for this late 19th to early 20th century sample than it is for modern samples (MOLLESON & ORBAN, 2019). The bone mineral density data do not offer such a clear picture. The male subjects show a large variation in bone density loss in the range of the NHANES reference. As far as the small size of our sample allows us to draw any conclusion, the female subjects seems to show above average bone density values until the age of 50. Then, female subjects show average bone densities at all measurement sites, with less variance than male subjects.

5.2. The Schoten sample in the context of other databases, including archaeological collections

The Schoten data can be compared with other databases with interest. Femoral bone mineral density (BMD) measurements obtained by X-ray absorptiometry (DEXA) for a French (Caucasian) reference population are provided by Laval-Jeantet *et al.* (1995) and are listed on Table 5. Laval-Jeantet *et al.* (1995) however do not precise the type of absorptiometer they used, it is therefore not possible to assess whether a conversion (MAYS *et al.*, 2006) is necessary. The femoral region of interest to which these measurements correspond is not indicated either. Considering the NHANES reference, they clearly correspond to the femoral neck (Figs. 5-6) and represent a similar modern population reference sample.

Data provided by Sansilbano-Collilieux *et al.* (1994) for the left/right femoral neck in a young (18-20 year old) and in an aged woman (more than 50 year old) are respectively 0.946/0.969 and 0.868/0.766 (necropolis of Cognac-Saint-Martin, 7th-15th century AD, values in g/cm2) and correspond to the Schoten data but again, the authors do not indicate the type of absorptiometer they used, it is therefore not possible to assess whether a data conversion is necessary.

Age (yr)	20-29	30-39	40-49	50-59	60-69	70-79	80-89
Female BMD	0.86	0.826	0.776	0.725	0.675	0.624	0.574
Male BMD	0.929	0.865	0.823	0.78	0.758	0.725	0.673

Tab. 5 – Femoral bone mineral density measurements for a French reference population (Laval-Jeantet *et al.*, 1995). Age in years. Bone mineral density values in g/cm^2.

Another set of data is provided by Fulpin *et al.* (2001) and Mafart *et al.* (2008) for skeletal remains from the cemetery of the crypt of the Notre-Dame-du-Bourg cathedral in Digne, Alpes-de-Hautes-Provence, France. It was a burial place for the inhabitants of the city from 11th to 17th century AD without known social discrimination. Mafart *et al.* (2008) provides bone mineral densities at the femoral neck and at the Ward's triangle region. Most of the elderly women (over 50 years) had bone mineral densities lower than the young women (under 30 years) and the gap between young and elderly female subjects appears to be greater than nowadays. The values of Mafart *et al.* (2008) are listed on Table 6. There is a striking contrast between female and male subjects and the female values appear to be in the lower range compared to both the NHANES reference and the Schoten data.

In the churchyard of St. Olav's church in central Trondheim (Norway), 928 skeletons dating to the period 12th-17th centuries AD were excavated (MAYS *et al.*, 2006). Mays *et al.* (2006) compared the Trondheim BMD results with those from Wharram Percy (11th-16th centuries AD). This is shown in Table 7 (adapted from MAYS *et al.*, 2006). There is no evidence for differences between the two populations in peak bone density and no evidence for differences in patterns of age-related decline in BMD (MAYS *et al.*, 2006). The Trondheim population resembled the Wharram Percy people, in terms of both age-dependent loss of BMD for both sexes and peak BMD values. There is however a slight difference if we consider the earlier loss of BMD at Ward's triangle in the Trondheim males in the 30–49-year group, which is significantly lower than in the Wharram Percy males (MAYS *et al.*, 2006). This differs from the Schoten sample where a drop of BMD values can be observed at Ward's triangle between 40-50 years in female but not in male subjects. This illustrates the bone mineral density variation between human populations. This is of interest because the Schoten sample is more recent than the Trondheim and Wharram Percy samples and the current Norwegian and UK populations now show differences in BMD, probably of recent origin (MAYS *et al.*, 2006).

Finally, concerning the Christ Church Spitalfields remains, a population almost contemporary with Schoten, the skeletal material excavated during the restoration of the church and

	Mean BMD femoral neck	*Mean BMD Ward's triangle*
Females under 30 yr	0.824	0.718
Females over 50 yr	0.622	0.391
Males under 30 yr	1.038	0.902
Males over 50 yr	0.91	0.742

Tab. 6 – Notre-Dame-du-Bourg BMD data from Mafart *et al.* (2008) transformed to Hologic values, using the following equations. For methods used to generate these conversion algorithms, see Mays *et al.* (2006). For the femoral neck; Hologic BMD = 0.789126 x Lunar BMD + 0.081403. For the Ward's triangle; Hologic BMD = 0.934769 x Lunar BMD - 0.140822. Age in years. Bone mineral density values in g/cm^2.

	Mean BMD femoral neck		*Mean BMD Ward's triangle*	
	Trondheim	*Wharram Percy*	*Trondheim*	*Wharram Percy*
Females				
18-29 yr	0.953	0.951	0.883	0.877
30-49 yr	0.783	0.808	0.636	0.642
>50 yr	0.702	0.724	0.532	0.535
Males				
18-29 yr	0.981	0.988	0.923	0.91
30-49 yr	0.886	0.934	0.713	0.811
>50 yr	0.828	0.826	0.603	0.625

Tab. 7 – Trondheim data values from Mays *et al.* (2006). Wharram Percy data values are from Mays *et al.* (1998) and were transformed to Hologic values (see table 8 for the equations). Age in years. Bone mineral density values in g/cm^2.

dated from 1729-1852 consist in 87 left femora from female subjects between the ages of 15 and 89 and 30 from male subjects (25-88). The values provided by Lees et al. (1993) are listed on Table 8.

Lees *et al.* (1993) concluded that the rate of femoral bone loss is significantly greater in modern-day women than in the women from two centuries ago, both pre- and post-menopausally. This is not consistent with either the NHANES reference means or our analysis of the Schoten sample for which the rate of female femoral bone loss is within the range of the current reference database from age 50 onward, but starting with healthier younger females (Figs. 5 & 7). This observation contrasts with the consistency over time of greater variability in BMD in men than in women. It should be kept in mind, as Molleson and Orban (2019) concluded for cross-sectional cortical thickness in femora, that with respect to bone mineral density, age-related trends in one sample will not necessarily be applicable to another, whether the two samples are contemporary or from different periods.

6. CONCLUSION

Bone mineral density values in the Schoten sample are within the range of the modern population reference sample (NHANES) and also show greater variability in men than in women for all femoral regions of interest and for each age group. Sex differences can also be observed with respect to the diagnosis of osteopenia and osteoporosis. Compared with the modern reference sample however, it can be noted that female subjects appear to have above-average bone density values up to the age of 50 years, followed by average bone densities until death, and this for all measurement sites.

	Mean BMD femoral neck	*Mean BMD Ward's triangle*
Females 55 yr old	0.729	0.506
Males 53 yr old	0.883	0.671

Tab. 8 – Christ Church Spitalfields data are values from Lees *et al.* (1993) transformed to Hologic values (see table 8 for the equations). Age in years. Bone mineral density values in g/cm^2.

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References

ACSÁDI G. & NEMESKÉRI J., 1970. *History of Human life span and mortality*. Budapest, Académiai Kiadó.

AOKI T.T., GRECU E. O., SRINIVAS P. R., PRESCOTT P., BENBARKA M. & ARCANGELI M. M., 2000. Prevalence of osteoporosis in women: Variation with skeletal site of measurement of bone mineral density. *Endocrine Pratice*, **6**: 127-131.

ARAUJO A. B., TRAVISON T. G., HARRIS S.S., HOLICK M. F., TURNER A. K. & MCKINLay J. B., 2007. Race/ethnic differences in bone mineral density in men. *Osteoporosis International*, **18**: 943-953.

BERENSON A. B., RAHMAN M. & WILKINSON G., 2009. Racial difference in the correlates of bone mineral content/density and age at peak among reproductive-aged women. *Osteoporosis International,* **20**: 1439-1449.

BOUCHEZ I., ARDAGNA Y., SALIBA-SERRE B. & DUTOUR O., 2011. Épidémiologie de la maladie dégénérative vertébrale dans des séries ostéologiques documentées. Proposition d'une nouvelle méthode de cotation et première application aux articulations interapophysaires lombaires. *Bull. Mém. Soc. Anthropol.*, **23**: 27-37.

BOW C. H., TSANG S. W. Y., LOONG C. H. N., SOONG C. S. S., YEUNG S.C. & KUng A. W. C., 2011. Bone mineral density enhances use of clinical risk factors in predicting ten-year risk of osteoporotic fractures in Chinese men: the Hong Kong Osteoporosis Study. *Osteoporosis International*, **22**: 2799-2807.

BRICKLEY M. & IVES R., 2008. *The Bioarchaeology of Metabolic Bone Disease*. New York, Academic Press.

CAULEY J. A., 2011. Defining ethnic and racial differences in osteoporosis and fragility fractures. *Clinical Orthopaedics and Related Research*, **469**: 1891–1899.

CHABOT B. & VAN CAMP L., 2000. Oud en Nieuw Kerkhof in Schoten. Wijkkrant Buurtcomité *Cordula*, **3** (1): 4-5.

ChANTLER S., DICKIE K., GOEDECKE J. H., LEVITT N. S., LAMBERT E. V., EVANS J., JOFFE Y. & MICKLESFIELD L. K., 2012. Site-specific differences in bone mineral density in black and white premenopausal South African women. *Osteoporosis International*, **23**: 533-542.

CURATE F., 2014. Osteoporosis and paleopathology: a review. *Journal of Anthropological Sciences*, **92**: 119-146.

FAN B., LU Y., GENANT H., FUERST T. & SHEPHERD J., 2010. Does standardized BMD still remove differences between Hologic and GE-Lunar state-of-the-art DXA systems? *Osteoporosis International*, **21**: 1227-1236.

FULPIN J., MAFART B., CHOUC P. Y. & DEMIANS D'ARCHIMBAUD G., 2001. Etude par absorptiométrie de la densité minérale osseuse dans une population médiévale (nécropole de Notre Dame du Bourg, Digne, Alpes de Haute-Provence France, XIe-XIIIe et XVIe-XVIIIe s.). *Bulletins et Mémoires de la Société d'Anthropologie de Paris*, n.s., **13**: 337-341.

FREITAG A. & BARZEL U. S., 2002. Differential diagnosis of osteoporosis. *Gerontology*, **48**: 98-102.

GILISSEN E., GANTOIS L., LEMORT M. & ORBAN R., 2006. La densité minérale osseuse au cours du vieillissement dans une série de squelettes issues d'une population belge du début du 20ème siècle. *Résumés 40 Coloquio del Grupo GRANDI « Croissance et vieillissement » Bilbao, Espagne*, 19-20.05.2006): 11.

GUR A., NAS K., CEVIK R., SARAC A.J., ATAOGLU S. & KARAKOC M., 2003. Influence of number of pregnancies on bone mineral density in postmenopausal women of different age groups. *Journal of Bone and Mineral Metabolism*, **21**: 234-241.

HEBERT L. E., SCHERR P. A., BIENIAS J. L., BENNETT D. A. & EVANS D. A., 2003. Alzheimer Disease in the US Population. Prevalence Estimates Using the 2000 Census. *Archives of Neurology*, **60**: 1119-1122.

HENRY Y. M., FATAYERJI D. & EASTELL R., 2004. Attainment of peak bone mass at the lumbar spine, femoral neck and radius in men and women: relative contributions of bone size and volumetric bone mineral density. *Osteoporosis International*, **15**: 263–273.

HERNANDEZ C. J., BEAUPRÉ G. S. & CARTER D. R., 2003. A theoretical analysis of the relative influences of peak BMD, age-related bone loss and menopause on the development of osteoporosis. *Osteoporosis International*, **14**: 843–847.

LAVAL-JEANTET A-M., BERGOT C. & ELMOUTAOUAKKIL A., LAVAL-JEANTET M., 1995. Imagerie quantitative et ansorptiométrie du squelette âgé. *Cahiers d'Anthropologie et Biométrie Humaine (Paris)*, **13**: 263-280.

LEES B., MOLLESON T., ARNETT T. R. & STEVENSON J. C., 1993. Differences in proximal femur bone density over two centuries. *The Lancet*, **341**: 673-675.

LEWIECKI E. M., WATTS N. B., MCCLUNG M. R., PETAK S. M., BACHRACH L. K., SHEPHERD J. A. & DOWNS R. W., 2004. Official Positions of the International Society for Clinical Densitometry. *The Journal of Clinical Endocrinology & Metabolism*, **89**: 3651-3655.

LOOKER A. C., MELTON III L. J., HARRIS T., BORRUD L., SHEPHERD J. & MCGOWAN J., 2009. Age, gender, and race/ethnic differences in total body and subregional bone density. *Osteoporosis International*, **20**: 1141-1149.

MAFART B., FULPIN J. & CHOUC P. Y., 2008. Postmenopausal bone loss in human skeletal remains of a historical population of Southeastern France. *Osteoporosis International*, **19**: 381–382.

MAYS S., 1996. Age-dependent cortical bone loss in a medieval population. *International Journal of Osteoarcheology*, **6**: 144-154.

MAYS S., 2000. Age-dependent cortical bone loss in women from 18th and early 19th century London. *American Journal of Physical Anthropology*, **112**: 349-361.

MAYS S., 2001. Effects of age and occupation on cortical bone in a group of 18th-19th century British men. *American Journal of Physical Anthropology*, **116**: 34-44.

MAYS S., 2006. Are-related cortical bone loss in women from a 3rd-4th century AD population from England. *American Journal of Physical Anthropology*, **129**: 518-528.

MAYS S., HARDING C. & HEIGHWAY C., 2007. *Wharram: Churchyard v. 11 (Wharram, a study of settlement on the Yorkshire Wolds)*. London, English Heritage.

MAYS S., LEES B. & STEVENSON J. C., 1998. Age-dependent bone loss in the femur in a medieval population. *International Journal of Osteoarcheology*, **8**: 97-106.

MAYS S., TURNER-WALKER G. & SYVERSEN U., 2006. Osteoporosis in a population from medieval Norway. *American Journal of Physical Anthropology*, **131**: 343-351.

MOLLESON T. & COX M., 1993. Vol. 2, The Anthropology. The Middling sort. *In*: H. A. WALDRON & D. H. WHITTAKER (eds), *The Spitalfields Project. York (UK)*. Council for British Archaeology, CBA Research Report, **86**, 231 p.

MOLLESON, T. & ORBAN, R., 2019. Variation in cross-sectional cortical thickness in femora of documented age at death from Schoten (Belgium). *Anthropologica et Præhistorica*, **127/2016**: 87-101.

MORIN S., LESLIE W. D. & MANITOBA BONE DENSITY PROGRAM, 2009. High bone mineral density is associated with high body mass index. *Osteoporosis International*, **20**: 1267-1271.

NAM H.-S., SHIN M.-H., ZMUDA J. M., LEUNG P. C., BARRETT-CONNOR E., ORWOLL E. S. & CAULEY J. A., OSTEOPOROTIC FRACTURES IN MEN (MROS) RESEARCH GROUP, 2010. Race/ethnic differences in bone mineral density in older men. *Osteoporosis International*, **21**: 2115-2123.

NELSON D. A. & MEGYESI M. S., 2004. Sex and ethnic differences in bone architecture. Current *Osteoporosis Reports* **2**: 65-69.

ORBAN R., ELDRIDGE J. & POLET C., 2011. Potentialités et historique de la collection de squelettes identifiés de Schoten (Belgique, 1837-1931). *Anthropologica et Praehistorica*, **122**: 19-62.

PEARSON O. M. & LIEBERMAN D. E., 2004. The ageing of Wolff's "Law": ontogeny and responses to mechanical loading in cortical bone. *Yearbook of Physical Anthropology*, **47**: 63-99.

RAUTAVA E., LEHTONEN-VEROMAA M., KAUTIAINEN H., KAJANDER S., HEINONEN O. J., VIIKARI J. &

MÖTTÖNEN T., 2007. The reduction of physical activity reflects on the bone mass among young females: a follow-up study of 142 adolescent girls. *Osteoporosis International*, **18**: 915-922.

ROZMAN B., KLAIC Z. B. & SKREB F., 2003. Influence of the incoming solar radiation on the bone mineral density in the female adult population in Croatia. *Collegium Antropologicum*, **27**: 285-292.

RUFFING J. A., COSMAN F., ZION M., TENDY S., GARRETT P., LINDSAY R. & NIEVES J. W., 2006. Determinants of bone mass and bone size in a large cohort of physically active young adult men. *Nutrition & Metabolism*, **3**: 14.

RUFFING J. A., NIEVES J. W., ZION M., TENDY S., GARRETT P., LINDSAY R. & COSMAN F., 2007. The influence of lifestyle, menstrual function and oral contraceptive use on bone mass and size in female military cadets. *Nutrition & Metabolism*, **4**: 17.

SANSILBANO-COLLILIEUX M., BOUGAULT D., DARLAS Y. & SABATIER J.-P., 1994. Incidence du sexe et de l'âge sur le contenu minéral osseux. *In* : Actes des 6e Journées Anthropologiques, Dossier de Documentation Archéologique n°17. Paris, CNRS Editions.

SCHOLTISSEN S., GUILLEMIN F., BRUYÈRE O., COLLETTE J., DOUSSET B., KEMMER C., CULOT S., CRÉMER D., DEJARDIN H., HUBERMONT G., LEFEBVRE D., PASCAL-VIGNERON V., WERYHA G. & REGINSTER J. Y., 2009. Assessment of determinants for osteoporosis in elderly men. *Osteoporosis International*, **20**: 1157-1166.

SRINIVASAN B., KOPPERDAHL D. L., AMIN S., ATKINSON E. J., CAMP J., ROBB R. A., RIGGS B. L., ORWOLL E. S., MELTON III L. J., KEAVENY T. M. & KHOSLA S., 2012. Relationship of femoral neck areal bone mineral density to volumetric bone mineral density, bone size, and femoral strength in men and women. *Osteoporosis International*, **23**: 155–162.

STINI W. A., 2003. Sex differences in bone loss-An evolutionary perspective on a clinical problem. *Collegium Antropologicum*, **27**: 23-46.

UNITED NATIONS, Department of Economic and Social Affairs, Population Division, 2019. *World Population Prospects* 2019. New York, United Nations.

WALKER P., 2000. Bioarcheological ethics: a historical perspective on the value of human remains. *In*: A, KATZENBERG &S. SAUNDERS (eds), *Biological anthropology of the human skeleton*. New York, Wiley-Liss, Inc.: 3-39.

WALKER M. D., SAEED I., MCMAHON D. J., UDESKY J., LIU G., LANG T. & BILEZIKIAN J. P., 2012. Volumetric bone mineral density at the spine and hip in Chinese American and White women. *Osteoporosis International*, **23**: 2499-2506.

WANG X-F. & SEEMAN E., 2012. Epidemiology and structural basis of racial differences in fragility fractures in Chinese and Caucasians. *Osteoporosis International*, **23**: 411-422.

WEI S., JONES G., THOMSON R., DWYER T. & VENN A., 2011. Oral contraceptive use and bone mass in women aged 26-36 years. *Osteoporosis International*, **22**: 351-355.

Author's addresses:

Emmanuel GILISSEN
Department of African Zoology
Royal Museum for Central Africa
Leuvensesteenweg, 13
3080 Tervuren (Belgium)
and
Laboratory of Histology and Neuropathology
Université Libre de Bruxelles
1070 Brussels (Belgium)
emmanuel.gilissen@africamuseum.be

Rosine ORBAN
Royal Belgian Institute of Natural Sciences
rue Vautier, 29
1000 Brussels (Belgium)
rosine.orban@gmail.com