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RESEARCH ARTICLE

Female skeletal health and socioeconomic status in medieval Norway (11th–16th centuries AD): Analysis of bone mineral density and stature

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Abstract

Little is known about the possible impact of socioeconomic status on bone health in medieval Norway. We measured bone mineral density in the skeletal remains of 101 females from five medieval burial sites in Eastern Norway representing distinct socioeconomic groups by comparing results from dual-energy X-ray absorptiometry and osteological analysis. Young adult females of high status were taller than parish population females (5.3 cm, $p = 0.01$), although their femoral neck bone mineral density did not differ significantly between the two groups ($p = 0.127$). We found that the parish population females had a significantly higher occurrence of osteopenia and osteoporosis in old adulthood ($p = 0.003$), with an estimated disease risk of 0.53 versus 0.16 in the high-status group, possibly related to a lower attained maximum bone mineral density. We discuss environmental and genetic factors in light of relevant research literature on life in medieval Norway and offer an explanation for the significant taller stature among high-status females and the higher risk for osteopenia/osteoporosis in the parish population. This work adds to our knowledge of young adult bone mineral density and bone loss in relation to socioeconomic status in a medieval female population of Norway.

KEYWORDS
bone loss, bone mineral density, dual-energy X-ray absorptiometry, female skeletal health, femur neck BMD, medieval period, osteoporosis, socioeconomic status

1 | INTRODUCTION

Previous research by the authors (Brødholt et al., 2022) has indicated that femoral neck bone mineral density (BMD) may be a valuable skeletal indicator of socioeconomic status (SES). Furthermore, the authors discovered greater SES differences for females than males in the medieval society of Norway. These results prompted us to investigate the present working hypothesis that SES differences in the medieval Norwegian population had a greater impact on female health and explore a possible explanation for this finding. Previous research on bone loss in archeological populations in Norway (Holck, 2007; Mays et al., 2006; Turner-Walker et al., 2001; Turner-Walker, Syversen, & Mays, 2000) and the other Scandinavian countries (Bennike & Bohr, 1990; Ekenman et al., 1995; Poulsen et al., 2001) has detected a varied pattern with regards to age-related bone loss. To our knowledge, the impact of SES on BMD and bone loss has not previously been examined in Scandinavia but has been addressed in several other international studies (Borre et al., 2015; Di Stefano et al., 2012; Mays, 1996; Miszkiewicz & Mahoney, 2016; Zaki et al., 2009).

Both sexes experience bone loss as a natural part of the aging process. However, a decrease in BMD below defined thresholds is defined as osteopenia (low bone mass) or osteoporosis (Meyer, 2016). The WHO definition of osteopenia and osteoporosis can be found in Section 3.2. According to the International Osteoporosis Foundation (2021), the risk of developing osteoporosis is greatly affected by non-modifiable (female gender, age, heredity, etc.) as well as modifiable factors (physical activity, smoking, alcohol, nutrition, etc.). Peak BMD (bone mass at the time of skeletal maturity) is a major factor influencing the development of osteoporosis. Failure to obtain the genetically determined maximum (peak) bone mass during development and maturation is strongly associated with the risk of developing osteoporosis (Heaney et al., 2000; Hernandez et al., 2003). Prehistoric skeletal remains demonstrate temporal and geographic variations in response to environmental and genetic factors (Cox et al., 2019). The positive association between stature and social status is well-documented and is associated with genetics, nutrition, and childhood health (Stulp et al., 2015).

In this study, we present the first in-depth analysis of how divergent living conditions among high-status and parish populations were mirrored in attained stature and BMD throughout life in a medieval female population. In addition, the association between young adult BMD (used as a proxy for peak BMD) and the onset of disease (osteopenia and osteoporosis) in our SES groups is discussed in relation to genetic and socioeconomic factors.

2 | MATERIAL

The study includes skeletal material from five medieval burial sites (11th–16th centuries AD) in Eastern Norway (Figure 1). It constitutes part of the Schreiner Collection at the Division of Anatomy, University of Oslo (UiO). See (Brødholt et al., 2022) for extensive information. The remains were analyzed with dual-energy X-ray absorptiometry (DXA), as previously described in Brødholt et al. (2021).

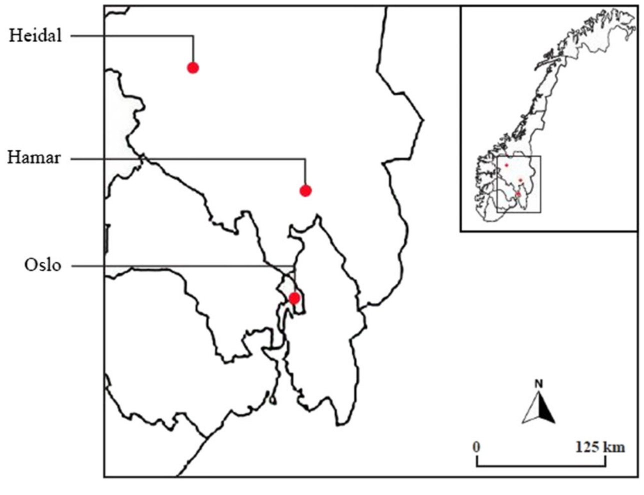

FIGURE 1 The five burial sites from Eastern Norway included in the study. Oslo: The Church of St. Mary, St. Clemens Church and St. Olav's Monastery. Heidal: The Church of Prestgard. Hamar: Hamar Cathedral [Colour figure can be viewed at wileyonlinelibrary.com]

2.1 | High status burials

The King's Estate in Oslo consisted of the King's Hall and the Church of St. Mary. The latter was erected in circa 1050 AD (Molaug, 1999) and was operative until circa 1540 AD. It was a burial place for the Norwegian royal family and the nobility, clergy, aristocracy, and gentry (Nedkvitne & Norseng, 2000; Pettersen, 1992; Roaldset, 2000). The remains of ~400 individuals have been unearthed (Brødholt, 2006, 2007a, 2007b; Brødholt et al., 2021; Brødholt & Holck, 2012; Holck, 2007; Torgersen et al., 1964). The ruin of St. Olav's Monastery in Oslo is the only preserved of the four medieval Dominican foundations in Norway (Åsen, 2015; Hommedal, 1987). The monastery was founded in 1239 AD (Bull, 1922; Holck, 1974; Schia, 1995) and was presumably operative until the reformation in 1537 AD (Hommedal, 1986; Lange, 1856). In 1924–1926 23 individuals were excavated from the south wing (Holck, 1974; Hommedal, 1986), later analyzed by Wagner (1927) and Holck (2007). The friars were recruited from the gentry, bourgeoisie, and universities (Ullern, 2003).

2.2 | Parish population burials

The Church of St. Clemens was a parish church that operated throughout the medieval period (Nedkvitne & Norseng, 2000). Some of the oldest Christian burials in Norway are excavated at this location. The skeletal material (~998 individuals) was excavated in 1920–1921 and analyzed by Wagner (1927) and Holck and Kvaal (2000). The stave church named Church of Prestgard (Prestgardskyrkja) was situated in the mountain valley of Heidal in the southern inland of Norway. The church was built during the first half of the 11th century on the farm Nørdre Prestgard. The churchyard served the small parish community (Nesse & Heidal, 1991) and likely represented a local circuit of farmers (Teigum, 2001). In 1925, the churchyard at Nørdre Prestgard was excavated by Schreiner (1939), and the remains from 77 individuals were unearthed, later analyzed by Holck (2007). Hamar Cathedral (early 12th century to ca. 1567 AD) was situated on a promontory overlooking the largest lake in Norway. The Cathedral was close to the small market town of Hamar, the fifth episcopal seat in Norway (Sellevold, 2001). In 1991–1992, remains from more than 500 individuals were unearthed from the cemetery (Sæther, 1998; Sellevold, 2001).

3 | METHODS

Ethical approval was obtained from the National Committee for Research Ethics on Human Remains (2015/396 and 2016/304).

3.1 | Osteological analysis

The Schreiner Collection database and archive literature provided osteological data on the skeletal remains, as did various publications: Hamar Cathedral (Sellevold, 2000, 2001) and the Church of St. Mary (Brødholt, 2006, 2007a, 2007b; Brødholt & Holck, 2012). All remains were subject to a separate analysis of sex, age, stature, pathology, and trauma prior to the DXA analysis performed (Brødholt et al., 2021). The analysis was conducted according to traditional methods given by Buikstra and Ubelaker (1994). The assessment of sex was performed by evaluating cranial traits (Acsádi & Nemeskéri, 1970) and pelvic features (Phenice, 1969). Next, we estimated age-at-death by evaluating cranial suture closure (Meindl & Lovejoy, 1985) and the pubic symphysis area (Brooks & Suchey, 1990; Todd, 1921). Finally, we estimated stature according to Trotter and Gleser (1952, 1958) and documented pathology and trauma following Ortner (2003) and Aufderheide and Rodríguez-Martín (1998). For extensive details, see (Brødholt et al., 2022). As per Buikstra and Ubelaker (1994), broad age groups were applied: young adult (20–35 years), middle adult (35–50 years), and old adults (50 + years). Mean stature was estimated for young adult females to avoid the confounding variable of age-related height loss associated with osteopenia and osteoporosis. The skeletal material is presumed to represent two highly diverse sosioeconomic groups: (1) High-status burials and (2) parish population burials, based on information from archeological excavations, osteological analyses, and literature pertaining to these burial sites.

3.2 | Dual-energy X-ray absorptiometry

A Lunar iDXA (GE Healthcare Lunar, Madison, WI, USA) was used for the BMD measurements, and the femoral neck (collum femoris) was defined as the region of interest (ROI). We refer to Brødholt et al. (2021) for extensive details on the procedure, inclusion criteria, and cross-calibration. We implemented strict DXA analysis inclusion criteria to account for post-depositional bone changes. The femora should be complete/approximately complete, and the external surface should be preserved and intact. Accordingly, fragmented remains with visible soil intrusion were excluded from the DXA analysis. An assessment of post-mortem changes was made consecutive during the DXA analysis. As a result, anomalies were detected by the Lunar iDXA and portrayed in the high-resolution images. Femora with pathologies known to influence BMD were excluded from the DXA analysis. Subsequently, 25 individuals were excluded after the DXA analysis as these had underlying bone pathology (including systemic diseases) or trauma to weight-bearing bones that may have affected the measured BMD. Previous research on BMD and post-mortem changes (Turner-Walker, Mays, & Syversen, 2000; Turner-Walker, Syversen, & Mays, 2000) indicate that the DXA measurements are representative of in vivo levels, despite considerable microbial reworking, redistribution of minerals, and mobilization of bone apatite.

The WHO definition of osteopenia is a T-score between −1.0 and −2.5 SD below the young female adult mean, and osteoporosis is present if the T-score is equal to or lower than −2.5 SD (Genant et al., 1999; WHO, 2007).

3.3 | Statistical analysis

Two sample *t*-tests were used to analyze stature differences between the high-status and parish population groups and whether the mean BMD or stature differed between the burial sites within each group. In addition, Pearson's chi-square test was used to test whether the proportion of osteopenia/osteoporosis was equal in the high-status and parish groups. The analyses were conducted in R (R Core Team, 2014), and the boxplots were created using the package ggplot2 (Wickham, 2016).

4 | RESULTS

4.1 | Osteological data

Applying our comprehensive DXA analysis inclusion criteria (see Section 3.2) resulted in a final study sample of 101 females. Twenty-five individuals represented high-status burials, and 76 individuals represented parish population burials (Table 1). Following the DXA analysis, we excluded six females (three high-status and three parish population individuals) due to bone pathology or trauma.

4.1.1 | Stature

The mean stature for young adult females of high status was 165.9 cm, whereas young adult females in the parish population had a mean stature of 160.6 cm (Table 1), a significant difference (5.3 cm, $p = 0.01$, *t*-test, Table 2). The comparison of mean stature between burial sites within SES groups for young adult females was non-significant (*t*-tests, Table 2).

4.2 | Dual-energy X-ray absorptiometry

4.2.1 | Femoral neck BMD measurements

Femoral neck mean BMD was calculated for three age categories (young, middle, and old adults) and used as a parameter for correlation to SES (Table 3 and Figure 2). The young adult mean BMD in the high-status group was 1.094 g/cm^2, whereas the mean young adult BMD for parish population females was slightly lower (1.014 g/cm^2). This inter-group difference in mean BMD in young adult females was not significant ($p = 0.127$) (Brødholt et al., 2022). Comparison of femoral neck mean BMD between burial sites within SES groups for young adult females was non-significant (*t*-tests, Table 2).

TABLE 1 Female skeletal remains per burial site and SES group, with indicated age and stature (cm)[a]

Burial site	SES	Sex	Age YA	MA	OA	*n*	Stature YA Mean (cm)	SD	Min	Max
High status sample										
Church of St. Mary	High	F	7	7	2	16				
St. Olav's Monastery[b]	High	F	5	2	2	9				
Total		F	12	9	4	25	165.9	5.65	154	173
Parish population sample										
St. Clemens Church[b]	Parish	F	4	2	4	10				
Prestgardskirken[b]	Parish	F	2	5	8	15				
Hamar Cathedral	Parish	F	8	15	28	51				
Total		F	14	22	40	76	160.6	3.94	155	169
Total study sample[c]		**F**	**26**	**31**	**44**	**101**				

Abbreviations: MA, middle adult (35–50 years); OA, old adult (>50 years); SES, socioeconomic status; YA, young adult (20–35 years).
[a]Partly reproduced from Brødholt et al. (2021).
[b]Data from Holck (2007).
[c]Six females (three high status and three parish population individuals) were excluded following DXA-analysis due to bone pathology and/or trauma (Brødholt et al., 2021).

TABLE 2 Results of two sample *t*-tests: Overall comparison of stature between SES groups for young female adults and comparison of BMD and stature between burial sites within SES groups for young female adults

Two sample *t*-test stature	***t*-value**	***p*-value**
High status versus parish population	2.75	0.01
Two sample *t*-test stature		
Church of St. Mary versus St. Olav's Monastery	0.54	0.60
St. Clemens Church versus Church of Prestgard	−1.11	0.28
Hamar Cathedral versus Church of Prestgard	−1.98	0.06
St. Clemens Church versus Hamar Cathedral	0.54	0.60
Two sample *t*-test femur neck mean BMD		
Church of St. Mary versus St. Olav's Monastery	−0.7	0.49
St. Clemens Church versus Church of Prestgard	0.09	0.93
Hamar Cathedral versus Church of Prestgard	−1.59	0.13
St. Clemens Church versus Hamar Cathedral	1.39	0.19

Abbreviations: BMD, bone mineral density; SES, socioeconomic status.

4.2.2 | Osteopenia and osteoporosis

The proportion of females with osteopenia/osteoporosis (Table 4) was significantly higher in the parish population group (estimated disease risk 0.53) than in the high-status group (estimated disease risk 0.16) ($p = 0.003$, Pearson's chi-square test), as illustrated in Figure 3. The occurrence of osteopenia was more than twice as high in the parish population group compared to the high-status group (38% versus 16%) and BMD defined as osteoporosis was observed exclusively in the parish population group (15%).

5 | DISCUSSION

5.1 | Peak BMD and onset of disease

Higher SES is generally associated with better health and longer life (Adler & Ostrove, 1999; Tyrrell et al., 2016). Low childhood SES is a risk factor for adult morbidity and mortality, and research indicates that improved SES does not mitigate this association in adolescence (Cohen et al., 2004). Risk factors associated with a suboptimal lifestyle (insufficient nutrition, disease, and lack of physical activity) may result in reduced bone mass and weakened skeletal strength in adulthood (Bonjour, 2001; Khosla & Riggs, 2005; Weaver et al., 2016). We have previously discussed living conditions during childhood and puberty and associated risk factors in our SES groups (Brødholt et al., 2022), including access to a varied and adequate diet and little evidence of malnourishment and disease. We highlighted the benefits of physical activity on BMD during childhood and puberty (Kersh et al., 2018), as child labor was widespread in the medieval peasant community (Miszkiewicz, 2019; Winger, 2018). Children of higher SES generally had a more sedentary lifestyle, although these commonly had daily combat training and horseback riding (Contamine, 1984). In brief, our findings did not support the notion of significant suboptimal living conditions during youth or adolescence in any of our SES groups.

Today, females experience progressive bone loss following menopause (NIH, 2015). The time interval until BMD falls under the threshold for osteoporosis (T-score −2.5) is, to a large degree, dependent upon the maximum or peak bone mass, which is strongly genetically determined (Bonjour et al., 1994, 1995; Heaney et al., 2000; Hernandez et al., 2003). To this end, we investigated how young adult BMD distributed between the SES groups, using the measured young adult BMD as an indication of attained peak bone mass. A theoretical

TABLE 3 Femoral neck mean BMD values in females within age and SES groups[a]

		High status				Parish pop.			
		n	BMD g/cm^2	SD	%[b]	*n*	BMD g/cm^2	SD	%[b]
Females	YA	12	1.094	0.09	100	14	1.014	0.16	100
	MA	9	0.898	0.15	82.1	22	0.902	0.22	89.0
	OA	4	0.975	0.07	89.1	40	0.815	0.15	80.4

Note: Excerpt of data from Brødholt et al. (2021).
Abbreviations: BMD, bone mineral density; MA, middle adult (35–50 years); OA, old adult (>50 years); SES, socioeconomic status; YA, young adult (20–35 years).
[a]Partly reproduced from Brødholt et al. (2021).
[b]The age-related changes are given as percent of the mean BMD in the Young Adult age category.

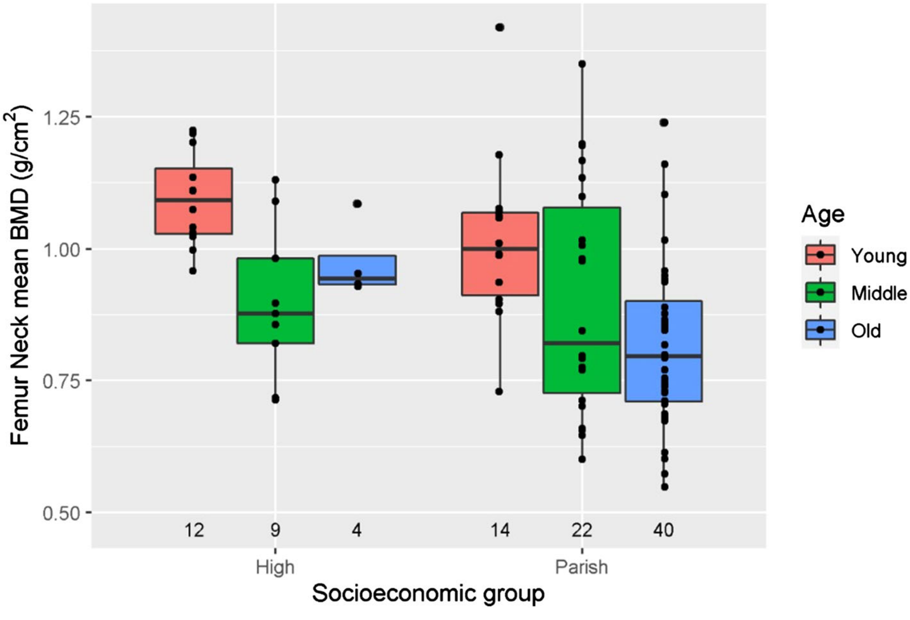

FIGURE 2 Female femoral neck bone mineral density (BMD) for each age and socioeconomic status (SES) group (mean and range). The number of individuals in each age group is shown under each box. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Occurrence and statistical analysis of osteopenia and osteoporosis in SES groups

	Sex	Normal	%[a]	OST	%[a]	OP	%[a]	DR	TS	*p*-value
		n								
High status	F	21	84	4	16	0	0	0.16		
Parish population	F	36	47	30	39	10	13	0.53		
Total		57		34		10				
Pearson's chi-square test									8.83	0.003

[a]Percent of total number of individuals in each SES group.
Abbreviations: DR, disease risk; OP, osteoporosis; OST, osteopenia; SES, socioeconomic status; TS, test statistic.

analysis by Hernandez et al. (2003) highlighted the significance of peak BMD rather than age-dependent bone loss or time of menopause for the development of osteoporosis. According to their model, a 10% higher peak BMD would delay the development of osteoporosis by 13 years. In our skeletal sample, young adult females of high status had a 7.3% higher BMD than young adult females from the parish population, possibly impacting the onset and development of osteoporosis. Although not significant, this difference in (peak) BMD in young adult females may have contributed to the significant difference in the occurrence of osteopenia and osteoporosis in our SES groups.

The age-related BMD variation in these two SES groups is presented in detail in (Brødholt et al., 2022) and revealed a highly contrasting pattern. The parish population females experienced a more gradual and non-distinct decrease in middle adulthood (11% reduction), followed by a further decline in old adulthood (8.6%). In comparison, the high-status females displayed a distinct early bone loss by middle adulthood (a 17.9% reduction), followed by a slight rebound in BMD later in life (a 7% increase). However, only the mean BMD in old adult females differed significantly between our two SES groups ($p = 0.011$). The distinct early bone loss in high-status females was seen in connection with the strain of early and repeated pregnancies

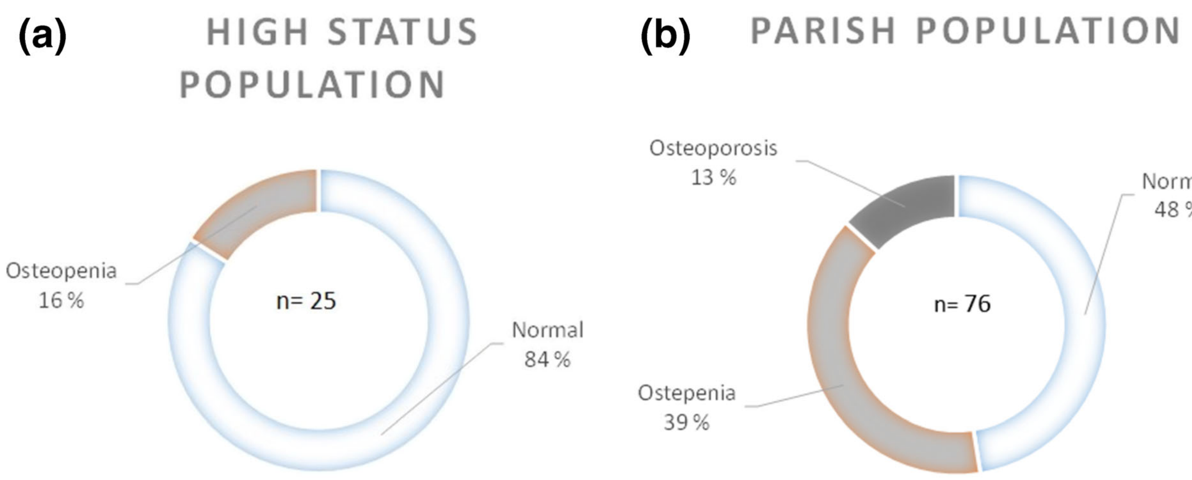

FIGURE 3 (a and b) The distribution of normal bone mineral density (BMD), osteopenia, and osteoporosis in females according to socioeconomic status (SES): The high-status population (a) and the parish population (b). Incidence in each category is given in percent and calculated according to the threshold values defined by the WHO (2007). [Colour figure can be viewed at wileyonlinelibrary.com]

and a more sedentary lifestyle. At the same time, daily labor and struggles may have reduced the bone loss accompanying pregnancy for the parish population females. During Europe's 14th and 15th centuries, wet nursing became popular in the upper classes; breastfeeding was inconvenient, delayed fertility (Baumgartel et al., 2016), and was considered unfashionable (Britton et al., 2018). Conversely, the lower social strata breastfed their infants themselves as they did not have the means to pay for a wet nurse (Baumgartel et al., 2016). This phenomenon, coupled with generally less advantageous living conditions, might contribute to explaining the lower BMD values in older parish females. Compared to modern populations, childbearing started earlier; the parity was high and weaning later in this period (Mays et al., 2006; Turner-Walker, Syversen, & Mays, 2000; Turner-Walker et al., 2001). First pregnancy in adolescence and a shorter reproductive lifespan are shown to reduce BMD (Stride et al., 2013). In the 13th century and onwards, customs of breastfeeding changed in the Nordic countries, from immediate to delayed commencement of lactation, which caused a general increase in neonatal and infant mortality (Benedictow, 1996). A high mortality rate of infants may have resulted in shorter interpregnancy intervals and a greater number of pregnancies (Lewis & Gowland, 2007). However, there is little specific information on SES-related differences in infant mortality rates in the medieval period in Norway.

The authors (Brødholt et al., 2022) interpreted the slight rebound in BMD in older high-status females to reflect favorable living conditions influencing BMD, such as housing, upkeep, and care in old age. However, not all aspects of their life were likely to impact BMD positively. During the 16th–18th centuries in Europe, a light complexion was a sign of aristocracy and social prestige, which contrasted with the dark skin of the peasants laboring outside, and women, in particular, took pains to avoid the sun (Petit, 2019). A lack of sun exposure and staying indoors may result in low vitamin D levels and negatively impact bone health (IOP, 2022). This phenomenon possibly contributed to bone loss later in life in the high-status females in our sample. On a general note, people living in the northern latitudes experience reduced sunlight exposure during the winter (Huotari & Herzig, 2008), which affects how much vitamin D is produced in the skin through exposure to sunlight (IOP, 2022). However, this phenomenon was likely to affect high-status females the most.

Overall, we hypothesize whether the observed lower (peak) BMD in young adult parish population females, combined with accumulated negative environmental influences during adult life, has been vital in the earlier development of osteoporosis and increased bone loss by old adulthood, as indicated by the present results. However, it is imperative to conduct further studies on other skeletal samples from prehistoric and historic Norway, preferably with larger sample sizes. Several factors can be invoked to explain this study's status-based patterns in BMD and stature. Our sample sizes were relatively small due to strict inclusion criteria, the preservation conditions varied between burial sites and not all burial sites were entirely excavated, so we cannot exclude the possibility of a sampling bias. Therefore, it is unclear whether the pattern of status-related differences in BMD and stature observed in this study are specific to the burial sites examined or are indicative of a broader pattern. We observe that the mean BMD values in the high-status group shown in Figure 2 generally show less variation than in the parish population group. However, it is difficult to determine whether the small sample size causes this or if the individuals in the high-status group were more homogeneous. The high-status group consists of individuals from two geographically close burial sites in Oslo (one royal burial church and one Dominican monastery), constituting the most privileged in the medieval society of Norway. The parish population group consists of individuals from three burial sites, geographically scattered and stretching across several social strata. We believe this indicates the representativeness of both groups, despite the small sample size in the high-status group.

5.2 | Stature according to socioeconomic status

Stature is primarily determined by genetics but is modified by environmental factors being of particularly import during development (Jelenkovic et al., 2020; Silventoinen et al., 2003; Stulp & Barrett, 2016; Vercellotti et al., 2014). Mean stature is taken to indicate a population's history of net nutrition (calorie intake minus calorie expenditure caused by disease, work, and maintenance) and consumption of essentials such as food, clothing, shelter, and medical care (Stulp & Barrett, 2016). The medieval population of Europe was exposed to a range of biological (climate change, population growth, and infectious diseases) and social stressors (socioeconomic stratification, warfare, mobility, and interregional trade) (Vercellotti et al., 2014). However, temporal analyses of stature (Steckel, 2004) have indicated that living conditions during the medieval period in Scandinavia were more optimal compared to the preceding and following periods. Geographic remoteness, limited development of trade (and thereby insulation from communicable diseases), predominantly rural dispersed settlement, and low population density in general (linked to lower mortality) are all factors deemed beneficial to health. However, the growing communities from the early medieval period and onwards and the consequent development of interregional and international trade networks connected this dispersed settlement to a greater extent than before. Larger supplies were gathered from a vast resource territory as outfields were vital for the wider network of trade and barter (Øye, 2005). This bustling trading network allowed pathogens and their vectors to circulate more widely than previously, spreading contagious diseases even to the most remote and isolated hamlets, often with profound consequences for population health (Benedictow, 2010; Harrison, 2017).

Previous work by the authors (Brødholt et al., 2022) showed that females of high status were significantly taller than parish population females, whereas no differences were found in the male population. Major negative differences in genetic background between our two SES groups, explaining the stature difference in females, are unknown and less plausible. However, a certain genetic contribution occurred via immigration (Hamre, 2017), probably affecting the high-status group the most. For example, the German influence of individuals of high stature at St. Olav's Monastery (Bull, 1922; Lange, 1856; Torgersen et al., 1964) and (marital) exchange and liaisons in the social strata buried at the Church of St. Mary (Holck, 2001; Roaldset, 2000). However, it is not currently possible to estimate this influence and, if any, how it affected the present material.

The bioarchaeological evidence for a status-based difference in diet in medieval Norway and Scandinavia was previously discussed (Brødholt et al., 2022). In brief, isotope, trace element, and faunal analyses indicated that high-status individuals consumed a larger amount of animal protein (Hufthammer, 2000; Kjellström et al., 2009; Yoder, 2012), whereas rural populations consumed a higher ratio of vegetables and cereals (Iregren et al., 2000). Stable isotope analysis by Kjellström et al. (2009) also demonstrated a link between diet and social stratification, as reflected in a different ratio of animal protein consumed. Benedictow (1996, 1997) discussed stature in relation to medieval female supermortality and malnourishment in a Nordic context and concluded that there is little support for the notion that females were discriminated against in terms of nutrition. Thus, there are few indications of deficiency diseases, undernourishment, and pathology in either SES group or for females in particular, as discussed in detail by (Brødholt et al., 2022). In conclusion, the existing archeological and scientific evidence does not indicate that the diet, in general, had a significant negative impact on health to the degree that it translated to impairment of bone health and stature.

Traditionally in bioarchaeological studies, stature has been viewed as a clear indicator of living conditions during early life, but the complex factors determining statural growth variations make inferences complex (Vercellotti et al., 2014). Research on bone lengths and stature has revealed that medieval children were shorter than modern and 19th-century children, indicating that children from a poor medieval rural community had worse living conditions than poor urban children during the Industrial Revolution (Mays, 2018). Commonly, bioarchaeological studies have detected marked differences in stature between males, not females (Sparacello et al., 2017; Vercellotti et al., 2011; Weiss et al., 2019; Zakrzewski, 2003).

The estimated mean stature for females in other parish population skeletal assemblages from medieval Norway (Brødholt, 2007b) and Scandinavia (Sellevold, 2001) proves to be rather similar to the mean stature observed in our parish population sample and lower than the mean stature in our high-status group. We cannot rule out the presence of a negative, unknown environmental influence affecting stature in the parish population group, but the lack of identified stress indicators affecting one group, in particular, could suggest that the difference may lie in conditions predominantly influencing females of high social status. It may be argued that the significant stature difference observed in our sample could reflect (epi-) genetic selection brought on by the favoring and recruitment of tall men in the high-status strata. Examination of the skeletal material from the Church of St. Mary (Brødholt, 2006, 2007b) revealed a predominance of males, high mean age at death, and a high stature for both sexes. This was interpreted by Brødholt and Holck (2012) as being connected to the recruitment of men to the royal administration in combination with a high standard of living and favorable living conditions in successive generations. These are all factors that may have contributed significantly to a higher stature.

The positive association between physical stature and social status widely observed across cultures may partly be explained by the positive correlation between physical stature and interpersonal dominance (Stulp et al., 2015). Taller males are physically stronger and display better fighting ability (Stulp, 2013), which may contribute substantially in attaining greater access to resources and status. These distinct social gradients in height are even observed in contemporary societies where physical superiority and the ability to fight seem unlikely to directly influence status and access to resources (Stulp & Barrett, 2016). Taller males may also have been more strongly favored as mates (as demonstrated in recent times) (Nettle, 2002; Pawlowski et al., 2000), thus positively influencing female stature and possibly amplifying the influence of natural selection (Stulp & Barrett, 2016).

This, combined with better living conditions in the high-status strata (diet, housing, occupation/physical work, access to resources, etc.), have, together with genetic/epigenetic changes, probably contributed to the higher stature in our high-status group.

6 | CONCLUSION

We analyzed how SES differences in the medieval female population of Norway were reflected in skeletal status as indicated by femoral neck BMD measurements and estimation of stature. This study revealed that females in the parish population exhibited a significantly greater occurrence of osteopenia and osteoporosis in old adulthood than high-status females. We also investigated young adult BMD as an indication of attained peak bone mass, as peak BMD significantly impacts the development and onset of osteoporosis. Young adult females from the parish population displayed a 7.3% lower mean BMD than young adult females of high status, although this difference did not reach significance. However, the observed difference in (peak) BMD in young adult females may have contributed to an earlier development of osteoporosis in the parish population females, which could partly explain the significant difference in the occurrence of osteopenia and osteoporosis in our SES groups. We, therefore, hypothesize that the lower attained, although not significant young adult BMD in parish population females, combined with accumulated negative environmental influences during adult life, resulted in earlier onset of osteoporosis and increased bone loss by old adulthood. The results also clearly demonstrated the association between stature and SES since females of high status were significantly taller. The taller stature among high-status females may result from genetic and/or epigenetic selection, possibly associated with a favoring and recruitment of tall men and amplified by mating preferences in combination with generally beneficial living conditions. In summary, we discovered a pattern of skeletal changes in our SES groups, possibly already starting with impaired attainment of BMD for parish population females in young adulthood.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

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

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