Low Bone Mineral Density in the Femoral Neck of Medieval Women: A Result of Multiparity?

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An archaeological investigation of a medieval cemetery gave us the opportunity to investigate 49 Danish skeletons dating from 1000 to 1250 A.D. and to compare them with 298 contemporary Danes (aged 19–79 years) and assess the millennial trend in bone mineral density (BMD) in populations considered genetically closely related. BMD and bone mineral apparent density (BMAD) of the femoral neck were measured by dual-energy X-ray absorptiometry (DEXA) and transformed into z scores. BMD_{zscore} was significantly lower in medieval women (−0.54 ± 0.25, p = 0.04), whereas BMD_{zscore} in medieval men was significantly higher (0.55 ± 0.22, p = 0.02). In medieval women, BMD_{zscore} tended to increase with age (r = 0.42, p = 0.07), whereas no change was seen in men (r = 0.19, not significant [n.s.]). Also, BMAD_{zscore} was significantly elevated in medieval men (1.00 ± 0.28, p < 0.01), but in medieval women no difference was found (−0.28 ± 0.21, n.s.). However, the correlation between BMAD_{zscore} and age was significant in the medieval women where it increased with advancing age (r = 0.49, p = 0.03). In conclusion, medieval women had lower BMD when compared with contemporary women, but this relationship was reversed in women who survived to older ages. In contrast, medieval men had significantly higher BMD as compared with contemporary men at all ages. The observed lower BMD in medieval women can be explained by the well-known selective mortality among the younger women. A high birth rate and prolonged periods of lactation are the main reasons for the observed increased mortality, and therefore can also very likely explain the associated low BMD. The increase in the incidence of osteoporosis in modern elderly women could possibly, or partially, be explained by the survival of women who would have died prematurely if they lived in earlier centuries. (Bone 28:454–458; 2001) © 2001 by Elsevier Science Inc. All rights reserved.

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likelihood age, which is as good an approximation to true age at death as is theoretically possible based on available anatomical information. To test the robustness of our results, we used a computer program to simulate age at death in each individual, assuming a skewed normal distribution around the maximum-likelihood age. This simulation was carried out 19 times and did not alter any of the basic conclusions. Therefore, results from the simulations are not shown in the figures. Statistical analyses were carried out using the SPSS software program.

In 54 cases, the femoral bones were in a condition suitable for BMD measurements, whereas measurement was impossible in the remaining cases due to lesions of the femoral head or neck (Figure 1C). One skeleton was excluded because gender determination was impossible. Only individuals aged >23 years (i.e., after attaining peak bone mass) were included. The resulting 49 individuals comprised 29 men, aged 29–80 years (mean 49.6 years), and 20 women, aged 26–72 years (mean 41.0 years).

Contemporary Controls

Healthy contemporary Danish women (n = 184) and men (n = 114), aged 19–79 years, from an ongoing study on normal bone metabolism served as controls. By structured interview, controls with previous or present diseases known to affect bone metabolism and women using oral contraceptives or hormonal replacement therapy were excluded. All subjects gave informed consent to be a part of a general Danish control group and the study was approved by the local ethics committee, and was conducted according to the Declaration of Helsinki II.

BMD Measurement

BMD was measured in the femoral neck by dual-energy X-ray absorptiometry (DEXA) using a Hologic QDR-2000 (pencil-beam mode) or Hologic QDR-1000 scanner. The comparability of the results from a phantom obtained from these two different machines was investigated and was shown to be insignificant (coefficient of variation < 0.5%). The medieval bones were placed in a Plexiglas box containing water acting as a soft tissue equivalent and scanned using the femoral protocol as indicated by the manufacturer. The coefficient of variation (cv) in vivo was 2.1%, and for the bones was 2.7%.

Statistics

BMD was measured as bone mineral content/projected area of the femoral neck (g/cm²). Moreover, we calculated bone mineral apparent density (BMAD; g/cm³) as BMD/mean femoral neck width. Age- and gender-specific means and standard deviations for BMD, BMADcontemporary, and SDcontemporary, respectively, were estimated by means of third-order polynomial regression analysis of the contemporary controls. Using these age- and gender-specific mean and standard deviations BMDs of medieval bone (BMDmedieval) were transformed into z scores using the formula:

\[ \text{BMD}_{\text{score}} = \frac{\text{BMD}_{\text{medieval}} - \text{BMD}_{\text{contemporary}}}{\text{SD}_{\text{contemporary}}} \]

Similarly, z score of BMAD was calculated. Normal distributions of z scores were checked visually by inspection of normal probability plots. Data are shown as mean ± SEM, unless stated otherwise. The two-sided t-test was used to test whether z-score values were significantly different from the expected zero. Finally, the relation between age and z scores within each gender was plotted graphically and tested using linear and quadratic regression analysis. \( p < 0.05 \) was considered statistically significant.

Results

Age, gender, BMDscore, and BMADscore values of the 49 medieval subjects are shown in Table 1. In Figure 2, BMD and BMAD values of medieval men and women are plotted against...
Table 1. Femoral neck $z$ scores of 49 skeletons from the early Middle Ages

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>20</td>
<td>29</td>
</tr>
<tr>
<td>Age (years)</td>
<td>41.0 (26–72)</td>
<td>49.6 (29–80)</td>
</tr>
<tr>
<td>BMD$_{score}$</td>
<td>$-0.54 \pm 0.25^a$</td>
<td>$0.55 \pm 0.22^a$</td>
</tr>
<tr>
<td>BMAD$_{score}$</td>
<td>$-0.28 \pm 0.21$ (n.s.)</td>
<td>$1.00 \pm 0.28^a$</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SEM or mean (range).

KEY: BMD, bone mineral density; BMAD, bone mineral apparent density; n.s., not significant.

*$p < 0.05$; **$p < 0.001$.

contemporary controls. BMD$_{score}$ was significantly lower in medieval women ($-0.54 \pm 0.25, p = 0.04$), whereas in medieval men it was significantly higher ($0.55 \pm 0.22, p = 0.02$) (Table 1). The age-related bone loss in the women was aggravated (Figure 2), except among the oldest individuals, in whom a reverse tendency was observed; this is reflected in the linear regression of BMD vs. age where the age-related bone loss is nonsignificant vs. zero ($p = 0.16$). BMD$_{score}$ increased with age ($r = 0.42, p = 0.07$ for maximum-likelihood age, but $p < 0.05$ in 16 of 19 simulations) (Figure 3). In medieval men (Figure 2), an age-related bone loss was evident ($p = 0.04$), but no significant age-related change in BMD$_{score}$ was seen ($r = 0.19$, not significant [n.s.]) (Figure 3). BMAD$_{score}$ was significantly elevated in medieval men ($1.00 \pm 0.28, p < 0.01$), but no difference was seen in medieval women ($-0.28 \pm 0.21$, n.s.) (Table 1). A correlation between BMAD$_{score}$ and age could, however, be found in the medieval women where it increased significantly with age ($r = 0.49; p = 0.03$) (Figure 3). No such correlation was found in the men ($r = 0.12$, n.s.).

![Figure 2](image)

**Figure 2.** Bone mineral density (BMD) and bone mineral apparent density (BMAD) of the femoral neck of 20 women (left) and 29 men (right) from the early Middle Ages as they relate to age. Solid lines indicate mean and 95% confidence limits of the medieval subjects, and stippled lines indicate the mean and 95% confidence limits of contemporary healthy controls. BMD was significantly lower in medieval women ($p = 0.04$) and significantly higher in medieval men ($p = 0.02$) compared with contemporary controls. BMAD was significantly higher in medieval men compared with the contemporary men ($p < 0.01$), whereas no difference was seen in the women.

![Figure 3](image)

**Figure 3.** BMD$_{score}$ of the femoral neck of 20 women (top left) and 29 men (top right) from the early Middle Ages as it relates to age. Linear regression shows a tendency for an increase in BMD$_{score}$ with age in the women ($p = 0.07$), whereas no tendency was seen in the men. Also shown is BMAD$_{score}$ of the femoral neck of the 20 women (lower left) and 29 men (lower right) as it relates to age. Linear regression shows a significant increase in BMAD$_{score}$ with age in the women ($p = 0.03$), whereas no difference was seen in the men.

**Discussion**

Previous studies of bone density in prehistoric skeletons have shown different trends. In a study of medieval skeletons from the 14th and 15th century from Sweden, men had slightly higher BMD in comparison with contemporary controls, whereas no difference was seen in women. In a Danish study, Bennike et al. found that BMD of the femoral diaphysis, as measured by dual-photon absorptiometry (DPA), was higher in neolithic bones (4200–1800 B.C.) but lower in medieval bones (1050–1536 A.D.) compared with recent autopsy cases. This does not support a consistent millennial trend toward lower BMD in the Scandinavian population.

In our series, age-related bone loss was seen in both men and women; however, this was much less pronounced in medieval women than in contemporary women. In German and English series from the 5th–7th and 10th–16th centuries A.D., respectively, age-related bone loss did not differ significantly from modern populations. In contrast, no age-related bone loss was evident, even after the age of 40 years, in the Swedish series, and Lees et al. reported a less pronounced age-related bone loss in women buried in a cemetery in London between 1729 and 1852. The reason for these discrepancies is not evident but may reflect geographical and historical differences in culture and environment.

The crucial factor influencing our results is the uncertainty of the age estimation. We used age simulations to test the robustness of our results as it is evident that the true age at death will remain unknown, because any method applied for skeletal assessment will contain error—possibly both systematic and random error. The advantage of transition analysis-based age estimates is that they contain only random error, under reasonable assumptions.

Obviously, presently living, healthy, modern people cannot be matched in a strictly epidemiologically correct way with long-deceased medieval people. Finding a modern population
that is more suitable for matching with medieval Danish skeletons is not possible. A reference database consisting of a larger number of deceased medieval individuals would be helpful but is presently unavailable. Moreover, such data would still be biased by selective mortality (see later).

It is not possible to provide a full palaeodemographic description of medieval Nordby. The skeletons buried in the cemetery are considered both archaeologically and palaeodemographically representative of the adult population of the village. The ratio of male/female skeletons of 2:1 is probably explained by the fact that men and women initially were buried in separate parts of the cemetery and that a significant number of female skeletons probably remain inaccessible because of a modern highway crossing a portion of the ancient cemetery. However, there is no reason to suggest that the excavated female skeletons were selected on the basis of BMD. BMD differs between ethnic groups and comparison of BMD between the Nordby population and the contemporary Danes relies on the assumption that the two populations share the same genetic pool. Certainly, migration into Denmark and mixture with other populations has been insignificant. The people of medieval Nordby had a smaller stature than modern Danes; however, estimation of height from skeletal remains is inaccurate and the major differences in stature between contemporary and medieval Danes pertain to differences in body proportions. Therefore, we chose to correct BMD data for variation in body size by calculating BMAD.

Several cross-sectional studies have demonstrated that BMD is higher in physically active as compared with sedentary persons. In our study, the significantly higher BMD in medieval men can be attributed to their higher level of physical activity.

It is assumed that carbohydrates constituted the main source of energy in the early medieval Denmark. However, reliable estimates of components in the diet important to bone health, including calcium and vitamin D intake, cannot be made. In theory, dietary differences between women and men could explain the observed difference in bone loss between the genders. There is, however, no archaeological information to suggest that medieval Danish women and men consumed different diets.

In our study, an age-related decline in BMD among the women was observed. This relationship was reversed in the older ages. Unfortunately, only a few medieval women 50 years were included. It could be speculated that this decline was caused by factors related to childbearing. Pregnancy, it seems, does not lead to bone loss due to strong adaptive changes in calcium absorption; however, there are few data on the effect of many pregnancies. Lactation, on the other hand, has been shown to be accompanied by a 5%–7% decrease in BMD. The cumulative period of breastfeeding for each woman was much longer than for contemporary women. The age-related decline and successively the relative increase in BMD in older age (Figure 2) can all be explained by these fertility-related factors. Importantly, however, our sample is biased by the fact that it consists only of deceased individuals. Because it is well-known that fertile women had a higher mortality rate in earlier centuries, these women are overrepresented among the younger women in the sample. This confounder is of great importance in the study. The observed higher mortality among the younger women was associated with a low BMD. The main reasons for the high mortality include the increased physiological demands associated with childbearing and breastfeeding. Only the strongest women survived to older ages. From an epidemiological point of view, the increase in the incidence of osteoporosis observed in elderly modern women may be explained by the survival of a female subpopulation that, in earlier centuries, would have died prematurely owing to the Darwinian principle of natural selection.

Only few studies on BMD in contemporary populations living under conditions comparable to those of medieval times have been published and comparison of these data from Africa and Arabia with a Scandinavian population is difficult. The pronounced age-related bone loss in medieval women could have been due to early menopause; however, no change in the age of menopause has been observed during this century.

In theory, soil conditions may have affected the BMD of the medieval bones during the elapsed period of approximately 800 years. However, postmortem degradation of the bones cannot explain the observed gender difference in BMD. This is due to the evolution of the bones or the pronounced age-related bone loss observed in medieval women. By soaking the bones in water we sought to imitate the density obtained from the blood and marrow elements when scanning fresh bone. Indeed, cadaver studies have shown that the slope of the regression line between results obtained postmortem and later from the skeletonized bodies were not significantly different from 1.0.

Despite the relatively low number of individuals in our study, we detected some interesting differences with regard to BMD in men and women. Medieval men had significantly higher BMD, but the age-related bone loss was virtually identical to that of contemporary men. In concordance with earlier studies, this difference between the men is most likely explained by the higher level of physical activity in the Middle Ages. The observations in the women seem to be in strikingly contrast to the men; the lower BMD in the younger women could probably be explained by the selective mortality caused by a high and heterogeneous birth rate and prolonged periods of lactation.

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