Rural versus nonrural differences in BMC, volumetric BMD, and bone size: a population-based cross-sectional study

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Abstract

Despite reports of lower fracture risk among rural versus urban populations, few studies have investigated rural versus urban differences in bone mineral content (BMC) and bone mineral density (BMD). Population differences in cross-sectional bone geometry and understanding lifestyle factors responsible for these differences may reveal insights into the reason for differences in fracture risk. We hypothesized that if lifestyle differences in bone mass, size, and geometry are a result of muscle strength, activity, or dietary differences, Hutterite and rural populations should have greater bone mass compared to nonrural populations. The study population consisted of 1189 individuals: 504 rural Hutterites (188 men), 349 rural individuals (>75% life farming, 184 men), and 336 nonrural individuals (never lived on farm, 134 men) aged 20 to 66 years. BMC, bone area, and areal BMD (aBMD) of the total body (TB), hip, femoral neck (FN), and spine by DXA; volumetric BMD (vBMD) and bone geometry at the 4% and 20% radius; polar stress strain index (pSSI), a measure of bone strength, at the 20% pQCT site; and strength, 7-day activity recall, and 24-h diet recall were collected and compared among groups. Hutterite women and men had greater grip strength compared to rural and nonrural populations (both, \( P < 0.001 \)). Rural women had greater activity versus Hutterite and nonrural (\( P < 0.001 \)), while both Hutterite and rural men had greater activity than nonrural (\( P < 0.001 \)). Hutterite and rural populations tended to have greater BMC and areal size than the nonrural population, while Hutterites had greater BMC and areal size than rural population at some (TB, FN for females only), but not all (proximal hip), sites. Cortical vBMD was inversely associated with periosteal circumference at the 20% radius in women (\( r = -0.25, P < 0.001 \)) and men (\( r = -0.28, P < 0.001 \)) and was higher in nonrural versus Hutterite and rural men. Hutterite and rural women and men had greater pSSI at the 20% radius compared to nonrural; inclusion of strength measurements explained population differences among women, but not men. Lifestyle differences did not explain population differences in BMC, aBMD, vBMD, or bone size.

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Keywords: Bone density; Epidemiology; Exercise and bone; Diet and bone; Bone strength

Introduction

There are numerous reports of lower fracture risk among rural versus urban populations [1–7]. However, few studies have investigated rural versus urban differences in bone mineral content (BMC) or bone mineral density (BMD), and these studies have only compared average BMD between geographical regions defined as either rural or urban and not based on the lifestyle of the individual [8,9]. Differences in physical activity and dietary intakes of calcium and vitamin D have been proposed as explanations for the observed differences in BMD and fracture risk, although most studies have not measured these variables. Despite the relatively good predictability of fracture risk by BMD measurements, no studies have reported the influence of lifestyle on bone size and cross-sectional geometry, which are at least equally important predictors of fracture risk [10].

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We previously reported high BMD and greater bone size among female members of the Hutterite Brethren and speculated that it was a result of greater dietary calcium intake or activity levels relative to the general population [11,12]. The Hutterites are an Anabaptist religious group who believes in isolated communal living and self-sufficiency through technologically advanced agricultural-based rural lifestyle. The purpose of the current study was to determine whether there are differences in BMC, BMD, bone size, and cross-sectional geometry among Hutterite, rural (non-Hutterite), and nonrural South Dakota populations and whether these differences can be explained by differences in muscle strength, activity levels, or dietary intakes of calcium or vitamin D. These measurements were not obtained in our previous study. We hypothesized that if lifestyle differences in bone mass, size, and geometry are a result of muscle strength, activity, or dietary differences, Hutterite and rural populations should have greater bone mass compared to nonrural populations.

Materials and methods

Subjects

The South Dakota Rural Bone Health Study (SDRBHS) is a study of 1189 healthy adults aged 20 to 66 years. Of the 1189 participants enrolled in 2001 and 2002, 504 were Hutterites, 349 were classified as rural non-Hutterites, and 336 were classified as nonrural non-Hutterites. There are approximately 105 Hutterite colonies in the United States, and more than 50% are located in South Dakota. Thirteen colonies participated in the current study. To be classified as Hutterite, an individual had to be of Hutterite descent and currently residing on a Hutterite colony. Both the rural (non-Hutterite) and nonrural populations were recruited from an eight-county area in eastern South Dakota that included at least one participating Hutterite colony. Based on the Rural—Urban Continuum Codes used by the U.S. Census Bureau (http://www.ers.usda.gov/briefing/rurality/RuralUrbCon/), four of these counties are classified as “completely rural or less than 2500 urban population,” and four counties are classified as “urban population of 2500 to 19,999.” To be considered as rural, the subject had to have spent 75% or more of their life on a working farm or ranch while working less than 1040 h/year off the farm. In order to be considered as nonrural, the subject could never have spent time living on a working farm or ranch. Both rural and nonrural participants were recruited by calling every 10th phone number from local phone books. This process was repeated once for one of the eight counties that had a large population of nonrural residents. In addition, individuals whose names were on County Zoning Offices phone lists of people owning land zoned agricultural in these eight counties also were called. We had difficulty obtaining sufficient numbers of participants who had never lived on a farm and eventually opened recruitment to anyone interested in participating. Sixty-nine (21%) of the 336 nonrural participants were recruited through open enrollment. These individuals were younger and more likely to be male than those nonrural participants that were recruited via telephoning (33 ± 11 vs. 44 ± 2 years and 55% vs. 36% male). Individuals with uncontrolled type 1 diabetes, parathyroid disease, or chronic regular use (>6 months) of oral steroids, anticonvulsants, or immunosuppressants were excluded. Since estrogen status is a potential covariate for females, we categorized women as either replete (N = 581: postmenopausal and receiving HRT; premenopausal) or deplete (N = 102: postmenopausal and no HRT). There were 11 women who stated that they had a menstrual cycle but self-reported themselves as menopausal. These women were included in the estrogen-replete group.

Procedures

Anthropometric, bone, and grip strength measurements and activity and diet information were obtained. Height without shoes and weight with light clothing were determined with a portable stadiometer (SECA) and digital scale (SECA, model 770). Height measurements, recorded to the nearest 0.5 cm, were taken in duplicate and repeated if they differed by more than 0.5 cm. Weight was recorded to the nearest 0.1 kg. Body composition and bone measurements of the total body (TB), spine, and hip were measured using a Hologic QDR 4500A (Bedford, MA). Due to decreased accuracy in spine scans obtained on obese patients, all scans with an epoxy equivalent thickness greater than 12 in., as determined by the Hologic software, were deleted per manufacturer recommendations (one rural female with weight of 153.6 kg, two non-Hutterite rural men with weights of 144.5 and 139.4 kg, and one nonrural man with weight of 149.5 kg). The coefficients of variation (CV) for total body, spine, and hip areal BMD (aBMD) measured by QDR4500A in adults are less than 1%. pQCT measurements of the left radius were obtained using a Norland-Stratec XCT2000 densitometer (Pforzheim, Germany). Arm length was measured from the elbow to the ulna styloid process, and a scout view was taken to identify the end of the radius. Slices were obtained at the 4% and 20% of the measured arm length from the distal radius using a voxel size of 0.4 mm and scan speed of 30 mm/s with a one-block rotation. The slices were analyzed using ContMode2, Peel Mode 2, and a threshold of 400 mg/cm³ to obtain trabecular density (4% site only). Cortical bone was identified using CortMode 3 (automatic threshold) at the 4% site, a density threshold of 710 mg/cm³ at the 20% site, and a threshold of 280 mg/cm³ for polar stress strain index (pSSI). Cortical density at the 4% site was not determined due to partial volume effects with small cortical thicknesses [13]. Cortical thicknesses and periosteal and endosteal circum-
ferences were calculated using the circular ring procedure. The polar stress strain index (pSSI) at the 20%, a measure of torsional bone strength, is based on structural and material properties obtained by pQCT:

\[
pSSI = \sum_{i=1,n} \frac{r_i^2 a (CD/ND)}{r_{max}}
\]

where \( r_i \) is the voxel position from the center, \( a \) is the area of the pixel, \( r_{max} \) is the maximum distance of the voxel to the bone center, CD is the measured cortical density of the voxel, and ND is the normal physiological cortical density (1200 mg/ccm) [14]. CVs from duplicate scans obtained on nine adults following repositioning and with a scout view were 0.5%, 1.2%, and 0.5% for cortical density, cortical thickness, and periosteal circumference at the 20% site and 2.6% and 2.4% for periosteal circumference and trabecular density at the 4% distal site.

Grip strength measurements were made on each participant as both a measure of arm strength and as an indicator of overall fitness level. Grip strength was measured using a digital GRIP-D grip strength dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). The dynamometer was fit to the hand size of the participant. While standing, the participant held the dynamometer in their dominant hand, with the arm relaxed and extended downward, and was instructed to squeeze the instrument as hard as possible for 1 s. Each measurement was made in triplicate and the highest value recorded.

Twenty-four-hour dietary recall interviews were obtained. Nutrient intakes were determined using the Nutritionist V software (First Data Bank, San Bruno, CA). Vitamin and mineral supplements were included in the nutrient intakes. Physical activity was measured using a modified Seven-Day Physical Activity Recall [15], which requires the participant to determine the average amount of time spent per day sleeping, sitting, or in vigorous or moderate activity during the previous week. The remaining time was classified as light activity. Vigorous activity was considered as any activity that leads to an increase in heart rate or heavy breathing and included such activities as running, brisk walking,

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### Table 1
Population characteristics by sex

<table>
<thead>
<tr>
<th></th>
<th>Hutterite</th>
<th>Rural</th>
<th>Nonrural</th>
<th>Significance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (N)</td>
<td>316</td>
<td>165</td>
<td>202</td>
<td></td>
</tr>
<tr>
<td>Estrogen status</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deplete</td>
<td>37 (12%)</td>
<td>44 (27%)</td>
<td>21 (10%)</td>
<td></td>
</tr>
<tr>
<td>Replete</td>
<td>279 (88%)</td>
<td>121 (73%)</td>
<td>181 (90%)</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Age (y)</td>
<td>38.3 ± 12.8ab</td>
<td>47.0 ± 14.0c</td>
<td>41.3 ± 10.5bc</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.6 ± 15.2</td>
<td>73.8 ± 14.7</td>
<td>74.2 ± 17.7</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.9 ± 5.3ab</td>
<td>164.4 ± 5.9a</td>
<td>163.9 ± 6.3b</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>% Body fat</td>
<td>35 ± 7</td>
<td>35 ± 6</td>
<td>35 ± 7</td>
<td>NS</td>
</tr>
<tr>
<td>Males (N)</td>
<td>188</td>
<td>184</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>38.8 ± 12.4ab</td>
<td>44.4 ± 13.6a</td>
<td>42.5 ± 11.9b</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>91.4 ± 15.0</td>
<td>94.9 ± 18.0</td>
<td>91.2 ± 18.0</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.2 ± 5.4ab</td>
<td>178.7 ± 7.8a</td>
<td>179.0 ± 7.4b</td>
<td>( P = 0.001 )</td>
</tr>
<tr>
<td>% Body fat</td>
<td>23 ± 6</td>
<td>24 ± 6</td>
<td>23 ± 6</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Significance based on one-way ANOVA; means with similar superscripts are different from each other at \( P < 0.05 \). Data are observed means ± SD. \( P \) values < 0.10 are reported.

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### Table 2
Lifestyle factors by population group and sex*

<table>
<thead>
<tr>
<th></th>
<th>Hutterite</th>
<th>Rural</th>
<th>Nonrural</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females (N)</td>
<td>316</td>
<td>165</td>
<td>202</td>
<td></td>
</tr>
<tr>
<td>Calcium intake (mg/day)</td>
<td>1132 ± 49</td>
<td>1098 ± 60</td>
<td>999 ± 57</td>
<td>( P = 0.09 )</td>
</tr>
<tr>
<td>Vitamin D Intake (IU/day)</td>
<td>250 ± 22a</td>
<td>279 ± 27b</td>
<td>236 ± 25</td>
<td>NS</td>
</tr>
<tr>
<td>% Time mod ± vig activity</td>
<td>18 ± 0.9a</td>
<td>26 ± 1.1ab</td>
<td>17 ± 1.0b</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Grip strength (kg)</td>
<td>32 ± 0.4ab</td>
<td>30 ± 0.5ab</td>
<td>28 ± 0.5bc</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Males (N)</td>
<td>188</td>
<td>184</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Calcium intake (mg/day)</td>
<td>877 ± 49a</td>
<td>1237 ± 48ab</td>
<td>1042 ± 56b</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Vitamin D Intake (IU/day)</td>
<td>196 ± 18ab</td>
<td>258 ± 18a</td>
<td>281 ± 21b</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>% Time mod ± vig activity</td>
<td>25 ± 0.9a</td>
<td>25 ± 0.9b</td>
<td>18 ± 1.0ab</td>
<td>( P &lt; 0.001 )</td>
</tr>
<tr>
<td>Grip strength (kg)</td>
<td>55 ± 0.6ab</td>
<td>51 ± 0.6a</td>
<td>50 ± 0.7b</td>
<td>( P &lt; 0.001 )</td>
</tr>
</tbody>
</table>

* Data are least square means ± SEM adjusting for age, weight, height, and % body fat. Estrogen status was included as a covariate in analyses of female data. Means with similar superscripts are different from each other at \( P < 0.05 \). \( P \) values < 0.10 are reported.

Vitamin D intakes were log-normally distributed. Reported statistical results are based on analysis performed on the log values.
shoveling, etc. Moderate activity was considered as an activity that required significant movement but did not noticeably increase heart rate or result in heavy breathing. Activity patterns for both week days and weekend days were included, and the number of days per week considered weekend days also was obtained. The average daily percent of time spent in moderate plus vigorous activity was then calculated.

Written informed consent was obtained from all participants, and the study was approved by South Dakota State University Institutional Review Board.

Statistical analysis

Statistical analyses were carried out using the JMP software package (Version 4.0, SAS Institute, Inc., Cary, NC). The data were analyzed using a general linear model (GLM) procedure. Population differences in DXA-derived bone data by sex were analyzed with sex included as a main effect. The two nonrural populations were included as main effects with Tukey’s post hoc analysis to identify differences. This analysis also included age, weight, height, and % body fat. Results are presented as least square means ± SEM adjusting for covariates. The significance level was set at 0.05.

Table 3
Population differences in DXA-derived bone data by sex (data in parentheses are the raw mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Hutterite</th>
<th>Rural</th>
<th>Nonrural</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Females</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB BMC (g)</td>
<td>2353 ± 19b</td>
<td>2290 ± 23w</td>
<td>2197 ± 20w</td>
<td>P &lt; 0.001 (P = 0.005)</td>
</tr>
<tr>
<td>(2322 ± 285)</td>
<td>(2312 ± 312)</td>
<td>(2238 ± 291)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB BA (cm²)</td>
<td>2038 ± 6b</td>
<td>1996 ± 7c</td>
<td>1961 ± 7c</td>
<td>P &lt; 0.001 (P = 0.005)</td>
</tr>
<tr>
<td>(2021 ± 145)</td>
<td>(2034 ± 158)</td>
<td>(1986 ± 145)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine BMC (g)</td>
<td>64.0 ± 0.7ab</td>
<td>61.6 ± 0.8a</td>
<td>60.8 ± 0.8a</td>
<td>P = 0.04 (NS)</td>
</tr>
<tr>
<td>(64.3 ± 10.9)</td>
<td>(64.2 ± 10.9)</td>
<td>(63.2 ± 10.4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine BA (cm²)</td>
<td>60.1 ± 0.3a</td>
<td>59.2 ± 0.4</td>
<td>59.1 ± 0.3a</td>
<td>P = 0.01 (NS)</td>
</tr>
<tr>
<td>(59.3 ± 5.5)</td>
<td>(60.4 ± 5.3)</td>
<td>(59.7 ± 4.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine aBMD (g/cm²)</td>
<td>1.06 ± 0.01a</td>
<td>1.04 ± 0.01</td>
<td>1.02 ± 0.01a</td>
<td>P = 0.006 (P = 0.07)</td>
</tr>
<tr>
<td>(1.08 ± 0.13)</td>
<td>(1.06 ± 0.13)</td>
<td>(1.06 ± 0.13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip BMC (g)</td>
<td>32.6 ± 0.4b</td>
<td>31.8 ± 0.4a</td>
<td>30.7 ± 0.4a</td>
<td>P &lt; 0.001 (P = 0.02)</td>
</tr>
<tr>
<td>(32.9 ± 5.1)</td>
<td>(32.7 ± 5.1)</td>
<td>(31.6 ± 5.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip BA (cm²)</td>
<td>33.6 ± 0.2</td>
<td>33.4 ± 0.2</td>
<td>33.0 ± 0.2</td>
<td>P = 0.06 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(32.9 ± 3.1)</td>
<td>(34.1 ± 3.0)</td>
<td>(33.2 ± 3.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip aBMD (g/cm²)</td>
<td>0.983 ± 0.007b</td>
<td>0.968 ± 0.009b</td>
<td>0.938 ± 0.009b</td>
<td>P &lt; 0.001 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(1.000 ± 0.122b)</td>
<td>(0.958 ± 0.120b)</td>
<td>(0.950 ± 0.127b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN BMC (g)</td>
<td>4.34 ± 0.04b</td>
<td>4.14 ± 0.04a</td>
<td>4.07 ± 0.04b</td>
<td>P &lt; 0.001 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(4.40 ± 0.61b)</td>
<td>(4.15 ± 0.63)</td>
<td>(4.18 ± 0.65)</td>
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<td></td>
</tr>
<tr>
<td>FN BA (cm²)</td>
<td>5.08 ± 0.02ab</td>
<td>4.97 ± 0.03a</td>
<td>4.93 ± 0.3b</td>
<td>P &lt; 0.001 (P = 0.04)</td>
</tr>
<tr>
<td>(5.02 ± 0.35)</td>
<td>(5.05 ± 0.38)</td>
<td>(4.96 ± 0.37)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN aBMD (g/cm²)</td>
<td>0.856 ± 0.007</td>
<td>0.835 ± 0.009</td>
<td>0.826 ± 0.008</td>
<td>P &lt; 0.003 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(0.877 ± 0.117b)</td>
<td>(0.823 ± 0.117b)</td>
<td>(0.843 ± 0.122)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Males**

<table>
<thead>
<tr>
<th></th>
<th>Hutterite</th>
<th>Rural</th>
<th>Nonrural</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB BMC (g)</td>
<td>3020 ± 20b</td>
<td>2945 ± 20a</td>
<td>2883 ± 23b</td>
<td>P &lt; 0.001 (P = 0.03)</td>
</tr>
<tr>
<td>(2975 ± 335)</td>
<td>(2996 ± 416)</td>
<td>(2882 ± 425)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB BA (cm²)</td>
<td>2440 ± 7b</td>
<td>2413 ± 7w</td>
<td>2356 ± 8w</td>
<td>P &lt; 0.001 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(2408 ± 150)</td>
<td>(2461 ± 180)</td>
<td>(2367 ± 185)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine BMC (g)</td>
<td>79.0 ± 1.0b</td>
<td>76.2 ± 1.0</td>
<td>74.4 ± 1.1</td>
<td>P = 0.006 (NS)</td>
</tr>
<tr>
<td>(77.9 ± 15.0)</td>
<td>(77.4 ± 15.0)</td>
<td>(74.8 ± 13.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine BA (cm²)</td>
<td>70.6 ± 0.4</td>
<td>70.3 ± 0.4</td>
<td>69.3 ± 0.4</td>
<td>P = 0.06 (P = 0.09)</td>
</tr>
<tr>
<td>(69.5 ± 6.6)</td>
<td>(71.0 ± 6.5)</td>
<td>(69.9 ± 6.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine aBMD (g/cm²)</td>
<td>1.10 ± 0.01ab</td>
<td>1.06 ± 0.01a</td>
<td>1.06 ± 0.01b</td>
<td>P = 0.01 (P = 0.009)</td>
</tr>
<tr>
<td>(1.11 ± 0.14)</td>
<td>(1.08 ± 0.15)</td>
<td>(1.07 ± 0.13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip BMC (g)</td>
<td>48.1 ± 0.5b</td>
<td>46.8 ± 0.6</td>
<td>46.3 ± 0.6a</td>
<td>P = 0.03 (P = 0.06)</td>
</tr>
<tr>
<td>(48.6 ± 8.1)</td>
<td>(49.0 ± 8.5)</td>
<td>(46.9 ± 8.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip BA (cm²)</td>
<td>45.3 ± 0.3a</td>
<td>45.3 ± 0.3b</td>
<td>43.9 ± 0.3ab</td>
<td>P &lt; 0.001 (P &lt; 0.001)</td>
</tr>
<tr>
<td>(44.4 ± 4.5)</td>
<td>(46.0 ± 4.6)</td>
<td>(44.2 ± 4.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip aBMD (g/cm²)</td>
<td>1.07 ± 0.01</td>
<td>1.04 ± 0.01</td>
<td>1.06 ± 0.01</td>
<td>NS, (P = 0.05)</td>
</tr>
<tr>
<td>(1.09 ± 0.13)</td>
<td>(1.07 ± 0.14)</td>
<td>(1.06 ± 0.13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN BMC (g)</td>
<td>5.25 ± 0.6</td>
<td>5.14 ± 0.6</td>
<td>5.16 ± 0.6</td>
<td>NS (NS)</td>
</tr>
<tr>
<td>(5.40 ± 0.74)</td>
<td>(5.32 ± 0.93)</td>
<td>(5.21 ± 0.90)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN BA (cm²)</td>
<td>5.88 ± 0.03a</td>
<td>5.85 ± 0.03</td>
<td>5.76 ± 0.03ab</td>
<td>P = 0.008 (P = 0.04)</td>
</tr>
<tr>
<td>(5.81 ± 0.35)</td>
<td>(5.90 ± 0.42)</td>
<td>(5.79 ± 0.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN aBMD (g/cm²)</td>
<td>0.893 ± 0.01</td>
<td>0.877 ± 0.01</td>
<td>0.895 ± 0.01</td>
<td>NS (P = 0.07)</td>
</tr>
<tr>
<td>(0.930 ± 0.13)</td>
<td>(0.903 ± 0.14)</td>
<td>(0.900 ± 0.14)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means with similar superscripts are different from each other at P < 0.05. P values < 0.10 are reported. TB indicates total body; FN, femoral neck; BMC, bone mineral content; BA, bone area; aBMD, areal BMD.

* Results are least square means (± SEM) adjusting for age, weight, height, and % body fat. Estrogen status was included as a covariate in analyses of female data.

v Quadratic term for age was included.
One-way analysis of variance techniques were used to evaluate population differences in potential covariates. General linear models were obtained that included age, weight, height, percent body fat, and population group. The quadratic term for age (age + age²) was included if significant at \( P < 0.05 \). Models for females included estrogen status (replete vs. deplete). Dietary intakes of calcium and vitamin D, grip strength, and percent time in moderate plus vigorous activity were then added to the models to determine whether population bone differences could be explained by these lifestyle variables. Significance values less than \( P = 0.10 \) are provided. Tukey Honestly Significant Difference (HSD) was used to determine which population groups differed at \( P < 0.05 \). Results are presented as means ± standard deviation (SD) or least square means ± standard error of the mean (SEM).

Results

Characteristics of the study population are given in Table 1. The Hutterite population was younger and shorter than the rural and nonrural populations, and height differences persisted in both women and men when age was included in the statistical model (both, \( P < 0.001 \)). Although the Hutterite women had similar calcium and vitamin D intakes as the rural and nonrural women, Hutterite men had lower calcium and vitamin D intakes than other rural men (Table 2). Rural women had a greater percent time in moderate + vigorous activity compared to Hutterite and nonrural women, whereas Hutterite and rural men had higher activity compared to nonrural men. Both Hutterite women and men had greater grip strength than both rural and nonrural women and men.

Female bone

Population differences

There were significant population differences in DXA BMC and bone area measurements among women even after controlling for potential covariates of age, height, weight, percent body fat, and estrogen status (Table 3). Hutterite women had greater total body, spine, and femoral neck (FN) BMC and larger total body and femoral neck bone area than both rural and nonrural women. Hutterite women also had greater hip BMC and larger spine and hip bone area compared to nonrural women. Rural women had greater total body and hip BMC, and larger total body bone area than nonrural women. Mean spine, hip, and femoral neck aBMD were 3.9%, 4.8%, and 3.6% greater in Hutterite women compared to nonrural women.

Population differences also were observed using pQCT technology (Figs. 1 and 2). Cortical volumetric BMD (vBMD) was inversely associated with periosteal circumference \( (r = -0.25, \ P < 0.001) \). Although there were no group differences in cortical vBMD, the Hutterite and rural women had larger periosteal circumference (greater bone cross-sectional area), which resulted in a greater pSSI at the 20% radius. Cortical thickness was smaller among the Hutterite women compared to rural and nonrural women, but the larger bone sizes among both Hutterite and rural women lead to a greater total cortical area among rural women. At the 4% distal radius, Hutterite women had greater total BMC, periosteal circumference, cortical bone area, and cortical thickness compared to both rural and nonrural women. Trabecular vBMD also was greater in Hutterite versus nonrural women.

Influence of strength, activity, and diet on population differences

Calcium and vitamin D intake, percent time in moderate plus vigorous activity, and grip strength were included in the regression analyses to determine whether population differences among the females in these lifestyle factors could explain bone differences (Tables 4 and 5). Grip strength was significantly associated with the DXA measure of total body bone area. Grip strength also was a significant predictor of cortical BMC, cortical area, periosteal and endosteal circumferences, and pSSI at the 20% distal radius and periosteal circumference, cortical area, and cortical thick-
ness at the 4% site. Percent time in moderate plus vigorous activity was positively associated with total BMC, and calcium intake was inversely associated with cortical thickness at the 4% site.

Population differences changed slightly when dietary intakes of calcium and vitamin D, activity, and grip strength were included as covariates. Prior to the inclusion of these covariates, Hutterite women had greater spine BMC and femoral neck bone area and aBMD than both rural and nonrural women. However, inclusion of dietary intakes, activity, and strength resulted in Hutterite women having greater spine BMC, and femoral neck bone area and aBMD than nonrural women only (Table 4). pQCT results were relatively unchanged, except that population differences in pSSI were no longer statistically significant.

**Male bone**

**Population differences**

There were population differences in DXA BMC and bone area measurements among men after controlling for potential covariates of age, height, weight, and percent body fat (Table 3). Hutterite men had greater total body BMC and bone area than both rural and nonrural men. Hutterite men also had greater spine and hip BMC and larger hip and femoral neck bone area compared to nonrural men. Rural men also had larger total body and hip bone area than nonrural men. Mean spine aBMD was 3.8% greater in Hutterite versus nonrural men.

Population differences also were observed using pQCT technology (Figs. 1 and 2): Cortical vBMD was inversely associated with periosteal circumference ($r = -0.28, P < 0.001$), and although there was a lower cortical vBMD among Hutterite and rural men at the 20% distal radius, the larger periosteal circumference resulted in a greater pSSI among Hutterite and rural men compared to nonrural men. Cortical thickness was lower among Hutterite men compared to rural and nonrural men, but the larger bone size among both Hutterite and rural men resulted in a greater cortical bone area among both Hutterite and rural men compared to nonrural men. At the 4% distal radius, Hutterite men had greater total BMC, periosteal circumference, and cortical bone area compared to both rural and nonrural men; and rural men had greater total BMC, periosteal circumference, and cortical bone area than nonrural men. Hutterite men also had greater cortical thickness than nonrural men. Trabecular vBMD was similar among the three population groups.

**Influence of strength, activity, and diet on population differences**

Calcium and vitamin D intake, percent time in moderate plus vigorous activity, and grip strength were included in the regression analyses to determine whether population differences in these lifestyle factors could explain bone differences (Tables 4 and 5). Grip strength was significantly associated with total body bone area measured by DXA, and cortical BMC, cortical area, and periosteal circumference at the 20% distal radius. Percent time in moderate plus vigorous activity was positively associated with total BMC and periosteal circumference at the 4% radius. Vitamin D intake was inversely associated with spine bone area.

Population differences changed slightly when these lifestyle factors were included in the analyses.
Table 5
Summary of the effects of lifestyle factors (strength, activity, and dietary intakes of calcium and vitamin D) on pQCT bone measurements and population differences before and after lifestyle factors included in the analyses.a

<table>
<thead>
<tr>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significant lifestyle factors</td>
<td>Population differences before including lifestyle factors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>20% Radius</th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical BMC (mg/mm)</td>
<td>Strength (+)</td>
<td>R &gt; (H = NR)b</td>
<td>No change</td>
<td>Strength (+)</td>
<td>(H = R) &gt; NRb</td>
</tr>
<tr>
<td>P = 0.02</td>
<td></td>
<td></td>
<td></td>
<td>P = 0.002</td>
<td></td>
</tr>
<tr>
<td>Cortical area (mm²)</td>
<td>Strength (+)</td>
<td>R &gt; (H = NR)b</td>
<td>No change</td>
<td>Strength (+)</td>
<td>(H = R) &gt; NR</td>
</tr>
<tr>
<td>P = 0.04</td>
<td></td>
<td></td>
<td></td>
<td>P = 0.001</td>
<td></td>
</tr>
<tr>
<td>Cortical vBMD (mg/ccm)</td>
<td>None</td>
<td>No group differencesb</td>
<td>No change</td>
<td>None</td>
<td>NR &gt; (H = R)</td>
</tr>
<tr>
<td>Ca intake (–)</td>
<td>p = 0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periosteal cir (mm)</td>
<td>Strength (+)</td>
<td>(H = R) &gt; NR</td>
<td>No change</td>
<td>Strength (+)</td>
<td>H &gt; R &gt; NR</td>
</tr>
<tr>
<td>P &lt; 0.001</td>
<td></td>
<td></td>
<td></td>
<td>P = 0.03</td>
<td></td>
</tr>
<tr>
<td>Endosteal cir (mm)</td>
<td>Strength (+)</td>
<td>H &gt; R &gt; NR</td>
<td>H &gt; NR</td>
<td>None</td>
<td>H &gt; R &gt; NR</td>
</tr>
<tr>
<td>P &lt; 0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cortical thickness (mm)</td>
<td>None</td>
<td>(R = NR) &gt; Hb</td>
<td>No change</td>
<td>Strength (+)</td>
<td>(R = NR) &gt; H</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P = 0.04</td>
<td></td>
</tr>
<tr>
<td>pSSI (mm³)</td>
<td>Strength (+)</td>
<td>(H = R) &gt; NR</td>
<td>No group differences</td>
<td>None</td>
<td>(H = R) &gt; NR</td>
</tr>
<tr>
<td>P &lt; 0.001</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>4% Radius</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total BMC (mg/mm)</td>
<td>Activity (+)</td>
<td>H &gt; (R = NR)</td>
<td>No change</td>
<td>Activity (+)</td>
<td>H &gt; R &gt; NR</td>
</tr>
<tr>
<td>P = 0.01</td>
<td></td>
<td></td>
<td></td>
<td>P = 0.03</td>
<td></td>
</tr>
<tr>
<td>Periosteal cir (mm)</td>
<td>Strength (+)</td>
<td>H &gt; (R = NR)</td>
<td>No change</td>
<td>Activity (+)</td>
<td>P = 0.01</td>
</tr>
<tr>
<td>P &lt; 0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trab vBMD (mg/ccm)</td>
<td>None</td>
<td>H &gt; (R = NR)b</td>
<td>No change</td>
<td>None</td>
<td>No differences</td>
</tr>
<tr>
<td>Cortical area (mm²)</td>
<td>Strength (+)</td>
<td>H &gt; (R = NR)</td>
<td>No change</td>
<td>None</td>
<td>H &gt; R &gt; NR</td>
</tr>
<tr>
<td>P = 0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cortical thickness (mm)</td>
<td>Strength (+)</td>
<td>H &gt; (R = NR)</td>
<td>No change</td>
<td>None</td>
<td>H &gt; NR</td>
</tr>
<tr>
<td>P = 0.004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca intake (–)</td>
<td>p = 0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

H indicates Hutterite; R, rural; NR, nonrural; vBMD, volumetric bone mineral density; cir, circumference; trab, trabecular; pSSI, polar stress strain index.

a Both models before and after adding lifestyle factors included age, weight, height, and % body fat. Estrogen status was included as a covariate in analyses of female data.
b Quadratic term for age was included.

Discussion

Several studies have reported lower fracture rates among rural versus urban populations [2–7], yet few studies have investigated rural versus urban differences in bone mass or size [8,9]. Gardsell et al. [8,9] observed higher forearm BMC, as measured by single-photon absorptiometry, among Swedish men and women living in rural areas versus in a city. Gardsell et al. suggested that these rural–urban differences in BMC are likely to explain differences in fracture incidence. Our findings of a higher BMC among individuals who farmed or ranched more than 75% of their lifetime (rural) versus those who never lived on an active farm or ranch (nonrural) are consistent with those of Gardsell et al. However, we also found significant rural versus nonrural differences in the majority of measures of bone size and geometry. We speculate that some of these differences are attributable to population differences in lifestyle. We further
speculate that, together with other apparent population differences in characteristics that are important risk factors for fracture (e.g., propensity to falling), the observed improvements in bone size and geometry provide a plausible explanation for the reported differences in fracture rates.

The role of bone size in determining bone strength has been the focus of several recent publications [16–18]. Bone loading causes an increase in periosteal expansion [19], and several studies have shown greater periosteal circumference in physically active individuals compared to less active individuals [20–22]. We originally reported greater BMD z scores and larger bone size among Hutterite women in South Dakota, which we attributed to adequate calcium intake and higher activity levels [11,12]. The purpose of the current study was to determine whether the Hutterite population had higher or similar BMC and bone size compared to other rural South Dakotans and how these bone measures compare to a nonrural population that has never lived on a working farm or ranch. The majority of previous studies that have compared rural–urban differences in bone mass or fracture risk have compared populations residing in rural and urban regions rather than comparing individuals with distinctly different lifestyles. All the counties that were included in this study were classified as either strictly rural or having an urban population of less than 20,000 and would have been considered as a rural county that was included in this study were classified as either strictly rural or having an urban population of less than 20,000 and would have been considered as a rural population. We also obtained individual measures of strength, physical activity, and dietary intake in order to determine whether population differences in bone could be ascribed to these factors.

Our finding that the rural non-Hutterite women had higher percent time in moderate plus vigorous activity compared to both Hutterite and nonrural women was not expected. However, grip strength was greater among Hutterite women and explained population differences in bone strength (i.e., polar SSI). These findings are consistent with those of Hasegawa et al. [14] who found that pSSI was significantly associated with grip strength. These investigators found that grip strength was a stronger predictor of pSSI than muscle cross-sectional area among 164 individuals aged 18 to 80 years [14]. Unfortunately, we did not obtain muscle cross-sectional area measurements in the current study and were not able to determine whether our findings were similar to those of Hasegawa et al. We speculate that the type of physical activity among Hutterite and rural non-Hutterite women differs and may explain the grip strength differences we observed. Hutterite women spend a significant amount of time in activities that emphasize gripping and forearm strength (i.e., large scale gardening, canning, butchering, and food preparation for communal dining), while rural women tend to farm alongside their husbands in more moderate and vigorous activities involved in caring for livestock. These differences in types of activities performed could explain the lower percent time in moderate plus vigorous activity, yet higher grip strength among Hutterite versus rural women.

The higher BMC and greater bone size at most of the predominantly trabecular-rich bone sites (i.e., 4% distal radius and spine) among both Hutterite women and men compared to both rural and nonrural populations persisted even after controlling for significant covariates. These findings are consistent with our previous study of spine BMC in Hutterite women compared to a small group of non-Hutterite South Dakota women [12]. One plausible explanation is the presence of a genetic trait that leads to a greater bone size that is more responsive to mechanical loading [23]. In general, the Hutterite population is in genetic isolation, and although first-cousin marriages are avoided, the continued genetic isolation and explosive population growth since their migration to the United States in the 1870s have resulted in an increased likelihood of consanguinity [24]. Survey studies conducted among the Hutterites have found an increased prevalence of well-known, recessive hereditary traits that are rare in the general North American populations [25–27]. Thus, it is possible that there may be genetic traits responsible for the high BMC and greater bone size among this population.

We speculate that population differences in activity levels early in life may be responsible for some of the bone differences we observed. Activity levels prior to puberty are considered by some investigators to be more influential in...
determining adult BMC and bone size than activity levels later in life [28,29]. This could explain the higher BMC and bone size among Hutterite and rural populations; both of which we speculate had greater activity levels prior to puberty compared to nonrural populations due to rural children often working on agricultural-related tasks. Televisions are not present in Hutterite homes, and television viewing has been shown to be inversely associated with activity levels in children [30,31]. Therefore activity levels may be higher among rural children, especially Hutterite children, and may explain some of the population differences in bone that we observed.

It has been speculated that greater calcium and vitamin D intake among rural populations may contribute to rural–urban differences in BMD and fracture risk [32]. Although the median calcium intakes among the women (904 mg/day) and men (931 mg/day) in this study were higher than those observed in the 1994 Continuing Survey of Food Intake by Individuals (CSFII) (606 and 857 mg/day in women and men aged 31 to 50 years, respectively) [33], the calcium and vitamin D intakes were not higher among the Hutterite and rural populations compared to the nonrural population, and we did not find any consistent relationships between the bone measurements and calcium or vitamin D intakes. Our marginally significant finding of inverse relationships between some of the bone outcomes and vitamin D and calcium intake may be due to individuals who are at increased risk of osteoporosis, perhaps due to a family history, increasing their intakes of these nutrients.

There are limitations to the cross-sectional design of this study. It is possible that one measurement of strength, a single week’s estimate of activity levels, or recall of 1 day of dietary intake is inadequate for categorizing an individual on these parameters. In addition, grip strength was measured on the dominant arm as a surrogate for overall fitness, while the pQCT measurement was made on the left arm. In spite of these limitations, we did find that bone size measurements were associated with grip strength and percent time in moderate plus vigorous activity, findings that are consistent with previous reports [19,34]. Longitudinal follow-up of these individuals, with repeated measures of activity levels and dietary intake throughout the year, may help clarify the role of these factors in determining bone mass and size.

In summary, we found that a rural lifestyle is conducive to greater BMC at some, but not all, bone sites. The influence of lifestyle is more apparent on bone size, rather than BMD, among both women and men. Lifestyle differences in dietary intakes of calcium and vitamin, physical activity, and strength did not explain population differences in BMC, BMD, or bone size.

Acknowledgments

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References


