THE INTERRELATIONSHIPS BETWEEN BONE MINERAL AT DIFFERENT SKELETAL SITES IN MALE AND FEMALE CADAVERA

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When assessing the mineral content of the skeleton investigators customarily make either radiographic or photon absorption measurements at one particular site on the assumption that the site selected is representative of the remainder of the skeleton. Unfortunately few of the established techniques for bone mineral quantification actually provide information on the relationship between the particular site selected and other parts of the skeleton. Measurements of skeletal mass in vivo by either morphological or densitometric techniques are strictly limited to those sites which are readily accessible, where the bony contour is most uniform and where large individual variations in soft-tissue coverage do not occur (Jackson 1951). It is for these reasons that the shafts of certain long bones have been used most frequently for the quantitative measurement of bone mineral in vivo (Henny 1950; Barnett and Nordin 1960; Doyle 1961; Meema 1963; Meema, Harris and Porrett 1964; Anderson, Shimmins and Smith 1966). The shaft sites that have been employed, however, are composed almost entirely of cortical compact bone where fractures seldom occur.

Many authorities consider that loss of trabecular bone is the dominant feature of osteoporosis, and therefore it is important to know just how representative of trabecular bone are measurements at sites where cortical bone predominates. Furthermore, fractures of the distal radius, the femoral neck and the vertebral bodies commonly occur in osteoporotic subjects, but these sites, which are largely composed of trabecular bone, are not readily amenable to reproducible measurements of density in vivo.

It was considered desirable therefore to examine the relationship between the mineral content at a variety of different skeletal sites where either cortical or trabecular bone predominated.

MATERIAL AND METHODS

The third right metacarpal, the right radius and right femur, and the third lumbar vertebra were removed intact from thirty-four male and twenty-one female cadavera. The subjects were aged thirty-one to ninety years with a mean age of sixty-three years in the females and sixty-seven years in the males. None of these subjects had suffered in life from metastatic cancer or specific diseases of the skeleton such as Paget's disease, and the lumbar vertebrae were found to be free of gross deformity.

Transverse sections of bone were cut with a double-bladed hacksaw from the midshafts of the femur, radius and metacarpal, and also from the femur and radius at a distance of one-eighth of the total length from their distal ends. A cuboid was cut from the centre of the third lumbar vertebra with a saw, great care being taken not to include either cortical bone or intervertebral disc in the sample. The volume of the vertebral cuboid was measured either physically or by liquid displacement. The mean thickness of each bone section was measured with a micrometer. The sections were laid flat on envelope-wrapped x-ray film and

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radiographed. The cross-sectional areas of these samples were obtained by weighing paper tracings of the radiographic images. Finally each sample was heated in a muffle furnace at 600 degrees Celsius for twenty-four hours and the resultant ash was weighed.

The mineral/unit length at each long-bone site was calculated by dividing the total ash by the sectional thickness, and the whole bone density was obtained by dividing the mineral/unit length by the area enclosed by the periosteum. Vertebral density was calculated by dividing the ash content by the volume of the original vertebral cuboid.

RESULTS

The configuration of the bone sections analysed and their relative trabecular and cortical bone contents are shown in Figure 1. The cross-sectional areas at the midshaft metacarpal and radius were individually compared with the cross-sectional areas of each of the other long bone sites, and were found to correlate with varying degrees of significance. The relationship between the cross-sectional areas of the midshaft metacarpal and the midshaft radius is shown as an example in Figure 2. A highly significant correlation was found in both sexes \( r=0.71, \ P<0.001 \) in the females; \( r=0.80, \ P<0.001 \) in the males.

The relationships found between the metacarpal midshaft whole bone density and that at the five other sites measured appear in Table I. In both sexes the best correlations were found between the metacarpal midshaft density and the densities of the midshaft radius and femur and distal radius. In all instances the relationships found in the females showed a higher degree of linear correlation than those found in the males. In the women a highly significant correlation was found between the metacarpal and the distal femur whole bone densities \( r=0.84, \ P<0.001 \), and a significant correlation was present between the metacarpal and vertebral body bone densities \( r=0.47, \ P<0.05 \), but no significant correlations were found between the metacarpal density and either the distal femur or the vertebral body densities in the men.

In Table II the midshaft radius whole bone density has been compared with the other sites measured. The correlations showed the same order of significance as was found using the metacarpal as the reference site.

In Table III the midshaft metacarpal mineral/unit length has been compared with the whole bone densities at the other sites. The previously established correlations are still present but are somewhat less significant, except the relationship between the metacarpal and the vertebral body densities in the females which is more significant \( r=0.54, \ P<0.02 \).

In Table IV the midshaft radius mineral/unit length has been compared with the whole bone densities at the other sites. It can be seen that in the females the midshaft radius mineral/unit length gave superior correlations with whole bone density at these other sites than was found between metacarpal mineral/unit length and the same sites, but no significant correlations were found in the males.

Figure 3 shows the relationship between the distal femur whole bone density and the
TABLE I

Relationship between metacarpal mineral/unit volume in milligrams/millimetre
\((x)\) and mineral/unit volume at other skeletal sites \((y)\) in thirty-four males and twenty-one females, using the equation \(y=bx+a\). \(r=\) coefficient of linear correlation. N.S. = not significant

<table>
<thead>
<tr>
<th>Site</th>
<th>Vertebral body</th>
<th>Distal femur</th>
<th>Distal radius</th>
<th>Midshaft femur</th>
<th>Midshaft radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>(b)</td>
<td>0.046</td>
<td>0.101</td>
<td>0.137</td>
<td>0.378</td>
<td>0.571</td>
</tr>
<tr>
<td>(a)</td>
<td>+0.082</td>
<td>+0.063</td>
<td>-0.212</td>
<td>-0.037</td>
<td>-0.013</td>
</tr>
<tr>
<td>(r)</td>
<td>0.23</td>
<td>0.47</td>
<td>0.30</td>
<td>0.84</td>
<td>0.64</td>
</tr>
<tr>
<td>(t)</td>
<td>1.36</td>
<td>2.33</td>
<td>1.76</td>
<td>6.59</td>
<td>4.70</td>
</tr>
<tr>
<td>Significance</td>
<td>N.S.</td>
<td>P&lt;0.05</td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>

TABLE II

Relationship between midshaft radius mineral/unit volume in milligrams/millimetre
\((x)\) and mineral/unit volume at other skeletal sites \((y)\) in thirty-four males and twenty-one females, using the equation \(y=bx+a\). \(r=\) coefficient of linear correlation. N.S. = not significant

<table>
<thead>
<tr>
<th>Site</th>
<th>Vertebral body</th>
<th>Distal femur</th>
<th>Distal radius</th>
<th>Midshaft femur</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>(b)</td>
<td>0.034</td>
<td>0.091</td>
<td>0.105</td>
<td>0.332</td>
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<tr>
<td>(a)</td>
<td>+0.087</td>
<td>+0.060</td>
<td>+0.223</td>
<td>+0.031</td>
</tr>
<tr>
<td>(r)</td>
<td>0.17</td>
<td>0.49</td>
<td>0.22</td>
<td>0.84</td>
</tr>
<tr>
<td>(t)</td>
<td>0.95</td>
<td>2.43</td>
<td>1.56</td>
<td>6.48</td>
</tr>
<tr>
<td>Significance</td>
<td>N.S.</td>
<td>P&lt;0.05</td>
<td>P&lt;0.001</td>
<td>P&lt;0.001</td>
</tr>
</tbody>
</table>

TABLE III

Relationship between metacarpal mineral/unit length in milligrams/millimetre
\((x)\) and mineral/unit volume in milligrams/millimetre
\((y)\) at other skeletal sites \((y)\) in thirty-four males and twenty-one females, using the equation \(y=bx+a\). \(r=\) coefficient of linear correlation. N.S. = not significant

<table>
<thead>
<tr>
<th>Site</th>
<th>Vertebral body</th>
<th>Distal femur</th>
<th>Distal radius</th>
<th>Midshaft femur</th>
<th>Midshaft radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>(b)</td>
<td>0.0008</td>
<td>0.0020</td>
<td>0.0007</td>
<td>0.0047</td>
<td>0.0074</td>
</tr>
<tr>
<td>(a)</td>
<td>+0.076</td>
<td>+0.051</td>
<td>+0.273</td>
<td>+0.102</td>
<td>+0.015</td>
</tr>
<tr>
<td>(r)</td>
<td>0.25</td>
<td>0.54</td>
<td>0.09</td>
<td>0.60</td>
<td>0.52</td>
</tr>
<tr>
<td>(t)</td>
<td>1.45</td>
<td>2.79</td>
<td>0.54</td>
<td>3.17</td>
<td>3.47</td>
</tr>
<tr>
<td>Significance</td>
<td>N.S.</td>
<td>P&lt;0.02</td>
<td>P&lt;0.01</td>
<td>P&lt;0.02</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>

vertebral body density in both sexes. In the males a highly significant correlation was found \((r=0.66, P<0.001)\), and a somewhat less significant correlation was obtained in the females \((r=0.55, P<0.02)\).

DISCUSSION

In previous studies in which radiographic techniques have been employed to assess skeletal mass using the calcaneus (Mack, Brown and Trapp 1949), the metacarpal (Barnett and Nordin
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1960, Anderson et al. 1966), the ulna (Doyle 1961), the radius (Meema 1963, Meema et al. 1964) and the femur (Barnett and Nordin 1960) the results have been expressed in terms of bone mass/unit diameter or bone mass/unit volume. By expressing their results in this way these workers considered that their figures had been normalised for variations in bone size. In the present study it was shown that the cross-sectional area at one site was related to the cross-sectional areas at other sites in the same subject, and in consequence the cross-sectional area at each site was employed as a normalising factor in order to make allowance for people of different sizes and to facilitate a comparison with previously published figures. In the female subjects the resultant whole bone densities of the metacarpal and radius

1. FIG. 2
Relationship between midshaft metacarpal (x) and midshaft radius (y) cross-sectional area in female △, and male ● cadavers. y=1.703x+14.5; r=0.82; t=10.60; P<0.001 for combined data.

2. FIG. 3
Relationship between whole bone density of distal femur and vertebral cuboid in female △ and male ● cadavers. r=0.55, t=2.79, P<0.02 in females. r=0.66, t=5.00, P<0.001 in males.
midshafts were found to correlate well with the whole bone densities of the distal radius and femur and of the purely trabecular bone of the third lumbar vertebra. Since the midshaft metacarpal and radius consist largely of cortical bone whereas these other sites are composed predominantly of trabecular bone, it is clear that in adult women whole bone density measurements of either the midshaft metacarpal or radius are indeed representative of the densities at other skeletal sites irrespective of their relative proportions of cortical and trabecular bone.

In the males the inter-site whole bone density relationships were relatively poor, and neither measurements at the midshaft metacarpal nor the midshaft radius gave representative estimates of the whole bone densities of the distal femur or the vertebral body. Measurements at predominantly cortical bone sites in males do not therefore appear to be representative of measurements at sites where trabecular bone predominates, although cortical bone sites correlated well with each other and trabecular bone sites correlated well with other trabecular bone sites—for instance, distal femur and the vertebral body.

This lack of correlation between cortical and trabecular bone in males is however not a serious problem, since the majority of patients with fractures of the vertebral bodies, the neck of the femur and the distal radius are women (Albright, Smith and Richardson 1941; Stewart 1955; Buhr and Cooke 1959), and furthermore, loss of bone mineral with age is far greater in women than it is in men (Nordin, MacGregor and Smith 1966; Garn, Rohmann and Wagner 1967; Smith, Anderson, Shimmins, Speirs and Barnett 1969).

Photon absorptiometric studies of the skeleton (Cameron and Sorenson 1963; Shimmins, Smith, Aitken, Anderson and Gillespie 1972) measure bone mass in terms of mineral/unit length of bone, and no normalisation is usually made to correct for variations in bone size. It was found in the present study that both midshaft metacarpal and radius mineral/unit length correlated well with the whole bone densities at the other sites measured in the females. The correlations found in the males were relatively poor and had little predictive potential.

The present study validates the use of measurement of either midshaft metacarpal and radius mineral/unit length or midshaft metacarpal and radius whole bone density to assess bone mineral status throughout the female skeleton. These findings suggest that the relative quantities of bone mineral present in different bones of the female skeleton are similar irrespective of whether the bones are composed predominantly of either cortical or trabecular bone. Nordin (1962) showed that morphological measurements on long bones were related to the density of iliac crest biopsies, and Chalmers and Weaver (1966) found that peripheral bone densitometry correlated fairly well with measurements on the spine in women, but that this relationship was poor in men. Our results confirm this sex difference, and suggest that
in men the relative quantities of cortical and trabecular bone in the skeleton are not closely related.

**SUMMARY**

1. Sections were cut from the third metacarpal, the radius, the femur and the third lumbar vertebra of thirty-four male and twenty-one female cadavers. The mineral content of these different specimens was measured by ashing and the relationships between the quantity of bone mineral present at these sites were examined.

2. In the females the whole bone density and mineral/unit length at both the midshaft metacarpal and the midshaft radius correlated significantly with the whole bone density at all the other sites.

3. In the males these correlations were much less significant and no significant correlation was found between the whole bone density of either the metacarpal midshaft or the radial midshaft and that of the third lumbar vertebra or the distal femur, although a highly significant correlation was found between those of the distal femur and the lumbar vertebra.

4. It is suggested that in women, measurements of either mineral/unit length or whole bone density of both the midshaft metacarpal and radius provide useful information on the whole bone densities at other sites throughout the skeleton.

This work was supported by the Scottish Hospital Endowments Research Trust, the National Fund for Research into Crippling Diseases and G. D. Searle and Co. Ltd., High Wycombe.

**REFERENCES**


