RELATIONSHIPS BETWEEN THE MECHANICAL PROPERTIES, DENSITY, AND CT SCAN DATA OF TRABECULAR BONE WITH AND WITHOUT METASTASES

*Keyak, J H; *Kaneko, T S; *Bell, J S; *Pejic, M R; **Tehranzadeh, J, +Department of Orthopaedic Surgery, University of California, Irvine.

INTRODUCTION: Pathological fracture of bones due to metastatic lesions is a common and serious consequence of breast, prostate, and lung cancer. Current methods for identifying patients who need treatment to prevent pathological fracture are inadequate. Understanding the mechanical behavior of bone with metastases is critical to assessing the risk of pathological fracture. Quantitative computed tomography (QCT) may be useful for assessing the effect of metastases on bone density and, therefore, mechanical properties. To address these issues, we measured the mechanical properties of trabecular bone with and without metastases. We determined the relationships between these properties and ash density (ρash) and between ρash and QCT data (ρQCT).

METHODS: Twelve fresh-frozen human cadaveric distal femora were obtained from 5 male and 5 female donors, ages 45 to 88 yrs. Based on gross visual and radiographic examination, four distal femora had lytic and/or blastic metastatic lesions (group L), four had no lesions but were from donors who died from breast, prostate, or lung cancer (group NL), and four were from donors with no cancer (group NC).

Each specimen was placed in an acrylic container filled with water. The container was placed on a calcium hydroxyapatite calibration phantom and transverse CT scan images were obtained using a GE High Speed Advantage CT Scanner (80 kVp, 280 mA s, 1 mm slice thickness, 0.488 mm pixel size, standard reconstruction).

From the CT scan images, 56, 15x15x15 mm cubes of trabecular bone (14 L, 20 NL, 22 NC) were located and the calibrated QCT density (ρQCT) of each cube was computed. These cubes were then physically cut and cued from each distal femoral condyle using a precision band saw (EXAKT Technologies, Inc., Oklahoma City, OK).

Elastic modulus (E) was measured by mechanically testing each cube nondestructively in each anatomic direction (superior–inferior (SI), mediolateral (ML), and anterior–posterior (AP)) to -0.4% strain in uniaxial compression for three cycles at 0.15 mm/s (1% s^-1). Each cube was then destructively tested in the SI direction. Yield strength (S_u) was determined from the stress-strain curve using a 0.2% strain offset based on actuator displacement. Ultimate strength (S_p) was the peak stress.

After mechanical testing, each cube was ashed at 600 degrees C for 24 hours and weighed. Apparent ash density (ρash) was calculated.

Regression analysis was performed for each group to identify power relationships between E and ρash, S_u and ρash, and S_p and ρash, and to identify linear relationships between ρash and ρQCT. Analysis of covariance was used to identify differences in relationships between groups. Repeated measures analysis of covariance was performed to determine whether the relationships between E and ρash depended on group or test direction. The Bonferroni correction was employed when multiple comparisons were performed.

RESULTS: Strong power relationships (ρ=0.001) that did not depend on group (p≤0.3) were found between strength (S_u and S_p) and ρash, and between E and ρash in each of the anatomic directions (Table 1). The relationships between E and ρash in the ML and AP directions were not significantly different from each other (p>0.9), but differed from the relationship between E and ρash in the SI direction (p≤0.04).

Table 1. Regression results for all groups combined

<table>
<thead>
<tr>
<th>Regression equation</th>
<th>r</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>E = 0.161ρash^-0.61</td>
<td>0.775</td>
<td>222 &lt; E &lt; 3350 MPa</td>
</tr>
<tr>
<td>E = 0.00578ρash^-0.15</td>
<td>0.844</td>
<td>77.3 &lt; E &lt; 1880 MPa</td>
</tr>
<tr>
<td>E = 0.00155ρash^-0.70</td>
<td>0.741</td>
<td>37.1 &lt; E &lt; 1060 MPa</td>
</tr>
<tr>
<td>S_u = 0.00831ρash^-0.06</td>
<td>0.939</td>
<td>1.64 &lt; S_u &lt; 15.3 MPa</td>
</tr>
<tr>
<td>S_p = 0.00592ρash^-0.75</td>
<td>0.941</td>
<td>1.36 &lt; S_p &lt; 16.2 MPa</td>
</tr>
</tbody>
</table>

ρQCT was linearly related to ρash when each group was considered separately and when data from all groups were combined (ρ<0.001, p=0.09, Fig. 1). The relationships for the L and NC groups were significantly different from each other (p<0.01), but were not significantly different from the relationship for the NL group (ρ>0.15). Including group as an independent variable in the relationship between ρQCT and ρash only accounted for an additional 0.4% of the variance in ρash, indicating that although the relationship for the L and NC groups were statistically significantly different, they were numerically similar.

Fig. 1. ρash versus ρQCT for all groups combined

DISCUSSION: This study has shown that metastatic disease does not significantly alter the relationships between the mechanical properties and ρash of distal femoral trabecular bone. This finding indicates that metastatic disease degrades E, S_u, and S_p of trabecular bone mainly through its effect on ρash and that, after accounting for changes in ρash, changes in micro-architecture or in the bone tissue do not affect E, S_u, and S_p. Metastases also do not significantly affect anisotropy with respect to E, as indicated by the finding that the relationships between E and ρash in each anatomic direction did not depend on group. Furthermore, this result, in combination with the close correlation found previously between E and S for normal bone, implies that metastases also do not significantly affect anisotropy with respect to S_p.

The similarity of relationships between ρash and ρQCT for the three groups indicates that metastases do not significantly affect the ability of QCT to provide an accurate and precise estimate of ρash. Thus, for trabecular bone with or without metastases, QCT can be used to estimate ρash and this value of ρash can be used to estimate E, S_u, and S_p.

Our results are similar to those reported previously for trabecular bone without metastases. However, our findings that the relationships between mechanical properties and ρash do not depend on the presence of metastases, and that there is a strong correlation between ρQCT and ρash when all groups were pooled, contrasts with the findings of Hipp et al. We attribute these differences to our use of apparent ash density, which has relatively few sources of error compared to apparent hydrated density.

Although the main area of concern for pathologic fracture of the femur is the proximal femur, this study examined trabecular bone from the distal femur. The mechanical properties of trabecular bone from these regions may differ because their trabecular patterns are different. We chose to use bone from the distal femur to obtain more cube specimens and reasonably consistent trabecular architecture. By controlling for trabecular architecture in this way, we limited the difference between groups to the effect of the metastatic lesions on the bone. Thus, our conclusions should be applicable to other sites of trabecular bone such as the proximal femur and the vertebral body.

The findings of this study, in combination with results from similar studies on cortical bone, may be useful for developing new methods for assessing the risk of pathological fracture.


ACKNOWLEDGMENTS: This work was funded by The Whitaker Foundation grant WF-25978 and by NIH grant #R21CA79568-01.

**Departments of Radiological Sciences and Orthopaedic Surgery, University of California, Irvine, CA.

49th Annual Meeting of the Orthopaedic Research Society Poster #0994