ACCURACY AND RELIABILITY OF MRI TO MEASURE HUMAN BONE GEOMETRY

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INTRODUCTION
Cortical bone size and structure are important surrogates of whole bone strength. Currently there are no established protocols to measure bone cross-sectional area at the clinically important sites such as the proximal femur. Magnetic resonance imaging (MRI) has shown to be a promising technique to measure bone structure in the femoral shaft using animal bones and phantom. However, the femoral mid-shaft contains mainly cortical bone whereas the proximal femur is a more complex structure with a thin cortical shell and greater amount of trabecular bone. The cortical-trabecular border must be identified to truly understand the cortical contribution to bone strength.

Although our goal is to establish an MRI procedure to assess the structural properties at the proximal femur, our preliminary work begins with a more simple structure, the distal site of the tibia. Similar to the proximal femur, the distal tibia contains both trabecular and cortical bone compartments. The aims of the study were 1) to assess how accurately MRI measures total bone and cortical cross-sectional areas, and 2) to evaluate the reliability of MRI measurement and data analysis.

METHODS
Specimen
12 human cadaver tibiae, (mean age 74, SD 6 years) were dissected and kept frozen until their use. This study was approved by the Clinical Ethics Review Board at the UBC.

Measurements
MRI Acquisition
12 tibiae submerged in saline were scanned using a 1.5 T MRI system (GE Signa, GE Medical Systems, Milwaukee, Wisconsin) with a quadrature head coil. The scan sequence used was a T1-weighted spin echo (repetition time TR=600 ms, echo time TE=14 ms) in the transverse plane in 3.0 mm sections with no gap (85 slices) and a matrix size of 512 x 256. All scans were performed by the same two trained technologists.

MRI Analysis
Images displayed low-intensity (dark) cortical bone and medium-intensity (gray-white) trabecular bone/marrow cavity. One seed point was selected in the marrow cavity, and the images were segmented into saline/soft tissue, cortical bone and trabecular bone/marrow cavity compartments based on intensity thresholds and a three-dimensional region growing algorithm from the seed point. Total cross-sectional area (ToA, mm²) and cortical cross-sectional area (CoA, mm²) were derived from the number of pixels within the outer cortical border and within the cortical segment, respectively. Analyses of 3 slices were averaged at site 10% and 25% of the tibia length, measured from the distal end.

Morphometry
10 tibiae were cut at 25% from the distal end plateau to allow validation of MRI assessments of total and cortical bone cross-sectional areas. A digital image of the 25% site was obtained. Outer and inner cortical borders were hand drawn with Image-Pro Plus software (Media Cybernetics, Inc.). The area within the outer border and the area between the outer and inner cortical borders were defined as ToA (mm²) and CoA (mm²), respectively. Each image was analyzed twice and averaged.

Accuracy
To evaluate the accuracy of MRI, the average of the absolute and percentage difference between MRI and direct morphometry variables were calculated. Pearson correlations were computed between direct morphometry and MRI variables at the 25% site.

RESULTS

Reliability
To evaluate reliability for the MRI measurement, the 12 bones were repositioned, rescanned and analyzed at the 10% site. To evaluate reliability of the analysis, 12 tibiae were reanalyzed a week following the first analysis. Intraclass correlation coefficients (ICCs) were computed to determine reliability of measurement and analysis at the 10% site.

DISCUSSION
This study is the first to assess accuracy and reliability of MRI with human cadaver bones and at sites that include cortical and trabecular compartments where the identification of the cortical-trabecular border was required. MRI appears to be an accurate measure of total bone area, but tends to overestimate cortical bone area. However, due to the large variation in human bone morphometry, more specimens are required for statistical comparison.

At the metaphyses of long bones, differentiating cortical from trabecular bone is challenging. In aging bone the increased porosity at the endosteal surface of cortical bone makes this discrimination particularly difficult. Even morphometric assessment of cortical area relied on the rater’s ability to discriminate between cortical and trabecular bone.

MRI measurement and analysis procedures are highly reliable for evaluation of both total and cortical areas at the distal site of the tibia. The cortical shell at the proximal femur is extremely thin, and the total area may play an important role in determining strength. Thus, MRI is a promising tool for clinical assessment of the proximal femur. Further work must improve our ability to identify the cortical-trabecular border.

REFERENCES

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c| MRI (sd) | Morph (sd) | % Diff. | 95% CI |
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<tr>
<td>ToA, mm²</td>
<td>389.4 (63.8)</td>
<td>378.2 (69.0)</td>
<td>3.5</td>
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<tr>
<td>CoA, mm²</td>
<td>213.1 (57.4)</td>
<td>191.1 (49.0)</td>
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The MRI measure of ToA at the 25% site was poorly associated with direct morphometric assessment (R²=0.91) (Figure 1). The MRI measure of CoA at the 25% site was poorly associated with direct morphometric assessment (R²=0.56) (Figure 1).

Figure 1. Total and cortical areas assessed by MRI and morphometry.

Table 1. Total and cortical areas measured by MRI and morphometry.

![Image showing MRI results](image-url)

ToA measured by MRI and morphometry were similar, but CoA appeared to be overestimated by MRI (Table 1).

![Image showing MRI results](image-url)