

Assessment of Cortical Bone Structure Using High-Resolution Magnetic Resonance Imaging

B. H. Hyun¹, D. C. Newitt¹, S. Majumdar¹
¹MQIR, UCSF Radiology, San Francisco, CA, United States

Introduction:

In the context of osteoporosis, for both fracture risk assessment and therapeutic monitoring, in vivo determination of bone strength factors plays a critical role. While high resolution MRI has been used to characterize trabecular bone structure [1,2], measurement of the important cortical bone factors of mineralization and geometry has generally been accomplished with x-ray based CT techniques. While MRI cannot currently assess bone mineralization, it can be used to measure bone geometrical parameters through the contrast of the solid bone to the surrounding soft tissues and enclosed marrow. In this study we: a) demonstrate a method for cortical volume measurements using a high in-plane resolution 3D FGRE sequence and a semi-automated cortical segmentation routine; b) establish the validity and accuracy of these methods by comparing them to ultra-high resolution CT images of ex vivo porcine femora specimens; and c) demonstrate the use of these methods in-vivo in the distal radii of a cohort of human subjects.

Methods:

Ten porcine femora were cleaned and harvested for imaging. High-resolution MR axial images were acquired on a GE SIGNA 1.5 Tesla (GE Medical Systems, Waukesha, WI) scanner using a 3D gradient-echo sequence (TR = 16.2 ms, TE = 4.9 ms, Flip angle = 20°, Resolution = 0.16 x 0.16, x 2.0 mm³) with a quadrature wrist coil (Medical Advances, Milwaukee, WI). CT ultra high-resolution images were acquired on a Philips MX8000 (Philips Medical Systems, Andover, MA) CT scanner (Resolution = 0.077 x 0.077 x .8 mm³). The cortical shell was segmented on the CT images using a threshold set at the midpoint between the peaks representing the high intensity bone and low intensity soft tissue surrounding the femur (Fig. 1). On the MR images, inner and outer cortical boundary contours were generated with a semi-automatic segmentation program, using a deformable snake to conform to the strongest gradient edges in the neighborhood of the user placed model (Fig 2). A trained operator then adjusted the contours where necessary. The program was developed in house using IDL (RSI, Boulder, CO). The MR cortical area was calculated as the enclosed area on each slice by the pairs of concentric contours. The corresponding CT areas were found by interpolating the measured areas to the center positions of the MR slices, and the difference between MR and CT areas were calculated. MR images of PTH patients (n = 15, Mean Age = 56.63 years, SD = 6.23 years) were acquired and cortical volume for each were calculated using the same process used for the porcine MR images.

Results and Discussion:

The total MR cortical volume per specimen, on average, differed from the CT derived values by 1.499% (SD = 1.179%) for overlapping 5.2 cm long regions along the bone. Figure 4 shows a scatter plot of cortical volume for a 16 mm centered on central minimum cross sectional area of each bone, where partial volume effects in the slice direction should be minimal. Agreement between the techniques is good, with a linear regression slope of .99 and R² = .96. Analysis of how the choice in the threshold used in the CT cortical bone segmentation has shown that, due to partial volume effects about the cortical edge, a 10% variation in the chosen threshold level yields an approximately 2% variation in the cortical volume measurement. Since the MR segmentation was dependant on user interaction, and that segmentation techniques between the two modalities differed this could account for the variation between the MR and CT derived porcine cortical measurements. Cortical measurements of PTH patient's radii were acquired using the same semi-automatic segmentation process (Fig. 3). To ensure that only corresponding cortical volumes were measured in each patient analysis was done on cortical bone 2 cm to 4 cm from the endplate. Measurements of cortical volume for the postmenopausal females had a mean value of 1.40 cm³ with a standard deviation of 0.174 cm³. Difficulties in segmenting and measuring cortical volume arose especially at the distal end where the cortical shell is thin and the tendons replicate the signal intensity of bone.

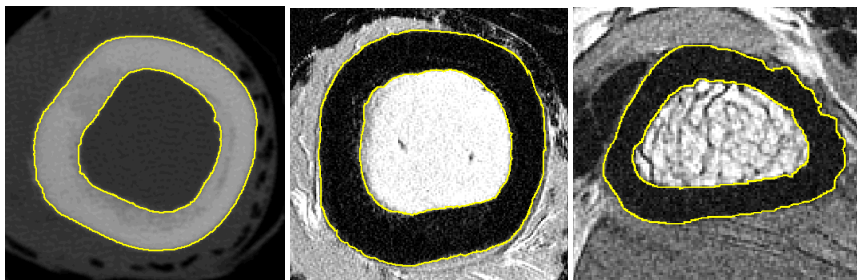


Figure 1

Figure 2

Figure 3

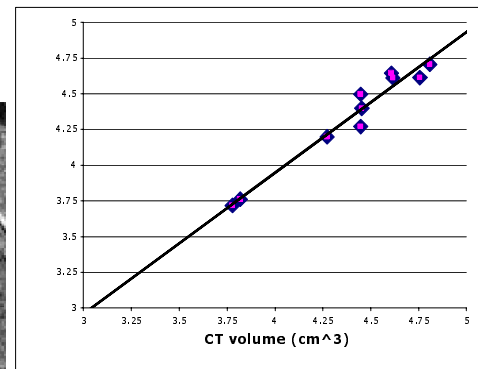


Figure 4

Conclusion:

MRI provides cortical volume measurements in good agreement with CT, and can be accomplished in vivo. With the potential for imaging trabecular bone micro-architecture, as well as cortical bone geometry, MR is a valuable tool for assessing bone changes in aging, osteoporosis and in monitoring therapy.

References:

- [1] Wehrli FW, Hwang SN, Ma J, Song HK, FOR JC, Haddad JG. Cancellous bone volume and structure in the forearm: non-invasive assessment with MR microimaging and image processing *Radiology* 1998;206:347-57
- [2] D. C. Newitt, B. van Rietbergen, S. Majumdar. Processing and Analysis of In Vivo High-Resolution MR Images of Trabecular Bone for Longitudinal Studies: Reproducibility of Structural Measures and Micro-Finite Element Analysis Derived Mechanical Properties. *Osteoporos Int* 2002, 13:278-287

Acknowledgements: Vesta March for acquiring CT images.