In vivo automatic 3D trabecular bone assessment using 7 T MR imaging of the human finger

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Introduction

Trabecular bone strength is mainly determined by bone mineral density, but trabecular architecture has been shown to influence significantly bone mechanical competence [1]. MRI is of interest for trabecular bone architecture studies as it is a non invasive method able to provide 3D images with isotropic resolution. However MRI resolution on current clinical scanners (1.5 T) is at present limited to a few hundred microns, i.e. larger than trabecular thickness. The aim of this work was to establish a reliable in vivo high-resolution MR image analysis protocol by combining $(156\ \mu m)^3$ resolution MR images of the human finger acquired in vivo at 7 T with automatic analysis tools. In order to compute architecture parameters on a well-defined representative Region of Interest (ROI), it was necessary to design a 3D method to delineate automatically trabecular and cortical regions. Reproducibility was also examined by computing architecture parameters using a segmentation algorithm based on a technique of partial volume reduction dedicated to in vivo trabecular bone MR images [2].

Materials and method

High-resolution MR images of the middle finger distal joint of two healthy volunteers were acquired at 7 T on a Bruker Biospec 70/20 with a maximum gradient strength of 196 mT/m. A short-T_E FLASH sequence was applied in order to encode a 128^3 matrix over a $(2\ cm)^3$ FOV, with timing parameters T_R/T_E of 2.6/1 ms and a bandwidth of 200 kHz. The flip angle was adjusted in order to maximize signal from bone marrow. The acquisition time was less than 6 minutes (8 accumulations). Zero-filling ($\times 2$ in each direction) yielded a 256^3 matrix with $(78\ \mu m)^3$ voxel size and a SNR of 10. After normalization of the 3D image to 256 gray-levels, the distal phalange was cropped from the image. Simple cropping along the three orthogonal axis was first performed to limit the ROI inside trabecular tissue. In order to extract the whole 3D trabecular tissue volume as well as the cortical one, the histogram was separated into three-modes: i) noisy voxels (cortical bone, thick trabeculae and tendons), ii) intermediate gray level voxels (partial volume voxels in trabecular bone and soft tissues), iii) high gray-level voxels (marrow and subcutaneous fat). Main clusters (MC) were identified on both the lower-level mode and the higher-level one, with the 26-connection rule. Two closed 3D surfaces enveloping each MC were computed using α-shapes [3] in order to define the cortical and trabecular bone ROIs. For two successive images of the same healthy volunteer processed without zero-filling (I_1 and I_2), a Bone Volume Fraction (BVF) map was calculated using a recent algorithm dedicated to reduce partial volume effect [2] in conditions of resolution and SNR comparable to ours. BVF maps were then thresholded in order to compute BVF and architecture parameters (surface density, trabecular thickness and separation, two anisotropy coefficients and the three Euler angles) on the trabecular region.

Results

Automatic definition of 3D cortical and trabecular ROIs was achieved on all images, with the same efficiency either at nominal resolution (156 µm voxel size) or with zero-filling (78 µm voxel size, see Figures 1, 2 and 3). With our method, the average delimited trabecular volume extracted from I_1 and I_2 was 370 mm^3, about seven times larger than from simple image cropping. Between I_1 and I_2, trabecular volume, BVF, morphometric parameters, anisotropy and orientation were recovered within 5%.

Discussion

This work showed the feasibility of 3D automatic trabecular bone analysis at 7 T. Further image analysis and validation of the BVF measurements using DEXA are in progress. Our method enables monitoring of architecture parameters on defined ROIs, and thus potentially the follow-up of disease progression or of treatment efficiency. We are now envisioning application at 1.5 T with the help of small superconducting probes [4] to compensate for the lesser sensitivity than at 7 T.

References

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Figure 1

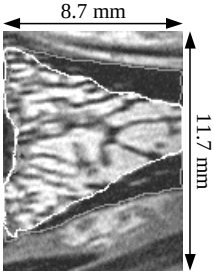


Figure 2

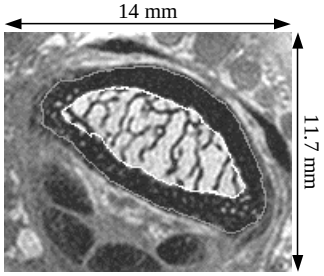
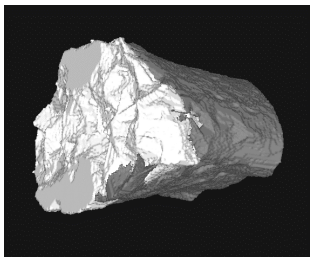


Figure 3



Figures 1 and 2: Two main slices (1: saggital:, 2: axial) of a $(78\ \mu m)^3$ MR image of the human middle finger (distal phalange). The white line and the gray one delimit respectively the trabecular ROI and the cortical one.
Figure 3: 3D rendering of the two ROIs (white: trabecular, gray: cortical).