Diffusion Tensor Imaging (DTI) as a Probe to Measure Trabecular Bone Orientation in-vivo

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Introduction: Trabecular bone orientation (anisotropy), together with bone mineral density, plays an important role in evaluating bone quality (e.g. mechanical competence). This structural information is also a key parameter in bridging bone mechanical behaviour at a macro-scale and its functional adaptation at a cellular scale [1]. Although many methods have been proposed to calculate trabecular bone orientation from reconstructed trabecular bone model [2,3], there is little research on methods for measuring it directly in-vivo. Trabecular bone can be considered as a typical porous media system [4] where diffusion MR is widely used to measure porosity and orientation [5]. Through anisotropic diffusion within red marrow filling in the pores of trabecular bone, diffusion tensor imaging (DTI) can be potentially exploited as a probe of trabecular bone orientation in-vivo. Here, we present the current results of an in-vivo study applying DTI to human tibia and the technique's ability to reveal trabecular network orientation at the micro-scale by reconstructing diffusion tensors and tracking the dominate diffusion directions.

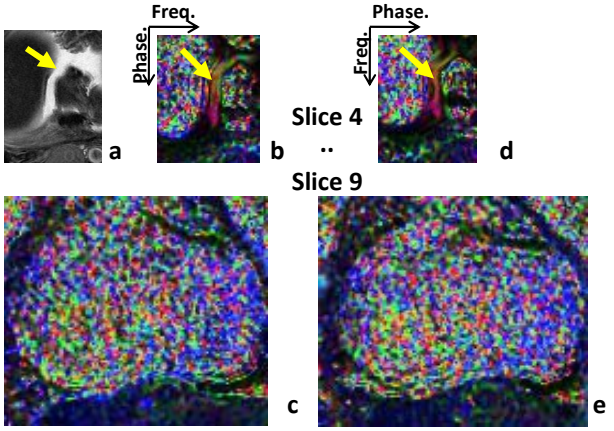

Figure 1: Examination of reproducibility of bone marrow DTI of one volunteer: anatomical landmark indicated in (a) (arrow) from T2 weighted image was found in both DTI acquisitions (switching phase and frequency encoding direction) with the same orientation (b, d). The reproducibility of tensor orientation in tibia bone region is illustrated in (c) and (e).

Methods: Two volunteers were recruited for this in-vivo study (one female, 20 years old, and one male, 46 years old, both with no record of any knee disorder). The right knees of both were scanned on a 3T GE SIGNA system with a diffusion-weighted pulse sequence (PGSE preparation with EPI read-out, parallel imaging mode on in order to reduce the EPI ghosts). Four non-diffusion-weighted datasets (b-value = 0 s/mm2) were acquired firstly. 20 uniformly distributed diffusion directions were then applied with b-value = 400 s/mm^2, with a frequency encoding direction right-to-left (R-L). An 8-channel knee-coil was placed over the lower end of femur head, across the knee joint and ended at upper tibia. The acquisition matrix was 128×128 and interpolated to 256×256, with in-plane resolution 0.70×0.70 mm, and slice thickness 3.2 mm. Scan time was 9 minutes for each DTI acquisition. T_2 weighted datasets (both axial and sagittal) were acquired before the DTI experiment to give anatomical correspondence. Reproducibility was checked by performing the same acquisition with switched frequency and phase encoding directions (i.e. anterior to posterior (A-P)). The diffusion tensor in each voxel was reconstructed by fitting the log-measurements to the Gaussian displacement model by weighted linear regression. The principle diffusion directions were calculated based on the eigensystem decomposition of the computed tensors. A region of interest was chosen inside the trabecular bone, and the coherence of the orientation of diffusion was calculated using a fibre tracking algorithm developed for brain diffusion imaging. All the analyses were performed using CAMINO [6] and MATLAB (R2008a) software. The noise level was assessed by comparing standard deviations of intensity in randomly chosen ROIs (9×9 neighbourhood) within background, muscles and bone regions respectively.

Results Calculated standard deviation (STD) values in bone and muscle ROIs are 15.63 and 18.58 respectively significantly more than the STD of 9.71 in noise ROI. The reproducibility results are shown in Figure 1. The colour map indicates the tensor orientation: red for the x axis (RL), green for the y axis (AP), blue for the z axis. The anatomical land mark was chosen at the region close to the cruciate ligaments (the structure shows great coherence, Figure 1 (b)), with a comparison to the T_2 weighted image (Figure 1(a)). Slices from the tibia region are also presented to show the consistent reproducibility through the datasets. Fractional anisotropy (FA) maps were then generated (Figure 2 (a)). The first principal direction in each voxel of the bone region in a sampled slice is shown in Figure 2(b). Figure 2(c) shows the tracks formed by following diffusion tensors, which visually follows the direction of trabecular bone in tibia.

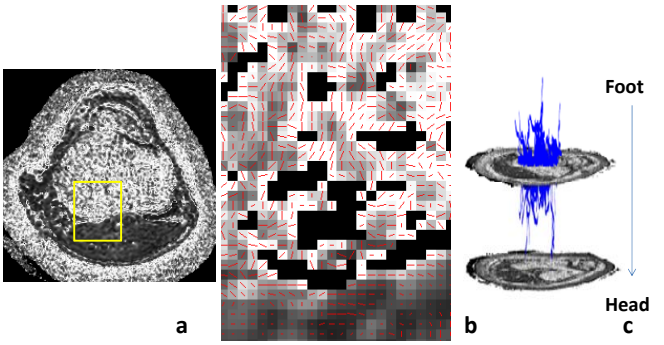

Figure 2: Orientation information indicated by diffusion tensors (computed from one volunteer, R-L DTI dataset,): (a) FA map of slice 9, (b) tensor orientation in the defined ROI (yellow box in (a)). (c) Orientation tracks by following principal tensor directions in the defined ROI.

Conclusion We have presented here the preliminary result to show the feasibility of applying DTI to the tibia in vivo and its reproducibility, its potential as a probe to indicate trabecular bone orientation, which is determined by the functional adaptation of bone [1]. Ongoing work is to reduce problems resulting from EPI distortion and chemical shift, and to use more robust fitting algorithm to reconstruct the diffusion tensor. Further work will be aimed at relating this to the principal directions of the stress tensor. It could then be used as a meso-scale parameter to bridge the macro-scale and micro-scale physiological activities inside bone.

References 1. S.C. Cowin [1986] JBENDY. 108:83-88. 2. F.W. Wehrli *et al.* [2002] IEEPAD. 91(10) : 1520-1542. 3. Hildebrand and Rüegsegger [1997] CMBBE 1 :15-23. 4. Capuani *et al.* [2005] SSNMR 28(2-4): 266-272. 5. P. Wong, [1999], Methods of the Physics of Porous Media; 6. http://www.cs.ucl.ac.uk/research/medic/camino/