Characterization of trabecular orientation in chicken femur by multi-directional SPENT (sub-pixel enhancement of non-uniform tissue)

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Introduction The recently proposed SPENT sequence can provide direction specific information based on the sub-voxel structural uniformity of a sample [1]. The SPENT sequence creates a 2π phase dispersion across a voxel by addition of a gradient between the excitation and refocusing pulses of a standard spin-echo sequence, thus manipulating the intravoxel spin system to evolve depending on the applied gradient direction. Therefore, given a voxel with a local anisotropic structure (e.g. trabecular bone), using SPENT applied in different directions, it is possible to characterize the orientation of sub-pixel micro-structure, as an analogy to diffusion tensor imaging in a stationary spin system. The trabecular bone network has a particular micro-architecture related to the direction of the forces it usually endures. This orientational anisotropy can be mapped to an ellipsoid (an ellipse in 2D) [2,3] and expressed in the form of a 'structure' tensor[4]. This information combined with bone density can increase the prediction of bone fracture risk [5]. In this work, a multi-directional SPENT series is investigated with a tensor based processing method to show its ability of measuring trabecular bone orientation. Multi-directional SPENT may be potentially combined with bone density information as a powerful tool to evaluate bone mechanical competence.

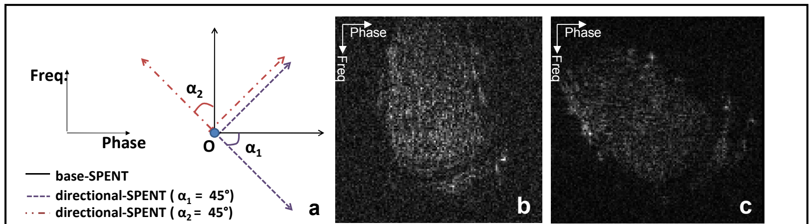

Figure 1. Gradient scheme (a) and examples of base-SPENT (b) and directional-SPENT (c).

Method *Multi-directional SPENT setup:* The multi-directional SPENT series is formed by orientating SPENT in three directions: the normal imaging plane (base-SPENT) first and then rotating the imaging plane by ± 45° (directional-SPENT) respectively with the k-space center as the rotation center in order to cover a semicircle uniformly in "SPENT-space". In each plane, SPENT gradients are added in both frequency and phase encoding direction respectively in each imaging plane, which forms a final 6-direction gradient scheme (Figure 1(a)). For each direction, a standard spin-echo (SE) image is acquired first in each imaging plane to co-register the following SPENT acquisition.

Sample preparation and experiment: A chicken (free-range) femur sample was obtained and the surrounding muscles were removed before scanning. The femur was scanned in the sagittal plane on a Varian 9.4T VMRS system with a Rapid Biomedical Gmbh volume coil with an inner diameter of 26mm. The acquisition matrix was 128 × 128, in-plane resolution 200 × 200 µm, slice thickness 500 µm, FOV 25.6 × 25.6 mm. Acquisition time was 8.5 minutes per direction.

Tensor reconstruction and analysis: The 2D tensor was reconstructed in each voxel by mapping the intensity values in the magnitude data onto an ellipse using linear regression. The SPENT data acquired with a rotational imaging plane was aligned with the original plane by applying the transformation matrix computed from registering the 3 SE images. Both tensor statistics (trace and relative anisotropy) and the corresponding eigensystem were computed to characterize the orientation information. A micro-CT acquisition was obtained immediately after the MR acquisition in order to validate the micro-structure qualitatively.

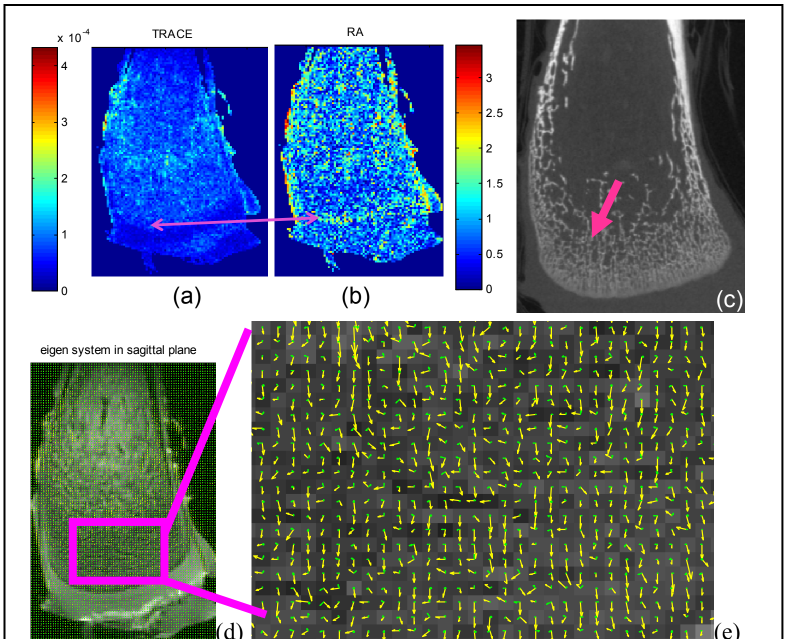

Figure 2. SPENT results: parametric maps, Trace (a) and RA (b); micro-CT slice(c) to show the structure correspondence in the reconstructed tensor systems (d-e). (e) is a closer look of the windowed region in (d).

Results The parametric maps, trace and relative anisotropy (RA), are shown in Figure 2 (a-b). The low isotropic region in trace (dark blue, arrow) corresponds to the high anisotropic region in RA (light blue, arrow) which lies in the region with highly orientated trabecular bone with high bone volume fraction (see from the arrow in the corresponding micro-CT slice; Figure 2 (c)). The 1st (yellow) and 2nd (green) directions of the eigensystem inside each voxel were rendered on top of the SE image acquired in the base-SPENT imaging plane to indicate the anatomical location (Figure 2(d-e)). The principal direction of each voxel agreed well with the trabecular orientation as qualitatively indicated from the acquired micro-CT image.

Discussion The multi-directional SPENT provides an alternative way of measuring trabecular orientation directly compared to other proposed post-processing methods [3]. It provides structural orientation information to diffusion tensor imaging in a similar way, but faster. The current 2D results have visually shown good agreement with the micro-structure of trabecular bone, which can be potentially combined with the bone volume fraction information also indicated by SPENT [1] to provide a powerful tool to predict the fracture risk of trabecular bone. Future work will be to extend multi-directional SPENT into 3D and correlate the derived orientation information with elastic properties as an index of bone mechanical competence.

References 1. M. C. Yiannakas *et al.* [2009] JBMR. 24: 324-333. 2. A. Odgaard [1997] Bone. 20(4): 315-328. 3. F. W. Wehrli [2007] MRM. 25: 390-409. 4. S.C. Cowin [1986] JBENDY. 108:83-88 5. Van Rietbergen *et al.* JORED [1998] 16(1): 23-28