Characterizing Tissue Microstructure Orientation by Multi-Directional Sub-pixel Enhancement of Nonuniform Tissue (SPENT) Sequence

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Introduction: At different resolution levels, the net appearance of the micro-architecture feature different degrees of tissue homogeneity. Such information can be revealed by the recently developed SPENT sequence, leading to a quantitative measurement of the direction specific inhomogeniety [1]. Given enough direction-specific measurements, a dominated structural direction of the sample can be determined by building a structure tensor analogous to a fabric tensor in stereological analysis [2]. An improved multi-directional SPENT (mSPENT) sequence was developed and applied to a chicken femur to characterize its trabecular bone orientation. The approach was further validated by applying the methodology to a pineapple sample with a known structural orientation.

Methods: *Pulse sequence and theory* An mSPENT series is composed of several directional SPENT sequences ($n \geq 3$, in case of a 2D tensor) as shown in Fig.1. The SPENT gradient strength G_{SPENT} is calculated as described in [3] to create a 2π phase dispersion in each voxel. In 2D, it is formed by a combination of the frequency (x) and phase (y) encoding direction SPENT gradients, G_x and G_y respectively by eq. 1. The orientation θ of the gradient is determined by the angle between the two gradient vectors G_x and G_y as indicated in eq. 2, instead of being created by a rotation of the imaging plane as in [4]. Thus in k-space, this gradient shifts the k-space centre, O, of the corresponding spin echo image (created by the same protocol with the SPENT gradient switched off, named $SPENT_0$, whose resolution is defined by λ) by a distance of $\sqrt{2\pi/\lambda}$ along the direction θ to O' (Fig. 2).

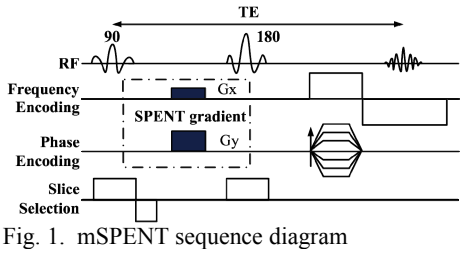

Fig. 1. mSPENT sequence diagram

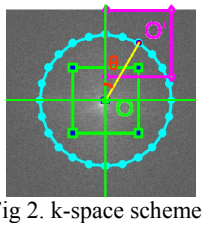

Fig 2. k-space scheme

$$G_{SPENT} = \sqrt{G_x^2 + G_y^2} \quad \textbf{(eq. 1)}, \qquad \theta = \arctan\left(G_y / G_x\right) \quad \textbf{(eq. 2)}$$

Methods 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 (acq.) matrix was 128×128, in-plane resolution 200×200 µm, slice thickness 500 µm, FoV 25.6×25.6 mm, TE 7ms. G_{SPENT} was set to be 11.47 G/cm and applied in 9 directions (uniformly distributed on a circle). Tensor analysis was applied as explained in [4] with software developed in MATLAB (Natick, MA, USA).

Validation The imaging protocol was further validated by measuring the microstructure orientation of a sample with known highly orientated structure, in this case a pineapple. A sample block (20×14×14.5 mm^3) was cut from the central axis of a fresh pineapple. A high-resolution image was acquired with a resolution of 80×80 (µm), acq. matrix 512×512. The SPENT imaging exploited a similar protocol with acq. matrix 64×64, in-plane resolution 200×200 (µm). Following the tensor analysis, a standard fibre tracking method was applied to the tensor system to extract the fibre tracks. These fibre tracks were later compared to the high-resolution image.

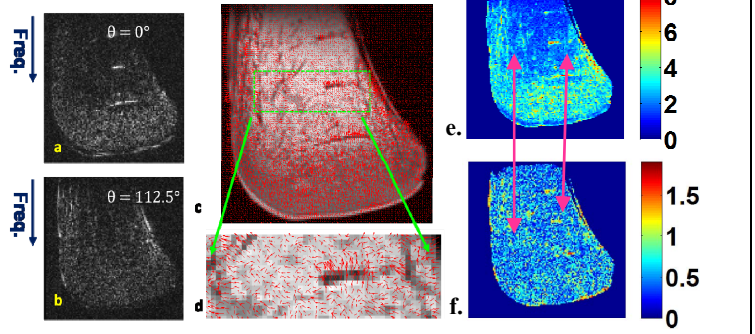

Fig. 3 mSPENT results of the chicken femur study

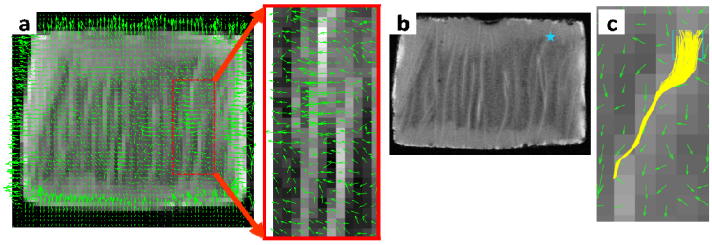

Fig. 4 Validation using a pineapple sample and tracked fibre example

Results: Fig. 3(a, b) present the imaging results of chicken femur head at gradient direction 0° and 112.5°. The principal directions were indicated in Fig. 3(c) with a zoomed ROI shown in Fig. 3(d). The trace map of the chicken femur Fig. 3(e) showed very interesting contrast at various structures with correspondences (pink arrows) in Fig.3 (f). The validation results are shown in Fig.4. In the central axis, the pineapple fibre tracks are parallel to the frequency encoding direction. The tensor image presented in Fig. 4(a) demonstrates agreement with strong inhomogeniety detected orthogonal to the fibres which can be observed in the high resolution (80 µm) pineapple data in Fig. 4(b). An example of extracted fibre tracks from the 200 µm mSPENT data is shown in Fig. 4(c). The seed ROI was mapped back to the high resolution data (see cyan star) in Fig. 4(b).

Conclusion: mSPENT has been shown to be a promising tool for non-invasive microstructure orientation characterization. Future work includes a more quantitative study and applying this method to classifying pathological cases where anisotropic information is involved.

References 1.M. C. Yiannakas *et al.* [2009] JBMR 2.E. R. Weibel Academic Press 1979-1980 3.B. Siow. et al. Proc. 18th ISMRM; 2010 p4942 4 B. Chen et al. Proc. 18th ISMRM; 2010 p793