Multi-Scatter Diffusion Imaging: Calibration for Isotropic Diffusion Sensitivity

C-P. Lin[1], J-H. Chen[1], D. S. Tuch[2]

[1]Institute of Electrical-Engineering, National Taiwan University, Taipei, Taiwan, [2]MGH-NMR Center, Martinos Center for Biomedical Imaging, Charlestown, Massachusetts, United States

Purpose - Magnetic resonance diffusion imaging's resolving power is ultimately limited by fact that the diffusion signal arises from a spatial ensemble average over all the spins in the voxel. By encoding the spin position with multiple non-collinear pulsed gradients, multi-scatter diffusion imaging may be able to measure the lengthscales separating subvoxel diffusion compartments, and thereby recover some of the information lost in the ensemble average. Multi-scatter diffusion imaging may also be able to resolve composite intravoxel structure not resolvable with current high angular resolution diffusion imaging (HARDI) methods [1, 2] such as intravoxel fiber dispersion and twisting. The canonical multi-scatter sequence is not suited to measuring diffusion anisotropy, however, due to directionally-dependent interaction term between the scattering vectors. Here, we describe a series of modifications to the multi-scattering sequence to minimize the cross-talk term and achieve isotropic diffusion sensitivity.

Background - In contrast to the traditional pulsed-gradient spin echo (PGSE) experiment which encodes the spin position with a single wavevector, the multi-scatter diffusion sequence encodes the spin position with multiple non-collinear diffusion wavevectors [3-5]. The multi-scattering method is also referred to as SERPENT (SEquential Rephasing by Pulsed field-gradients Encoding N Time-intervals) [3] or multiple wavevector imaging [4]. The multi-scatter experiment we describe here uses the sequence: 90-q_1-q_2-180-q_3-acq where q_1 and q_2 are separated by time duration Δ_1 and q_2 and q_3 are separated by a time Δ_2. From the multi-scatter signal, we can reconstruct the two-point ensemble-average propagator $P(r_1,r_2)$ which describes the probability for a spin which displaced r_1 in diffusion time Δ_1 to then displace r_2 in time Δ_2. However, the b-value has an interaction term $b_{intxn}=2/3q_{1i}q_{2i}\delta$ which causes the b-value to be directionally-dependent. The interaction term can be minimized by using small δ and designing the q-space sampling schemes so that $q_{1i}q_{2i}>0$. To test the feasibility of acquiring multi-scatter diffusion imaging with isotropic diffusion sensitivity we acquired multi-scatter data in formaldehyde solution using a combined q-space and diffusion tensor imaging sampling scheme.

Methods - Multi-scatter diffusion imaging data of 4% formaldehyde solution was acquired on 3T MRI Biospec system (Bruker, Germany) with an microgradient insert, i.d.=6cm and maximal gradient intensity=1000mT/m. A microquadrature volume coil with i.d.=3.5cm was used for RF transmission and reception. Data were acquired using the multi-scattering diffusion sequence described above. The first wavevector was sampled separately along the read, phase, and slice directions from q=-645 to 645cm^{-1} in 12 steps of Δq=107cm^{-1}. The second wavevector sampling scheme consisted of a dodecahedron with q=645cm^{-1}. The two-point propagator was reconstructed by modulus Fourier transform with respect to the first wavevector and a standard tensor reconstruction for the second wavevector. The imaging parameters were TR/TE=2000/30ms, g_{max}=500mT/m, $\Delta_1/\Delta_2/\delta$=8/8/3ms, b_{max}=3429s/mm^2, FOV=2cm×1cm, matrix size=128×64, slice thickness=1.5mm, in-plane resolution 160μm ×160μm, total acquisition time=32 hours.

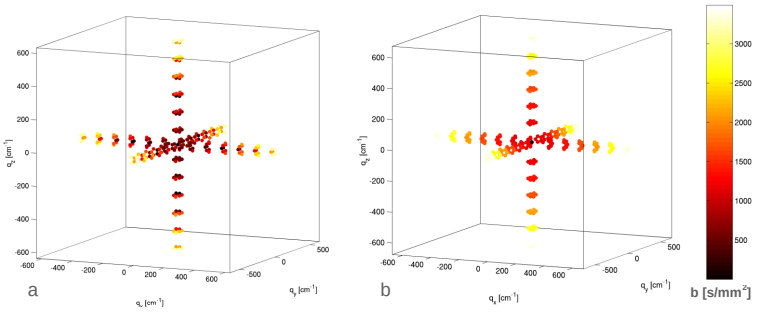

Fig 1. Multi-scatter sampling schemes with (a) opposite and (b) same sign. The same sign scheme gives significantly more isotropic diffusion sensitivity. The color-scale gives the b-value.

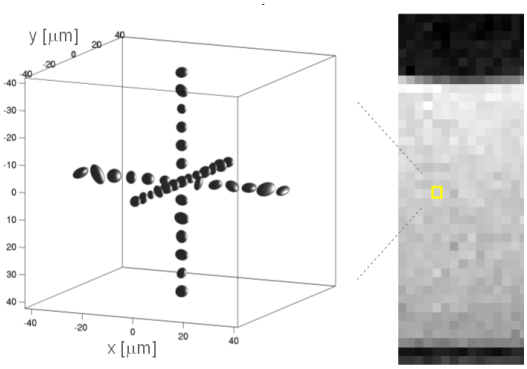

Fig. 2. Distribution of tensors within a *single* voxel (yellow square). Each tensor is associated with a spin displacement position.

Results - Fig. 1 shows the calculated b-value when the second wavevector sampling scheme has the (a) opposite sign from the first wavevector scheme, and the (b) same sign. Note that when the two wavevectors have the same sign the b-value has significantly more isotropic sensitivity. Fig. 2 shows the intravoxel distribution of tensors for a single voxel. The relative isotropy of the reconstructed diffusion tensor indicates that the wavevector cross-talk term was successfully suppressed.

Discussion - Preliminary calibration data indicate that it is feasible to collect multi-scatter diffusion imaging data with isotropic diffusion sensitivity. In the near future, we will collect *in vivo* data to determine whether multi-scatter diffusion imaging can resolve intravoxel tissue structure not resolve by current HARDI methods.

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