# DTI based Muscle Fiber Tractography in Humans at 4 Tesla using Stimulated-Echos

**R. A. Waggoner[1], T. Oda[2], R. Kinugasa[2,3], K. Ueno[4], K. Cheng[1,4], H. Yokota[2], and R. Himeno[2]**

[1]Laboratory for Cognitive Brain Mapping, RIKEN - Brain Science Institute, Wako-shi, Saitama-ken, Japan, [2]Living Matter Simulation Research Team, RIKEN, Wako-shi, Saitama-ken, Japan, [3]School of Sport Sciences, Waseda University, Tokorozawa, Saitama-ken, Japan, [4]fMRI Support Unit, RIKEN - Brain Science Institute, Wako-shi, Saitama-ken, Japan

**Introduction:** DTI of white matter in the brain is a well established technique, and use of DTI to study skeletal muscle architecture is beginning to receive considerable attention.(1,2) T2 is considerable shorter in muscle than it is in the brain and this problem is exacerbated at higher fields. The T2 of muscle at 1.5T has been reported to be between 31-35ms(3,4), while at 4T it is only 26ms.(3) With such short T2s, the use of typical Spin-Echo based DTI pulse sequences is difficult and to date, no DTI studies of muscle above 3T have been reported. The problem of studying diffusion with magnetic resonance, in systems with short T2, has long been addressed by using the Stimulated-Echo.(5) Stimulated-Echo muscle DTI has been used in some studies at 3T and recently it has been show to be beneficial, even at 1.5T.(6) Here we report the first results of DTI muscle based tractography at 4T, using two Stimulated-Echo (STE) based pulse sequences. The combination of higher thermal polarization and longer T1 at higher fields, could potentially make STE based DTI muscle fiber tractography at high fields, and attractive alternative to studies at lower fields.

**Methods:** Figures 1A&B diagram the two STE based pulse sequences used in this study. Figure 1A show a standard STE with an additional delay, $T_{seled}$ period at the end. Gibbs and Johnson proposed the use of a second set of 90° pulses at the end of a diffusion pulse sequence to use the stimulated echo technique to distance the signal acquisition from the motion probing gradients (MPG) in spectroscopic studies, which they termed an LED.(7) Our $T_{seled}$ period is a spin-echo version of this delay that both distances the signal acquisition from the MPG gradients, and allows for the preparatory imaging gradient pulses, which are temporal separated from the MPG gradients. At the end of the $T_{seled}$ delay an EPI read-out is used. Figure 1B shows the Cott's 13-interval STE (C13) sequence,(8) again with the $T_{seled}$ period added at the end. Wu et al. have shown that bi-polar MPG gradients such as those in the C13 sequence minimize eddy-current effects.(9) In addition the C13 sequence is designed to eliminate gradient cross-terms from the diffusion weighting of the signal. Cross-terms become an issue if there are susceptibility gradients generated by the system being imaged, such as would be expected around veins. The C13 sequence eliminates cross-terms if $\delta_1=\delta_2$. In this case the $T_{seled}$ period is especially useful, otherwise Te would need to be extremely long in order to accommodate the imaging preparation gradient pulses, since the necessary time would need to be present in all $\delta_1$ and $\delta_2$ delays.

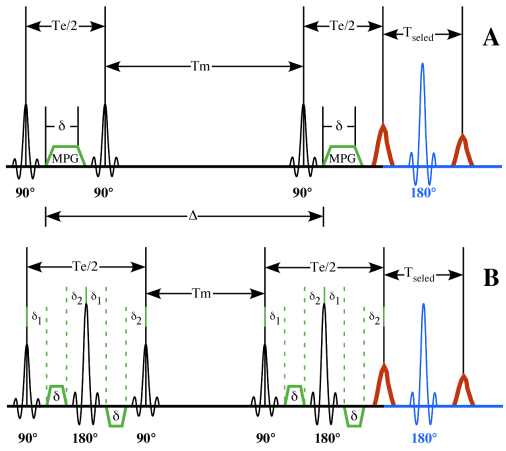



**Figure 1. A**. Standard STE pulse sequence, with SELED period added. **B.** Cott's 13-interval STE sequence with SELED period added.

For the tractography experiment a 32yr old male was placed supine and relaxed, feet first into a Varian Inova 4T (Varian Inc., Palo Alto, CA) whole body MRI system. A 19cm i.d. birdcage transmit coil, and a 4-channel "bi-temporal" receive array coil (Nova Medical Inc. Wakefield, MA) were used to collect the images. In each case a single-shot EPI acquisition was used, with a homodyne reconstruction using 4 overscan lines. Sum-of-square images were generated from the individual receive array images. For single-shot stimulated-echo based images a b-value of 0.0 is not possible, because the actual stimulated-echo would be overwhelmed by the FID from the final 90° pulse, b-value of 0.0 images were approximated with a b-value of 5 s/mm$^2$. In addition images with 6 MPG gradient orientations (X, Y, Z, XY, -XZ, -YZ) were acquired with b=600 s/mm$^2$. 15 slices just below the knee of the right leg were imaged, to cover the FOV where the receive coils were sensitive. Nex=8 was used to enhance SNR. For the STE sequence Tr/Te/Tm/$\delta$/$T_{seled}$ = 7.2s/24ms/296ms/5ms/23ms. For the C13 sequence Tr/Te/Tm/$\delta$/$T_{seled}$ = 7.2s/38.4ms/281.6ms/2.5ms/23ms. Coincident FSE anatomical images were also acquired with an echo spacing of 17ms and ETL=8. The FOV of the DTI images was 20x12.5 cm$^2$ with a matrix size of 128x80, for an in-plane resolution of 1.56mm isotropic. The slice thickness was 5mm. The DTI data was analyzed with DTV.II (Tokyo University Radiology Department).

**Results:** Figure 2 show the fiber tracts in the calf muscle determined with the STE sequence, and Figure 3 the fiber tracts determined with the C13 sequence. For the STE results in Figure 2, the region highlighted by the red circle is devoid of fiber tracts, while the C13 results show dense fiber tracts in this region. This artifact in the STE data is likely due to eddy-current effects, or possible cross-term effects. Even though the C13 sequence is more sensitive to T2 and thus has lower SNR, it's reduced sensitivity to eddy-currents and eliminations of cross-terms, allowed it to clearly give the better results. With either pulse sequence, dense fiber tract bundles could be resolved a 4T.

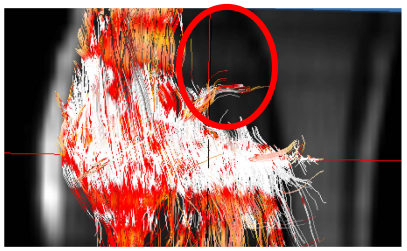
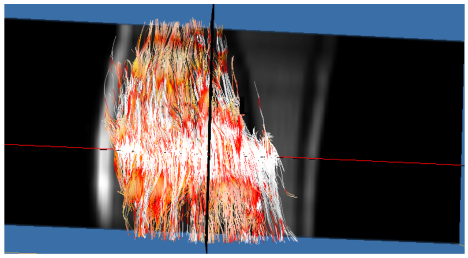


**Figure 2.** STE fiber tracts. Thresholds (FA > 0.1, Angle < 30°)

**Figure 3**. C13 fiber tracts. Thresholds same as Fig2



**Conclusions:** Both pulse sequences were able to resolve a large number of fiber tracts. Even though the C13 sequence is more sensitive to T2, with it's reduced sensitivity to eddy-currents and cross-terms, it clearly gave the better results.

**References:**

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