# Use of probabilistic diffusion tractography to improve visualization in skeletal muscle tractography

**Y. Okamoto[1], K. Tadano[2], T. Masumoto[1], Y. Hirano[1], T. Isobe[2], and M. Minami[1]**

[1]University of Tsukuba Hospital, Tsukuba, Ibaraki, Japan, [2]University of Tsukuba, Tsukuba, Ibaraki, Japan

## Introduction

One report found that visualization of tractography of the soleus muscle tended to be poorer in males than in females (1) This report also suggested that this sex difference in visualization resulted from differences in the size and variations in the pennation angle. Therefore, we concluded that there was a limitation to perfect visualization of muscles with a large and variable angle of pennation using skeletal muscle tractography generated by deterministic diffusion tractography. In particular, deterministic diffusion tractography has limitations in visualizing "tangled" muscle fibers (hereafter referred to as "tangled fibers"). A new method of tracking fibers, called probabilistic diffusion tractography (PDT) has been developed and is being used in neuroradiology to predict the presence of crossing fibers in the brain (2, 3). We have noticed that the crossing fibers in the brain and tangled fibers in skeletal muscle show morphological similarities at the microscopic level, which suggests that PDT might also help resolve difficulties in visualizing tangled fibers from using deterministic diffusion tractography.

The purpose of this study was to perform skeletal muscle tractography using PDT to quantitatively evaluate its visualization ability. We also sought to elucidate whether visualization varies by muscle and whether differences in PDT scan parameters also affect visualization.

## Materials & Methods

Five healthy male volunteers ages 22-25 were recruited into this study. We employed a 3T clinical MRI machine (Achieva, Philips, Best, and the Netherland). Subjects were positioned in a supine position, feet first. Bilateral calves were scanned using a 6ch Torso coil. The thickest part of the calf was used as the reference image. Our DTI studies included three scans per subject, each scan using a different set of parameters that involved varying the number of MPG directions and NEX: 6 MPG directions and 16 NEX (scan 1); 15 directions and 6 NEX (scan 2); 32 directions and 3 NEX (scan 3). Calculations showed that these three sets of parameters had almost the same signal-to-noise ratio (SNR): scans 1 and 3 had identical SNRs, and scan 2 had an SNR slightly inferior to the other two. Other scan parameters were as follows: TR 4000 msec, TE 58 msec, FOV 380 mm, slice thickness 6mm and gapless, matrix 256 × 256, SENSE factor 2, number of slices 12. B-factor was used for 500 mm sec2. Total scan times were 13 minutes 56 seconds for scan 1, 12 minutes 28 seconds for scan 2, and 13 minutes 8 seconds for scan 3, respectively.

FSL (FMRIB, Oxford, UK) was used to generate PDT. Four muscles, the right gastrocnemius medialis (GCM), gastrocnemius lateralis (GCL), soleus (SOL), and anterior tibialis (AT), were reconstructed from the acquired DTI data for each of the three scan parameter sets. We generated a total of 60 tractography images: five volunteers scanned using three different sets of parameters (scans 1-3), generating tractographies of four muscles for each scan. For tractography generation, a free-hand ROI was positioned at slice 1 as a seed point, and the target was positioned at slice 12. The parameters used the following values in both BEDPOSTX and PROBTRACKX: BEDPOSTX fibres 2, weight 1, burn-in 1000; PROBTRACKX Basic Options samples 5000, curvature threshold 0.2, verbose off loopcheck on, use modified Euler streamlining off, maximum number of steps 2000, step length 0.5mm, use anisotropy to constrain tracking off, use distance correction off. ROIs were set using a single mask and a termination mask. The visualization thresholds were set at 2,500 (minimum) and 50,000 (maximum).

Tractography visualization was assessed quantitatively. "Reaching rate" (R) was calculated using the following equation: R= (a / b)×100 (%)
where a = dimension area (pixels) of tracts which can reach to the target dimension b = actual dimension area (pixels) of the target ROI.

"Elaborate degree" (E) was also calculated using the following equation; E= [(c / d) / e] ×104
where c = number of voxels which show higher probability of exceeding threshold minimum by 20,000.d = approximate volume of subject calf muscle, calculated as follows: [(dimension area (pixels) of seed ROI + dimension area (pixels) of target ROI) /2] ×12. e = dimension area of seed ROI.Note: e is the factor used to normalize (c / d) in order to cancel out individual differences in muscle size, as the number of FSL calculations corresponds with the number of pixels in the seed dimension area.

The mean values of "reaching rate" (R) and of "elaborate degree" (E) for the 60 tractography images were compared among the four muscles (GCM, GCL, SOL, and AT) and also among the three sets of scan parameters (scans 1, 2, and 3). Two-factor fractional ANOVA with post hoc test (Tukey) was used for analysis.

## Results & Discussion

Reaching rate denotes the possibility of tracking fibers completely from seed to target. Elaborate degree denotes the extent to which PDT can accurately track actual fiber direction. AT and GCL were the highest scored muscles in reaching rate (Figure 1) and elaborate degree (Figure 2), respectively, with scores statistically significantly higher than the other muscles. SOL muscle, which was representative of "tangled" muscle fibers in the calf, had almost the same reaching rate as GCL and almost the same elaborate degree as AT. The parameter sets including 15 and 32 MPG directions were superior to 6 MPG directions for visualization (Figure 3 and 4).

**Figure 1 Comparison of mean reaching rate among the four muscles**

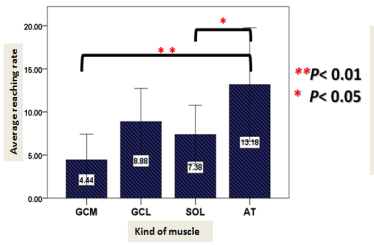



**Figure 2 Comparison of mean elaborate degree among the four muscles**

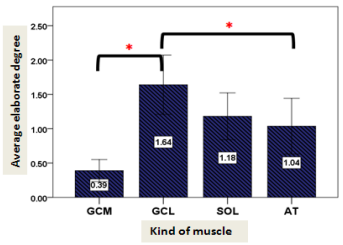



**Figure 3 Comparison of mean reaching rate among scan parameters**

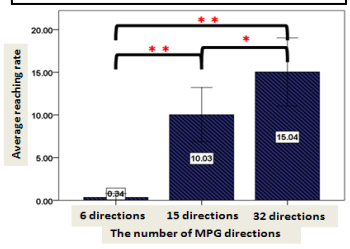
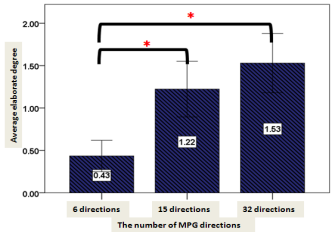



**Figure 4 Comparison of mean elaborate degree among scan parameter**




In our study, the visualization of SOL (tangled fibers) was the essentially the same as GCL in the reaching rate and the same as AT in the elaborate degree. Okamoto et al. performed visualization grading of calf tractography in males in their twenties and thirties, using deterministic diffusion tractography (1). They graded visualization of the right GCM as 3 out of 5, GCL as 5 out of 5, SOL as 1 out of 5, and AT as 4 out of 5, respectively. Of course, the detailed parameters of scan and the reconstruction were different between Okamoto's group and ours. However, both study groups were able to perform relative comparisons of visualization among GCM, GCL, SOL, and AT under the same scan parameters and algorithms in their study population. Therefore, a comparison of Okamoto et al.'s results using deterministic diffusion tractography with our study findings provides some evidence that PDT may be superior to deterministic diffusion tractography in visualizing SOL.

## Conclusion

We successfully tracked skeletal muscle using the PDT method. PDT appears to be especially useful for demonstrating tangled muscle fibers, like SOL. Scan parameters using more MPG directions can produce better visualization.

**References** 1) Magn Reson Med Sci. 2010;9:111-118.2) Neuroimage 2008; 43:81– 89.3) J Magn Reson Imaging 2003;18:242–254