

## Validation of Diffusion Tensor Imaging for Determining Muscle Pennation with Ultrasound

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### Target Audience

Muscle biomechanists and imaging scientists interested in quantitative muscle MRI or post-processing of diffusion tensor imaging data.

### Introduction

The angle at which pennate muscle fibers insert into an aponeurosis is known as the pennation angle ( $\theta$ ). Pennation naturally corresponds to a decrease in muscle fiber length and an oblique arrangement of these shorter length fibers with respect to the muscle's mechanical line of action.<sup>1</sup> Recent developed methods for non-invasively studying muscle architecture in humans *in vivo* include Ultrasonography (US) and Diffusion Tensor Imaging (DTI). Many studies have used either US or DTI, but there has been little or no research comparing the two techniques. The goal of this study was to compare the results of US and DTI for measuring human muscle fiber orientation *in vivo*.

### Methods

**Subjects:** Four subjects provided written informed consent to participate in this study. All studies were conducted with the subject in a supine position and the foot positioned in 10° of dorsiflexion and again in 20° of plantarflexion.

**US Acquisition:** US data were collected using a GE Medical Systems LOGIQ Book e:Triplex Doppler US system with a Model 8L-RS 8 MHz linear array musculoskeletal vascular probe. The image field of view was 3.5 x 3.5 cm, allowing visualization of the superficial and deep compartments of the mid-portion of the tibialis anterior muscle. So that the DTI and US imaging planes could be matched, the angle of the probe head with respect to the leg was recorded and fiducial markers were affixed to the skin.

**DTI Acquisition:** A 3.0T Philips Intera Achieva MR Imager/Spectrometer with an 8 channel parallel array knee coil was placed over the anterior compartment of the leg. T<sub>1</sub> weighted scout images were acquired and used to place the DTI images in line with the fiducial markers. The following parameters were used: TR=4000ms, TE=48, b-value=485 s/mm<sup>2</sup> with 15 encoding directions, FOV=192x192, slice thickness=6mm, matrix size=128x128, N<sub>ex</sub>=6.

**US Analysis - Manual angle measurement:** The US images were imported into Osirix where two to three pennation angles were measured over visible fascicles in both the superior and deep compartments (Fig. 1). The inter-compartment difference in fascicle orientation was calculated ( $\Delta\theta_{\text{Man}}$ ).

**US Analysis - Automatic angle measurement:** A previously described<sup>2</sup> method for automated muscle fiber orientation measurements was implemented. Briefly, the US images were imported into Matlab and convolved using four Gaussian kernels having variances of 1.5, 2, 2.5, and 3 pixels and a grid size of 13x13. A Hessian matrix of the convolved images was created and from it, the maximum vesselness response was found. Anisotropic wavelet analysis was then performed to determine the muscle fascicle orientation at each pixel (Fig. 2). After median filtering, ROIs were specified in the superficial and deep compartments of the muscle. The inter-compartment difference in fascicle orientation was calculated ( $\Delta\theta_{\text{Auto}}$ ).

**DTI data analysis:** An ROI was specified in each compartment. The mean signals were calculated and the diffusion tensor was formed. The tensor was diagonalized and the eigenvalues were magnitude-sorted. The inter-compartment difference in fascicle orientation ( $\Delta\theta_{\text{DTI}}$ ) was calculated as the difference between each compartment's  $\epsilon_{1,R}$  (Fig. 3).

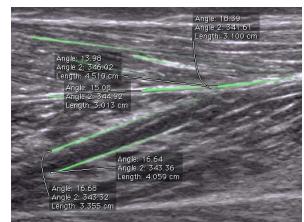
**Statistical analysis:** One-way ANOVA was performed on the data in addition to calculations for the linear regression and correlation coefficients.

### Results and Conclusion

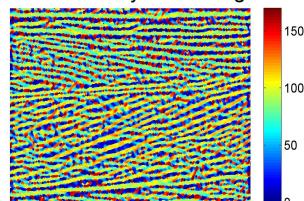
The measurements of muscle pennation from the DTI, US manual, and automatic methods were in good agreement; 21.9° (4.3), 18.6° (4.4) and 21.9° (6.4), respectively ( $p=0.40$ ). Fig. 4 shows scatter plots with pairwise comparisons of the three methods. The correlation coefficient between  $\Delta\theta_{\text{DTI}}$  and  $\Delta\theta_{\text{Auto}}$  was 0.69 ( $p=0.09$ ) and between  $\Delta\theta_{\text{DTI}}$  and  $\Delta\theta_{\text{Man}}$  was 0.64 ( $p=0.12$ ). Although the sample size is currently small, the data shows good agreement, particularly between the DTI and the manual US methods. Because manual US is regarded as the gold standard for *in vivo* muscle architecture measurements, this finding supports the use of DTI for this purpose.

### References

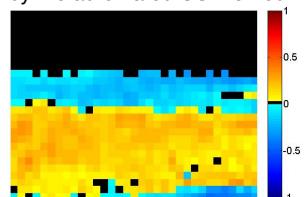
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2. Rana M, et al.: *J Biomech* 2009, **42**(13):2068-2073.



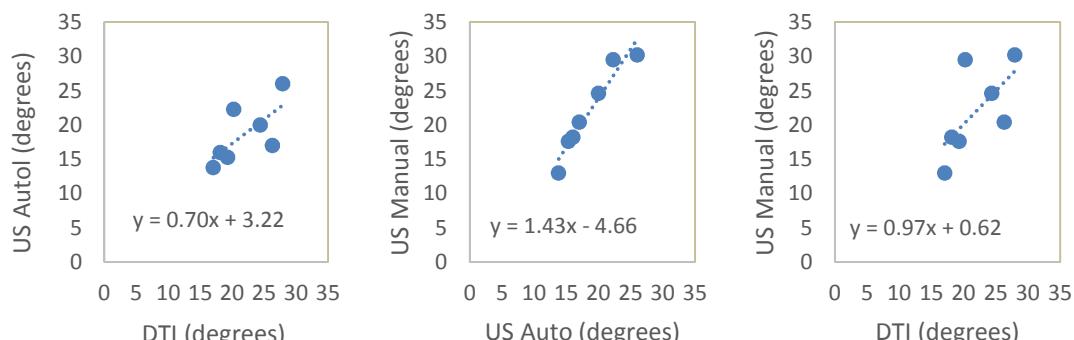
**Figure 1.** Raw US image with manually drawn angles.



**Figure 2.** Image of the median fiber orientation as determined by the automated US method.



**Figure 3** The anterior-posterior component of  $\epsilon_1$ .



**Figure 4.** Scatter plots showing single comparisons between all methods with the linear slope labeled.