Diffusion tensor derived soleus architecture at rest and under plantarflexion.

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Introduction: Diseases of muscle such as muscle dystrophy, prolonged bed-rest or near-zero gravity space flight almost always result in reduced force production. This arises from changes in muscle physiological parameters such as atrophy, reduced neurological activation, and changes in architectural parameters such as pennation angles, fiber length. In the calf muscle, the internal architecture of the soleus is the most complicated with a multipennate arrangement of fibers. The objectives of this study were to (i) map the soleus architecture using diffusion tensor imaging (DTI) and qualitatively correlate it with earlier studies that inferred fiber orientation from histological data of the Visible Human (VH) [1] and (ii) track the architectural changes in soleus muscle with plantarflexion.

Materials and Methods: Five subjects were imaged with a previously optimized MR DTI imaging protocol on a 3T GE Excite system, with a dedicated 8-channel leg coil, and computer-controlled hydraulic foot-pedal system. The optimal sequence was a single 180^0 spin echo EPI with a matrix size of 128, acceleration factor of 2, with a TE of 48ms. Other parameters were: 24cm FOV, 5mm Thk, Contiguous, 24 Slices, 6400~4700ms TR, 13 diffusion gradient directions, 6 Avgs, $500 s/mm^2$ b-values, spatial spectral fat saturation, scan time: 6:44mins. T2-FSE images were also collected for distortion corrections, with the same slice locations, thicknesses and TE. DTI images were collected with the foot at 90^o (relaxed), $+20^o$ plantar-flexed. Susceptibility induced and eddy current distortions were corrected using a free form optical flow algorithm using the T2-FSE images as reference. Tensor data derived from this pre-processed DTI data were smoothed using the log-Euclidean aniostropic filter available from MedINRIA .

Results and Discussions: Fig 1 shows the results of the smoothing. Figs. 2, 3 show the calf muscle at the mid- axial and coronal locations respectively along with images from corresponding locations from the VH database. The fiber orientations in the soleus muscle is complex in contrast to the TA and gastrocs.

Fig 1: Coronal view of the calf with tensors displayed as arrows. The results of the smoothing algorithm can be seen in these images. Clearly tensors are smoothed within each muscle region while discontinuities between muscle regions are preserved without undue blurring. Large tensors at the edges are from fat signal which shows large erroneous fractional anisotropy.
Note: Numbers in Figs 2 and 3 refer to the same regions

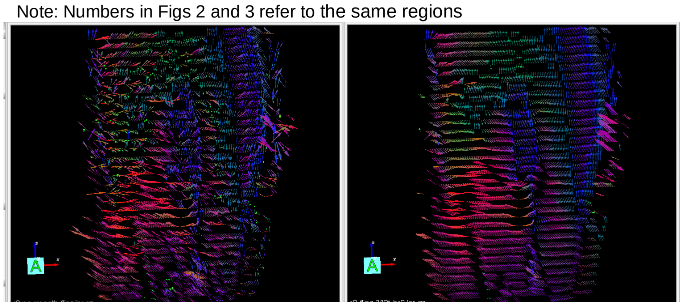
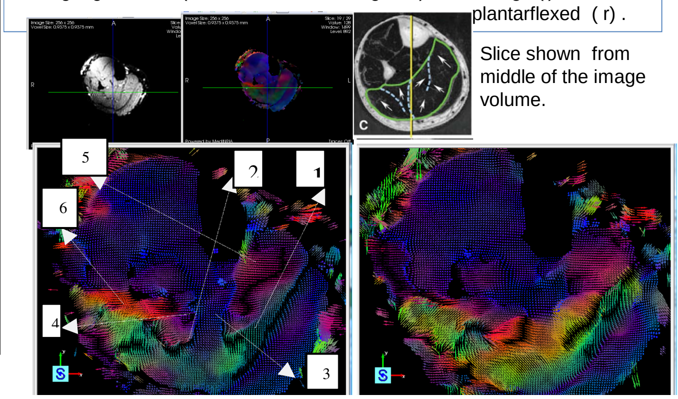


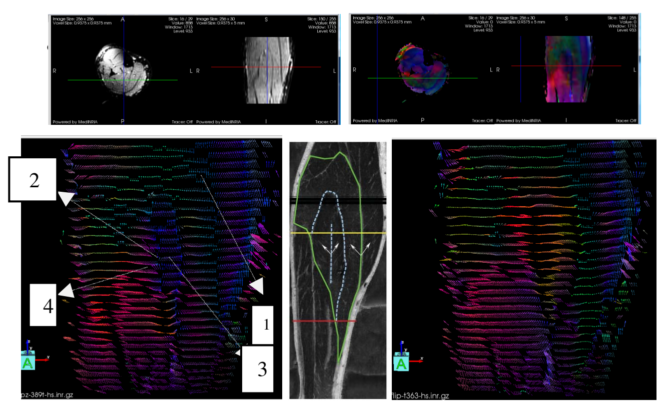
Fig. 2: Calf Muscle (axial)-Top row (l to r):: Bo image, color coded FA image, Visible Human image with arrows of inferred fiber direction. Bottom row: diffusion tensor images as arrow display with color from the direction of the leading eigenvector (SI: blue, RL: red, AP: green): Rest image (l), plantarflexed (r) .



Slice shown from middle of the image volume.

The posterior soleus (1)is clearly seen at this level corresponding t to the green region in the color FA and tensor map . The AP direction of the fibers conforms with both the VH and a 3D model derived from cadaveric specimens [2]. The anterior soleus can also be visualized with the median septum (2) dividing the two compartments. The anterior soleus compartments (3 &4) have both S medial compartment of the anterior soleus (3) more aligned along the SI direction. The fiber direction of the anterior soleus compartments is also in conformance with that of the VH data (see inset) as well as the 3D model [1,2]. Besides the anterior and posterior soleus there are two other regions in the soleus (axial image): both with predominantly RL fibers. In addition, one of the regions (anterior medial, 5) has a distinct bipennate structure that has a corresponding aponeurosis on the magnitude image. These last two regions may correspond to the marginal soleus reported in the 3D model paper [2]. On plantarflexion, the lateral anterior compartment has a stronger RL component than in the rest state. The medial anterior compartment changes dramatically from an almost SI direction to one with large RL component. This change in the eigenvector direction to in-plane is in conformance with larger angles of pennation and shorter fiber lengths that is expected on plantarflexion. The second observable change is that the anterior compartment is much larger and the posterior compartment much smaller in the plantarflexed state than in the rest state. The posterior compartment also has a stronger AP component than in the rest state, reflecting the fact that shorter large pennation angle fibers result from a larger in-plane component for the fiber direction.

Fig.3: Top row (l to r): axial and coronal b0 images; corresponding color FA maps. Bottom row (l to r): rest, corresponding slice from Visible Human, plantarflexed.



Conclusions: DTI can be used to visualize the fiber orientation in the soleus and track changes with plantarflexion.

Refs: [1] Hodgson et al, JOURNAL OF MORPHOLOGY 267:584–601 (2006); [2] Agur et al, Clin Anat 16:285–293 (2003).