DTI and Fiber Tracking Study of the Effects of Aging on Musculoskeletal Architectural and Functional Parameters

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Background: Muscle force output is affected severely by the ageing process through its complex dependency on various musculoskeletal (MSK) architectural and physiological factors such as decrease in muscle size, altered contractile properties (both fiber and tendon), fiber type conversion, impaired neural drive and others. We believe one of the important parameters that can account for the disproportionate loss of force (>60%) in comparison to the decrease in muscle volume (~<10%) is the change in "gear ratio". This refers to the amplification factor that multiplies the strain of contracting muscle fibers producing force to yield the final displacement of calcaneous (in the case of the lower leg). It is a straight-forward geometric problem to prove that this gear ratio depends on the inter-aponeurosis separation and the pennation angle of muscle fibers with the aponeurosis [1, 2], both of which are significantly affected by ageing [3]. Musculoskeletal diffusion tensor imaging (DTI) provides a unique tool to study non-invasively in humans the underlying MSK architecture and thus the structural correlates of functional changes.

Purpose: To perform DTI in the lower leg in humans to monitor age-related changes in muscle microarchitecture based on diffusion eigenvalues, fractional anisotropy, and subsequently using muscle fiber tractography to study changes in parameters affecting the gear ratio, namely, fiber pennation angle and length.

Methods: Twelve normal female subjects of Japanese ethnicity were selected, after obtaining IRB approved consent, for the study: 6 in the young age group (30.3 ± 7.8 years) and 6 in the old age group (80.8 ± 2.1 years). All scans were acquired on a 3T MR scanner (GE) using an indigenously developed 8-channel phased array leg coil with the subjects in a supine state. Care was taken to position the long axis of the leg strictly parallel to the magnetic field using the laser alignment beams and foam pads, with the center of FOV approximately 10 cm below the tibial head. A fat suppressed single shot spin echo diffusion weighted EPI sequence was used with the following parameters: TE/TR/FOV/Matrix/Av/sl_thk/gap: 49 ms/ 4000 ms/ 24 cm/ 80x80 / 4av / 5 mm/ 0 mm. A 'b' value of 400 s/mm^2 and 32 directions were used to sample the diffusion tensor. Images were transformed into Analyze format, imported into MedInria for tensor calculations, and the tensors were then fed into either DTIStudio or DTITools for tracking fibers (this combination yielded the best results).

Table 1: Values of the diffusion indices in young (Y), old (O). Significant differences are highlighted in yellow (p<0.05)

	FA	λ_1	λ_2	λ_3
MG-Y	0.16±0.02	2.00±0.04	1.59±0.03	1.49±0.07
MG-O	0.18±0.02	1.91±0.00	1.46±0.00	1.36±0.00
LG-Y	0.24±0.06	2.10±0.00	1.58±0.08	1.31±0.09
LG-O	0.36±0.13	2.25±0.00	1.41±0.00	1.09±0.00
AT(D)-Y	0.20±0.01	1.99±0.00	1.53±0.08	1.34±0.00
At(D)-O	0.27±0.02	2.14±0.02	1.57±0.00	1.26±0.04
Soleus-Y	0.16±0.03	1.87±0.09	1.47±0.05	1.39±0.06
Soleus-O	0.20±0.1	1.77±0.00	1.38±0.05	1.21±0.00

Results: Regions of interest measurements were made in muscle compartments: deep compartment of the Anterior Tibialis (AT(D)), Soleus, Medial Gastrocnemius (MG), and Lateral Gastrocs (LG). Care was taken to avoid blood vessels and artifacts in the placement of the ROIs. Fractional anisotropy and eigenvalues (λ1, λ2, λ3) were measured in each ROI (Table 1), in the two cohorts (young (Y) and old (O)). Fibers were tracked from seed points manually placed in the medial gastrocs and pennation angles of fibers with the deep aponeurosis and fiber lengths from deep aponeurosis to superficial aponeurosis were estimated (Table 2). MG fibers tracked in a young and old subject are shown in Figure 1.

Discussion & Conclusion: **λ3** decreased significantly in the plantarflexors with age. **λ3** also decreased in the AT but it was not significant. One diffusion model [4] that has been proposed correlates **λ3** to the fiber diameter. Thus reductions in **λ3** reflect a decrease in fiber diameter. This is in conformance with an anticipated decrease with age due to disuse atrophy. Further, FA also increased with age in all muscles and is related to a large decrease in **λ3** with a concomitant small or no changes in **λ1**. However, only the AT showed a significant increase in FA with age. Decrease in **λ3** and **λ2** are in agreement with an earlier study [4]; however the latter reported decreases or no change in FA. Importantly, these DTI studies reveal for the first time that the MG muscle fiber pennation angles decrease as much as ~30% with age. This has a direct consequence on the gear ratio, which is theorized to have 1/cos(pennation angle) dependence. This reduction in gear ratio has a direct consequence on and accounts for to a large extent the disproportionate loss of muscle function and performance. MG fiber length increases with age in conformance with the smaller pennation angles and reduced aponeurosis separation. It should however be noted that there is a large variability in the measurement of this parameter. The ability to non-invasively monitor the MSK fiber architecture and the changes therein with different clinical conditions such as sarcopenia, atrophy and cachexia will potentially allow evaluation of the diseased states and the remedial progression with medication and rehabilitation.

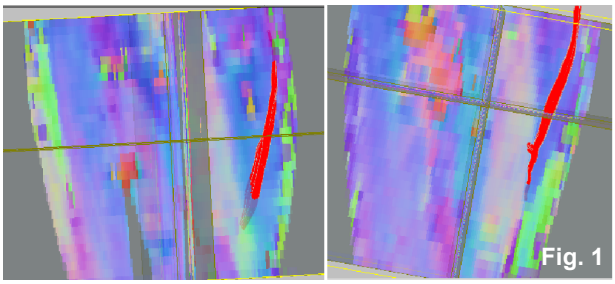

Table 2: Fiber length and pennation angles of MG fibers.

Fiber Length (mm)		Pennation Angle (deg)	
Young	**Old**	**Young**	**Old**
45.8±26.9	56.7±16.2	25.6±0.6	19.1±1.9

References: [1] Gans. *Exerc Sport Sci Rev* 1982); [2] Hodgson et al *J Morphol*, 2006; [3] Narici et al. *J Appl Physiol* 2003; [4] Galban et al, *J Gerontology*, 2007.