Using DTI to Assess the Effect of Obesity and Physical Activity on Muscle Quality in Elderly Women

A. A. Gharibans[1], D. D. Chen[1], C. L. Johnson[1], D. D. Guest[2], C. Ward[3], B. Das[2], E. M. Evans[3], and J. G. Georgiadis[1]

[1]Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, United States, [2]Department of Kinesiology and Community Health, University of Illinois at Urbana-Champaign, Urbana, IL, United States, [3]Department of Kinesiology, University of Georgia, Athens, GA, United States

Introduction

Obesity is more common in older women than in men [1]. Muscle quality, quantified as leg strength normalized by leg mineral-free lean mass, has been determined to be the most important factor for physical function in obese frail elderly individuals [2]. Although muscle quality has been conventionally defined in the aging literature from whole limb measures (i.e. knee extension strength and thigh lean or muscle mass), muscle quality can also be assessed in terms of the effective muscle physiological cross-sectional area (PCSA) [3]. Motivated by recent observations [4,5] that the axial component of water diffusion in the human calf has a strong linear correlation to the PCSA and that water diffusional anisotropy is a manifestation of the histoarchitecture of muscle [6], we set out to relate the latter with established measures of muscle quality. The aim of this project is to establish certain DTI measures of quality, and connect them with muscle strength and physical function in elderly women differing in adiposity and habitual physical activity.

Methods

Subjects: A total of forty-eight elderly women (67±6 years old) comprising three groups: obese (O); lean, but sedentary (LS); and lean and active (LA) were examined in this study. Women with BMI>28 were assigned to group O (n = 26). The remaining women were assigned into groups LS (n = 11) and LA (n = 11) based on their daily activity level as determined by a pedometer. The peak torque during knee extension was measured with a HUMAC device.

MRI Acquisition: The subjects were scanned while in supine position, with thighs relaxed and parallel to the magnetic field of a 3T full-body Siemens Trio scanner (Siemens Medical Systems, Erlangen, Germany), using a combination of an eight-channel spine coil and a flexible body matrix surface coil centered over the midpoint of the left thigh. Diffusion tensor imaging (DTI) data were acquired using a single-shot twice-refocused spin-echo EPI sequence with the following parameters: TR/TE = 3000/71 ms, FOV = 25x25 cm^2, slice thickness = 10 mm, matrix = 76x76, and N_{ex} = 10. Diffusion weighted gradients were applied along 30 non-collinear directions with a nominal b-value of 550 s/mm^2. Water excitation was performed using a spatial-spectral RF pulse. Seven axial slices were acquired with an imaging volume positioned using bony landmarks.

Tractography: Regions of Interest (ROI) were hand-drawn containing all seven slices of the vastus medialis for each subject and fiber tracking of the primary and secondary eigenvectors was performed with *TrackVis* software [9] using the interpolated streamline algorithm with 0.5 mm step size [10]. One random seed per voxel was used and the stop criterion was an orientation change between points greater than 20 degrees for both the primary and secondary tracts. Each tract is colored according to anatomical orientation; blue is superior/inferior, red is left/right, and green is posterior/anterior, cf. Figure 1.

Results

The statistics for fractional anisotropy (FA) and planar index (CP) [6] are obtained from the DTI data by averaging over each ROI and then segregating the data according to the three groups (O, LS, LA), cf. Tables 1 and 2. While Table 1 compares lean and obese subjects, Table 2 compares the active and sedentary subjects from the lean group. For each subject, organized nets were also constructed through an algorithm that identifies nodes of crossing primary and secondary tracts. To avoid artificially inducing crossing tracts, both the primary and secondary eigenvectors were randomly seeded in the voxel. The tractography and net calculations were repeated ten times and averaged for each subject, and then the data was segregated according to the same groups. The Nets metric in Tables 1 and 2 is the sum of the number of nets and mean size of the nets normalized to the ROI size. The p-value was calculated from a Student's t-test performed using unequal variances and a one-tailed distribution.

Figure 1. Comparison of primary (blue) and secondary (green) tracts for the vastus medialis of a (a) lean and (b) obese subject

Table 1. Comparing lean and obese subjects

	LA/LS (n = 22) (mean±stdev)	O (n = 26) (mean±stdev)	p-value
FA	0.173±0.023	0.193±0.023	0.014
CP	0.122±0.019	0.133±0.016	0.014
Metric (Nets)	0.097±0.052	0.068±0.031	0.015
Peak TQ / Weight	1.6525±0.501	1.327±0.317	< 0.001

Table 2. Comparing lean active and lean sedentary subjects

	LA (n = 11) (mean±stdev)	LS (n = 11) (mean±stdev)	p-value
FA	0.163±0.021	0.184±0.021	0.015
CP	0.114±0.017	0.129±0.018	0.029
Metric (Nets)	0.114±0.0063	0.080±0.034	0.069
Peak TQ / Weight	1.845±0.537	1.460±0.399	0.044

Discussion and Conclusion

Although the primary tracts are very similar, there is a qualitative difference in the secondary structure between lean and obese subjects, cf. Figure 1. Three parameters related to the asymmetry of the diffusion tensor in the direction perpendicular to the muscle fiber can be used as quantitative measures of muscle quality: FA, CP and number of tract nets per ROI. Tables 1 and 2 reveal a statistically significant difference of muscle quality across the three groups such that: slender/active group > slender/sedentary group > obese group as FA and CP increase, while the Net metric and peak torque/body weight decrease. Given that intramuscular fat content increases with obesity [7], it is plausible that this fat provides additional barriers to in-plane diffusion, making the DTI tensor more anisotropic. On the other hand, it is also plausible that lower quality muscle has fewer lateral connections between muscle fibers [8] resulting in fewer organized nets. Constructing nets out of the primary and secondary tracts provide a quantitative method of measuring the organization of the secondary structure. The results of the present cross-sectional study bolster the hypothesis that we can use DTI to quantify muscle quality in elderly women.

References: [1] Ogden, CL, et al., *JAMA*, 2006. 295:1549-1555; [2] Villareal, DT, et al., *Obes Res,* 2004. 12:913-920; [3] Lieber, RL & Friden, J., *Muscle & Nerve*, 2000. 23:1647-66; [4] Galban, CJ, et al., *NMR Biomed*, 2005. 18:489-498; [5] Galban, CJ, et al., *Eur J Appl Physiol*, 2004 93:253-262; [6] Karampinos, DC, et al., *Ann Biomed Eng*, 2009. 37:2532-46; [7] Hwang, JH, et al., *J Appl Physiol*, 2001. 90:1267–1274; [8] Passerieux, E, et al., *J Struct Biol,* 2006. 154: 206-216; [9] Wang, R, et al., *Proc. ISMRM*, 2007. no. 3720; [10] Conturo, T, et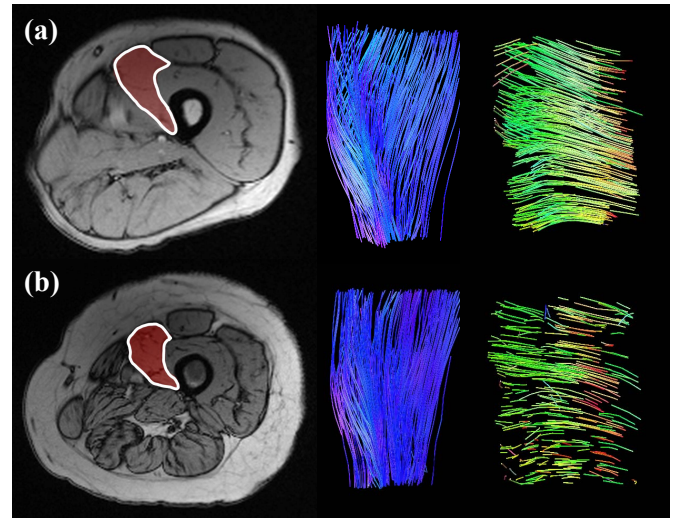 al., *P Natl Acad Sci Usa*, 1999. 96: p. 10422-27.