Diffusion Property Differences of the Lower Leg Musculature between Athletes and Non-Athletes using 1.5T MRI

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Introduction

Several studies on the measurement of diffusion properties of human skeletal muscle have discussed the significance of the measured values. The basic methodology employed in these studies involved the measurement and comparison of diffusion properties (i.e., FA, λ1, λ2, λ3, and ADC) of skeletal muscle between two different groups of subjects and, based on the results, inferring which microstructures and microstructural changes corresponded to the observed changes in diffusion properties. Specifically, comparisons have been made between the muscles of youths and elderly persons (effect of aging) (1), males and females (effect of gender) (2), non-injured and injured persons (3), and resting and fatigued conditions (4). The effects of the type of contraction (active or passive) have also been examined by comparing the muscle in contracted and resting states (5). However, the conflicting results obtained as well as the varying interpretation of results have obscured the relevance of measuring diffusion properties of skeletal muscle, indicating a need for additional studies of skeletal muscle diffusion properties.

Physical training causes marked changes in skeletal muscle microstructures (6). It is well known that skeletal muscle hypertrophy occurs due to repeated contraction and laxity of the muscle during long-term training (6). The purpose of the present study was to compare diffusion properties between trained and non-trained muscles in volunteers belonging to athlete and non-athlete groups, respectively.

Materials & Methods

Twelve athletes (Group A) and 11 non-athletes (Group B) were recruited for this study. All were healthy females in their 20s. All 12 athletes were from the Department of Physical Education of our university and had been recruited to the university with sports scholarships. They were all active, well-trained student-athletes - 4 tennis players and 8 Kendo (modern Japanese sword-fighting) practitioners - with high athletic achievement levels. All 11 non-athletes were also healthy, but did not do physical training in their daily life. We scanned the proximal portion of both calves using a 1.5 Tesla (T) clinical MR machine (Nova Dual release 2.6, Philips, Best, the Netherlands). The 4-channel sensitivity encoding (SENSE) body coil (45×30 cm for parallel imaging) was wrapped around the anterior and posterior aspects of both calves. Diffusion-weighted images were acquired using a single-shot spin-echo echo planner imaging (EPI) sequence with the following parameters: b-values of 0 and 500 seconds/mm^2, field of view (FOV) 350 (mm), rectangular FOV 51.79%, matrix size 224×224, slice thickness 6 mm without gap, internal number of slices 12 (7.2 cm of the length of scan range), TR = 4000 ms, TE = 60 ms, SENSE factor 2.2, number of motion probing gradient (MPG) directions 6, number of excitations 6, and total scan time 5 minutes 20 sec. We converted the collected DICOM imaging data to PAR/REC files to derive the FA, λ1, λ2, λ3, and ADC maps (Figure 1). These data were analyzed by a PAR/REC reader, using PRIDE version 4.1 developed by Philips.We measured FA, λ1, λ2, λ3, and ADC for the right and left gastrocnemius medialis (GCM), gastrocnemius lateralis (GCL), soleus (SOL), and anterior tibialis (AT) muscles for each volunteer. Box-shaped 20-pixel ROIs were seeded for measurement at three points in each muscle at the thickest slice of the calf. We compared each averaged FA, λ1, λ2, λ3, and ADC in GCM, GCL, SOL, and AT by two-factor fractional ANOVA. Between-subject factors included training (A and B) and right (Rt) and left (Lt). There were 24 subjects in A, 22 in B, 23 in Rt, and 23 in Lt for each comparison.

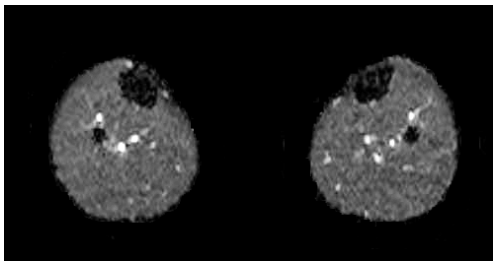

Figure. 1
Axial gray-scale parametric map of ADC images of the calves of a 20-year-old athlete volunteer. Actual measured values of ADC of the athlete in the right GCM, GCL, SOL, and AT and the left GCM, GCL, SOL, and AT were 1.38, 1.36, 1.47, 1.56, 1.43, 1.39, 1.42, and 1.52, respectively

Results & Discussion

The actual diffusion property value, its standard deviation, and comparisons of each muscle for FA, three eigenvalues, and ADC between A and B, and between Rt and Lt, are shown in Tables (GCM, GCL, SOL, and AT, respectively). In all muscles of bilateral calves, all three eigenvalues and ADC were lower in Group A than in Group B, with statistically significant differences in all muscles for λ1, λ2, and λ3 and ADC, with a P-value of <0.01. Moreover, statistical differences were also found between right and left for λ1, λ2, and λ3 (P<0.05), and ADC (P<0.01) of the SOL muscle. FA showed no statistically significant differences in any muscles. Our results suggest that trained and hypertrophied human lower leg musculature tends to show presumably lower eigenvalues (λ1, λ2, λ3) and ADC.

GCM	Group A		Group B		Training		Rt / Lt	
	Rt	Lt	Rt	Lt	F	P	F	P
FA	0.34 (0.02)	0.34 (0.02)	0.33 (0.02)	0.33 (0.02)	3.245	0.079	0.081	0.777
λ1	1.92 (0.05)	1.95 (0.05)	2.11 (0.06)	2.10 (0.07)	88.92	<0.01**	0.746	0.393
λ2	1.38 (0.05)	1.38 (0.05)	1.52 (0.06)	1.52 (0.05)	66.21	<0.01**	0.145	0.705
λ3	0.93 (0.05)	0.94 (0.05)	1.05 (0.08)	1.08 (0.06)	46.05	<0.01**	0.949	0.336
ADC	1.41 (0.05)	1.42 (0.04)	1.56 (0.06)	1.57 (0.05)	81.66	<0.01**	0.319	0.575

GCL	Group A		Group B		Training		Rt / Lt	
	Rt	Lt	Rt	Lt	F	P	F	P
FA	0.36 (0.02)	0.36 (0.02)	0.35 (0.02)	0.35 (0.02)	1.229	0.274	0.014	0.905
λ1	1.85 (0.05)	1.87 (0.07)	2.09 (0.09)	2.07 (0.08)	91.71	<0.01**	0.010	0.922
λ2	1.30 (0.05)	1.35 (0.06)	1.48 (0.05)	1.50 (0.07)	77.88	<0.01**	3.147	0.083
λ3	0.86 (0.06)	0.85 (0.08)	0.99 (0.03)	0.99 (0.06)	47.40	<0.01**	0.073	0.788
ADC	1.34 (0.05)	1.36 (0.06)	1.52 (0.05)	1.52 (0.06)	98.01	<0.01**	0.348	0.558

SOL	Group A		Group B		Training		Rt / Lt	
	Rt	Lt	Rt	Lt	F	P	F	P
FA	0.33 (0.02)	0.33 (0.04)	0.32 (0.03)	0.34 (0.02)	0.089	0.767	1.251	0.270
λ1	1.96 (0.09)	1.91 (0.07)	2.08 (0.06)	2.02 (0.07)	25.56	<0.01**	5.408	0.03*
λ2	1.44 (0.07)	1.40 (0.07)	1.55 (0.09)	1.48 (0.07)	18.28	<0.01**	5.363	0.03*
λ3	0.98 (0.08)	0.93 (0.12)	1.09 (0.11)	1.00 (0.06)	9.365	<0.01**	6.896	0.02*
ADC	1.46 (0.06)	1.41 (0.08)	1.57 (0.05)	1.50 (0.06)	20.49	<0.01**	7.439	<0.01**

AT	Group A		Group B		Training		Rt / Lt	
	Rt	Lt	Rt	Lt	F	P	F	P
FA	0.37 (0.03)	0.39 (0.02)	0.37 (0.03)	0.38 (0.02)	0.402	0.530	2.965	0.09
λ1	1.97 (0.07)	1.98 (0.08)	2.10 (0.07)	2.08 (0.06)	26.31	<0.01**	0.015	0.99
λ2	1.38 (0.06)	1.37 (0.04)	1.44 (0.07)	1.42 (0.05)	9.299	<0.01**	0.726	0.39
λ3	0.88 (0.09)	0.84 (0.06)	0.98 (0.06)	0.95 (0.05)	21.02	<0.01**	2.851	0.09
ADC	1.41 (0.06)	1.40 (0.04)	1.50 (0.05)	1.48 (0.03)	30.93	<0.01**	1.158	0.28

Tables Actual diffusion properties of GCM, GCL, SOL, and AT, and its comparisons by training level and Rt vs Lt

Considering previously reported results, λ1 appears to primarily represent the direction of water diffusion parallel to the diffusion restricting factor, while λ2 and λ3 mainly represent water diffusion orthogonal to the three-dimensional direction of λ1 in the intracellular space. Muscle cell membranes can account for most of the water diffusion restriction. In the literature, several other factors have been also reported to influence the diffusion properties of muscle tissue. Such factors include subcellular barriers, such as mitochondria, the sarcoplasmic reticulum, and macromolecules. Papadopoulos et al. (7) studied protein diffusion in living skeletal muscle fibers, and reported that myofilament lattices may also influence water diffusion restriction. In trained muscle, we suppose that an increase in density of contractile protein filaments, including actin and myosin, might play an important role in the water diffusion restriction. It is well known that these filaments increase in size and number as a result of physical muscle training (8). On the contrary, it is also well known that skeletal muscle hypertrophy induces an increase of endomysium or sarcoplasmic reticulum (9) in the extracellular space. This might also induce passive morphological deformation of the cell membrane, resulting in water diffusion restriction.

Conclusion Our results indicate that training causes a decrease of the three eigenvalues and ADC, which we hypothesize is due to an increase of density of myofilaments in the intracellular space, and deformation of the cell induced by enlargement of extracellular components.

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