Gender-specific differences in MR fiber tractography of skeletal muscles

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Introduction

Muscle fiber tractography using DTI clearly reveals the three-dimensional course of muscle fibers. It has great potential for diagnostic imaging and could open up new fields of diagnostic imaging. To realize this, it is therefore necessary to analyze the relationship between the visualization of the tracts and the individual differences of the microstructure of the skeletal muscle so as to optimize MRI parameters. It has also been well-known that males and females differ in the microstructures of their skeletal muscle, morphologically and/or physiologically (1,2). The purpose of this study was to determine whether there are any differences in the visualization of fiber tractograph of the skeletal muscle between males and females and to identify what microstructure of human skeletal muscle could affect it.

Materials & Methods

The study involved twenty-four volunteers which included thirteen males and eleven females in their twenties and thirties. We scanned the proximal portion of their bilateral calves (including the part with the thickest diameter) using 1.5 T clinical Philips MRI scanner. Subjects were set in a supine position with feet first. The SENSE body coil for parallel imaging was convolved around the anterior and posterior aspects of their bilateral calves. Diffusion-weighted images were acquired using a single-shot spin-echo EPI sequence with the following parameters: FOV 400 (cm), RFOV 75%, matrix size 12, slice thickness 6 mm, number of slices 12, TR = 2500 ms, TE = 59 ms, SENSE factor 2, number of MPG directions 6, and NEX 10. The total scan time was 5 minutes, 30 sec. Before the DTI, we scanned T1-FFE as anatomy using the following parameters: matrix size 192, slice thickness 6 mm, number of slices 12, TR = 13 ms, TE = 2.3 ms, and SENSE factor 1.4. The total scan time was 3 minutes, 4 sec. After collecting the imaging data, we reconstructed the muscle fiber tractographs of eight muscles including bilateral gastrocnemius medialis (GCM), gastrocnemius lateralis (GCL), soleus (SOL), and anterior tibialis (AT) in each volunteer, seeding the region of interest (ROI) at the highest and lowest slice of the scan range by referring to the anatomical data. We classified all acquired muscle tractographs into five categories based on the visual scores reflecting the proportion of successfully tracked fibers. Specifically, when almost 100% of the fibers in the assessed muscle could be visualized, the tractograph was given a score of five (5) and was rated as excellent. When the proportion of visualized tracked fibers was assessed as that having a score between 5 and 3, a score of four (4) was given, and it was rated as good. When 50% of fibers could be visualized, a score of three (3) was given, and it was rated as moderate, and if the fraction of visualized tracked fibers was assessed as that having a score between 3 and 1, it was given a score of two (2) and was rated as poor. When most fibers could not be visualized, it was rated as none and was given a score of one (1). Two radiologists who are well-trained and experienced in musculoskeletal radiology assessed and scored the tractographs independently, and decided the final score by consensus. Mann-Whitney U-test was conducted to compare the visual scores of the eight muscles in the male and female volunteers.

Results & Discussion

Females showed superior visualization. In particular, bilateral SOL muscles in females showed better visualization than in males ($P<0.05$). Furthermore, GCL was the best visualized muscle in all volunteers. The median value of the visual score for the right SOL was 1 in males against 4 in females (U value was 25.5), while for the left SOL, it was 1 in males against 3 in females (33.5). The median values obtained in males and females, respectively, were 3 and 4 for both right and left GCM, 5 and 5 for both right and left GCL; 4 and 5 for right AT; and 4 and 4 for left AT. These values showed no significant statistical differences. These results suggest that there are micro-structural morphological differences between the skeletal muscles of males and females which strongly influence the visualization of muscle fiber tractograph.

Over the past twenty years, there have been significant advances in the studies of ultrasonographic (US) analysis of individual microstructural morphological differences of skeletal muscles 3)-6). These US studies primarily used triceps surae muscles and analyzed fiber length, the pennation angle, and muscle thickness. In this regard, the pennation angle data were of particular interest to us because these data and the proportion of the tracked fiber obtained in this present study seemed to show the same tendency. The results of several published studies concerning absolute pennation angle of skeletal muscle are summarized in Table 1. Most studies showed the lowest absolute value in the GCL and the highest in the SOL. Chow et al. also studied micro-structural differences among 36 healthy human males and females using US analysis of *in vivo* triceps surae muscles 7). They emphasized that there were marked differences in the pennation angles between males and females, particularly in the anterior and posterior SOL. Based on our own data as well as on published ultrasonography data, we hypothesize that the smaller the pennation angle, the better the visualization of the skeletal muscle tractographs.

Conclusion

Our results suggest that muscle fiber tracking of the bilateral calves was more superior in females compared to males of similar ages. These results may be attributed to the differences in the pennation angle as indicated in the published ultrasonographic data.

References

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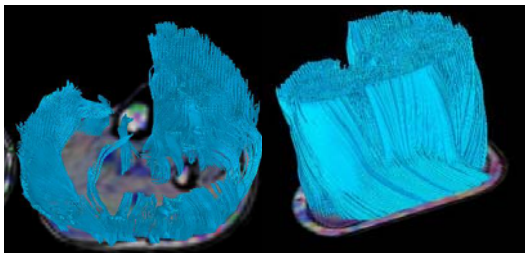

Figure 1. Example of a tractograph of the right calf of a male (a) and a female (b) volunteer.
The visual score of (a) is 5 for GCM, 5 for GCL, 2 in SOL, and 5 for AT. The visualization of the SOL muscle is extremely poorer compared to the other muscles. The visual score of (b) is 5 for all muscles including GCM, GCL, SOL, and AT

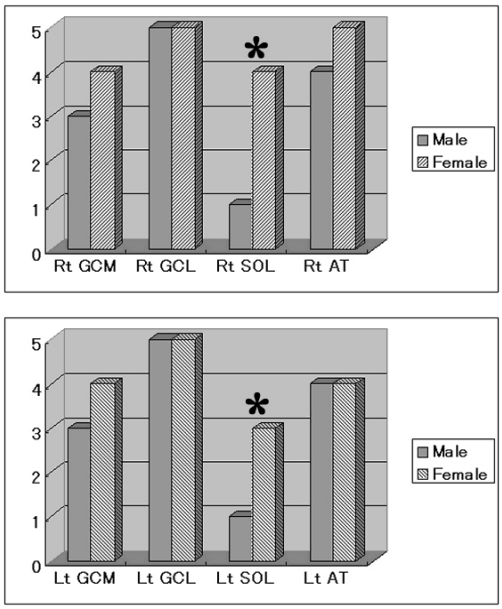

Figure 2. Comparison of visual scores for right (a) and left (b) calf muscles of males and females volunteers.
The median values of the visual scores of right calf muscles including GCM, GCL, SOL, and AT muscles of males (solid bars) and females (diagonally filled bars) are shown. The visual score was higher in females than in males. For the SOL, the visualization was lowest in males (1) and good (4) in females in (a), and also lowest in males (1) and moderate (3) in females in (b) with a statistically significant difference (* $P<0.05$).

GCM	GCL	SOL	Author (year)
21.6	14.4	25.3	Morse et al. (2000) 15 young males
18.7	11.7	21.5	Morse et al. (2000) 12 elderly males
22.3	11.3	25	Magnaris et al.(1998) 6 males
11	7	34	Spoor at al.(1991) 3 males
16.7	8.3	25	Wickiewicz et al. (1983) 3 (sex unspecified)

Table 1 Published absolute pennation angle data for triceps surae muscles