

Dynamic DTI during muscle contraction by electrical stimulation.

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Introduction: We reported that the signal intensity in diffusion weighted echo planar imaging (DW-EPI) decreases during muscle contraction caused by percutaneous electrical stimulation [1]. Although the signal decrement of the DWI indicates that the muscle contraction using electrical stimulation (ES) induced rapid movements of water molecules, the exact speeds and directions of water molecules during muscle contraction are uncertain. On the other hand, diffusion tensor imaging (DTI) provide with information of the tissue water movements about the directions as well as the speeds. The purpose of this study is to estimate speeds and directions of water molecules using dynamic DTI during muscle contraction.

Material & Methods: Four healthy volunteers were asked to lie in supine position and underwent MRI of the lower extremities with single shot DW-EPI and T2 images for anatomical information, respectively. A Signa LX 1.5 T (CN/I, GEMS) and tow 5-inch surface coil was used. To estimate rapid movement during muscle contraction, low b DWI ($b = 4.6 \text{ s/mm}^2$, 45 ms TE) were performed. The 6 DWI at 20 ms after the ES were acquired and calculated for dynamic DTI. In addition, DTI at static muscle were also measured using high b DWI ($b = 600 \text{ s/mm}^2$, 61.3 ms TE) in order to compare with the dynamic DTI. The other scanning parameters of the DWI were chosen as follows: 8 s effective TR, 240 x 240 mm FOV, 96 x 96 matrix, 4 mm slice thickness and 6 mm gap, 4 averages and 100 KHz receiver band width. A needle was inserted to tibialis anterior muscle as electrode and the stimulation intensity of the ES was set 1.2 times of the minimum amount causing muscle contraction. Slices were set in the same location as the needle electrode, 10 mm distal and 20 mm distal from the needle, respectively.

Results: Fig.1 displays the T2 image (Fig.1a) and a typical ADC image with ES at 20 ms after (Fig.1b). Fig.1a shows needle insertion to tibialis anterior muscle, and it was shown signal decrement (arrow). In the tibialis anterior muscle that was contracted by the ES, the increment of ADC was observed (Fig.1b). In the analysis of the dynamic DTI, λ_1 of the tibialis anterior muscle during electrically stimulated contraction ($4.4 \times 10^{-1} \pm 2.1 \times 10^{-1} \text{ mm}^2/\text{s}$) showed remarkable increased compared with those of the gastrocnemius muscle ($2.4 \times 10^{-2} \pm 1.3 \times 10^{-2} \text{ mm}^2/\text{s}$) as control ($p < 0.001$). λ_2 of the tibialis anterior muscle in the dynamic DTI also showed significant increased ($p < 0.05$). Fig. 2 displays the changes of λ_1 angle of the z-axis for x-y plane. In the static DTI, the λ_1 angle of the z-axis along muscular long axis was almost perpendicular to the x-y plane. However, the λ_1 angle during the muscle contraction significantly decreased in the same location as the needle electrode ($p < 0.001$). The angle was gradually recovered as away from the location of the needle.

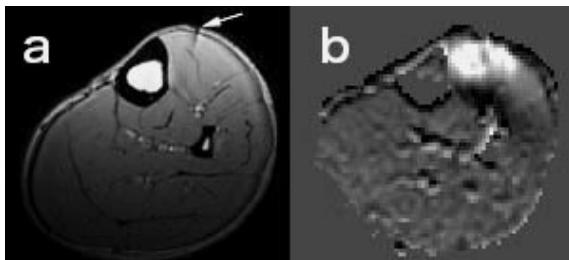


Fig. 1: T2 image (a) and a typical ADC image with ES at 20 ms after (b).

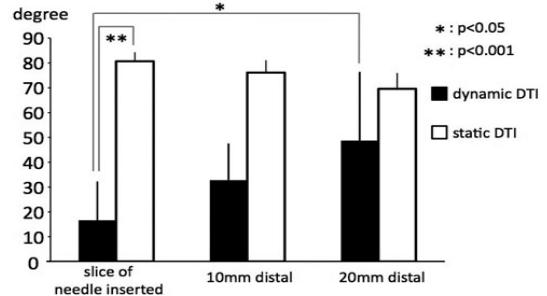


Fig. 2: The graph of λ_1 angle changes of the z-axis for x-y plane.

Discussion: The values of λ_1 and λ_2 showed significant increase during the muscle contraction. These results indicate that rapid water movement occurred in the direction other than muscular long axis at least during the muscle contraction. The λ_1 angle of the z-axis in static DTI was almost perpendicular to the x-y plane because of reflecting the orientation of the muscle cell. However, the λ_1 angle significantly decreased in dynamic DTI (Fig. 2). These results also suggest that water molecules moved in the direction of muscular short axis on the slice location including the needle. In conclusion, this study suggests that the muscle contraction by ES induced the movements of the rapid water molecules to muscular short axis direction as well as long axis.

[1] Y.Watanabe, K.Kimura, M.Umeda , et al. ; Proc. Int'l. Soc. Mag. Reson. Med., 13 (2006), 1726.