Fanctional Imaging of Muscle Contraction caused by Electric Stimulation

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Introduction : Transcutaneous electrical stimulation can be used to treat a muscular and articular pain. It is known that percutaneous electricity irritation produces analgesic effects by secretion of intracranial opioid peptide. Though many reports on the analgesic mechanism in central nervous system are reported, only a few studies investigate the muscle contraction or effects of soft tissue induced by electric stimulation. In specific, reports on the visualization of the muscle contraction are very scarce. We have reported that the signal intensity in diffusion weighted magnetic resonance imaging (DWI) using echo planar imaging (EPI) is decreases during skeletal muscle contraction [1], heart muscle contraction [2] and pressure deformation [3]. The purpose of this study is to visualize muscle contraction during electric stimulation using dynamic DWI.

Material & Methods : Seven healthy volunteers were asked to lie in supine position and underwent MRI of the lower extremities with single shot diffusion EPIs and phase contrast gradient echo, respectively. A Signa LX 1.5 T (CN/I, GEMS) scanner and two 3-inch surface coils configured as a dual phased array were used. The scanning parameters of the DWIs were chosen as follows: a single shot, 96x96 matrix, 37 ms TE, 6 mm slice thickness, 160 x 160 mm FOV, and 64 KHz receiver band width. Different motion sensitizing gradients of 4 ms duration and 0-4 gauss/cm strength (b-factors 0, 0.3, 1.2, 2.6, 4.6, 7.2, 10.4, 14.1, 18.4 s/mm2) were used in x, y and z direction. Scanning parameters of the axial slice phase contrast image were: 256x128 matrix, TE=4 ms, FA=10 degree, velocity encoding = 4 mm/s. Scanning parameters of the axial slice phase contrast gradient echo image were: 256x256 matrix, TR/TE=17/4 ms, FA=10 degree. The slice location was set 10 cm distal the head of the fibula. The ADC images were calculated using MRVision software (MRVision co., USA). The stimulating electrodes were set antero-inferior of the head of the fibula and 10 cm proximal lateral of the malleolus. The electric stimulation was applied with 1Hz, for duration of 10ms. The strength of the electric stimulation applied was nominal threshold level for the contraction.

Results : Figure 1 displays the obtained T1-weighted image (a), the phase contrast image (b) and DWIs (c, d). The DWI of the fibularis longus muscle and the tibialis anterior muscle obtained with the sensitizing gradient applied in z-direction was found to be decreased by the electric stimulation (Fig.1 (c)-(d)). The decrease of the DWI signal was observed with the sensitizing gradient in x-direction and y-direction as well as in z-direction. The calculated ADC values were increased significantly compared to those of the controls. The area that showed signal changes in the phase contrast MRI matched well with the signal reduced area in the DWI. Muscle contraction speed estimated from phase contrast MRI was about 5.2 mm/s. This speed was equivalent to approximately 4% muscular shortening per second, which was estimated from the differences between the moving speed of sequential slices.

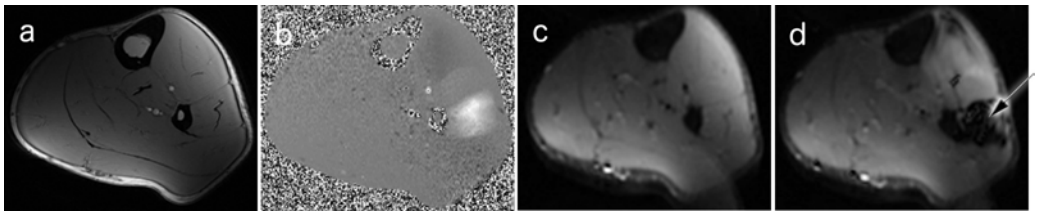

Fig. 1 : T1-image (a) and phase contrast image with electric stimulation (b), the DWIs for control (c) and acquired during electric stimulation (d) applying gradient pulses in z direction, respectively.

Discussion : This is the first report on the real-time detection of areas, in which muscle contractions is induced by electrical stimulation. Investigating the phase contrast MRIs is a useful method to estimate the speed of periodic muscular motion during acquisition of the images. However, using single shot EPI combined with MPG can additionally detect contraction and deformation of the muscle in real time.

Some papers report that the deformation of the muscle increases the signal reduction when using MPGs [4]. However, a contracting speed under 5 % per second does not give rise to signal reduction in DWI using MPGs with duration of 10ms. It is suggested that the signal reduction in DWI may be caused by incoherent tissue water movement due to the intramuscular structure.

References : [1] Watanabe, Y., et al. Proc. ISMRM, 8 (2000) 136. [2] Umeda, M.; et al. Proc. ISMRM,10 (2002), 1595. [3] Umeda, M., et al. Proc. ISMRM, 13 (2005) 1305. [4] Stefan, E.F., et al., Limitations of Stimulated Echo Acquisition Mode Techniques in Cardiac Applications. MRM 1995, 34:80-91