# High time resolution DWI of Muscle Contraction during Electrical Simulation.

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**Introduction :** Transcutaneous electrical stimulation (ES) can be used as a method to treat muscle and articular pain, however, the exact area of muscle contraction is not clear. We reported that the signal intensity in diffusion weighted MRI (DWI) using echo planar imaging (EPI) decreases during percutaneous electrical stimulation [1]. Commonly, tissue movements of skeletal and heart muscles are evaluated by phase contrast (PC) MRI. However, several seconds are required in order to obtain an image and it is difficult to observe tissue deformation during contractions. In comparison, single shot DW-EPI has a short time window to visualize the amount of muscle deformation. The purpose of this study is to demonstrate that DWIs are able to visualize muscle contraction following electric stimulated pulses with high time resolution (10 ms).

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

**Material & Methods :** Seven healthy volunteers were asked to lie in supine position and underwent MRI of the lower extremities with single shot diffusion EPI and PC gradient echo, respectively. A Signa LX 1.5 T (CN/I, GEMS) and tow 3-inch surface coils configured as a dual phased array coil were used. The scanning parameters of the DWIs were chosen as follows: 96x96 matrix, 37 ms TE, 6 mm slice thickness, 160 x 160 mm FOV, non average and 64 KHz receiver band width. DWIs were obtained every 10 ms after the ES, and 0 to 300ms later (total 31 images) were acquired. Different motion sensitizing gradients of 4 ms duration and 40 mT/m strength (b-factors 18.4 s/mm$^2$, 10.4 ms diffusion time ( $\Delta$ )) were used in z-direction (applying long axis of muscle). In addition, ADC maps were calculated from 5 DWIs (b-factors 0, 1.2, 4.6, 10.4, 18.4 s/mm$^2$) at 30ms, 100ms and 200 ms after the ES. Scanning parameters of the axial slice PC image were: 256x128 matrix, TE = 4 ms, FA = 10 degree, velocity encoding = 10 mm/s. The slice location was set 13 cm distal the head of the fibula. The stimulating electrodes were set 8 and 21cm anteroinferior the head of the fibula. The ES was applied with 1Hz and 1ms duration. Stimulation intensity was set to the minimum amount causing muscle contraction. The ADC images were calculated using MRVision software (MRVision co., USA).

**Results :** Figure 1 displays the obtained T2 image (Fig.1 (a)), the PC image (Fig.1 (b)) and DWIs (Fig.1 (c)-(f)). The signal intensity at the tibialis anterior muscle in the DWI was decreased by the ES (Fig.1 (c)-(f)). Remarkable decrement occurred at 20–30 ms after the ES (Fig.2). After 50ms, the signal recovered to approximate 20%. In the subsequent images, signal intensity change and the signal change region were similar to that of the control. The ADC of the tibialis anterior muscle 30ms after showed significantly high values *($4.5x10^{-2} \pm 1.3x10^{-2}$ mm$^2$/s)* compared with those of the soleus muscle*($2.2x10^{-3} \pm 0.4x10^{-3}$ mm$^2$/s)* as control. To visualize muscle contraction using electrical threshold intensity of the muscle contraction, the PC image showed little changes during electric contraction (Fig.1 (b)).

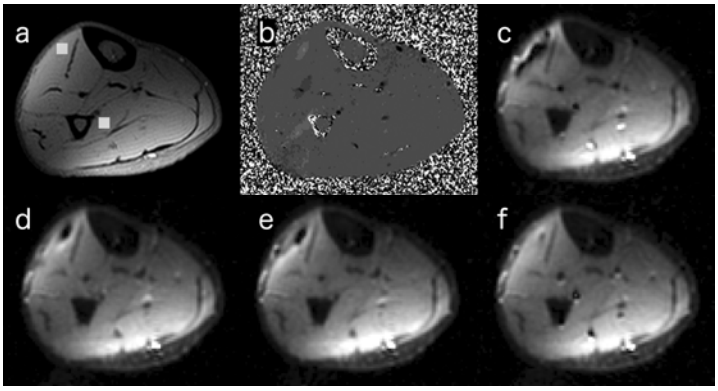


**Fig. 1 :** *T2 image (a) and PC image with electrical stimulation* at 30 ms *(b), the DWIs at 30ms (c), 100ms (d), 200ms (e) and 300ms after (f) of the electrical stimulation applying gradient pulses in z-direction.*

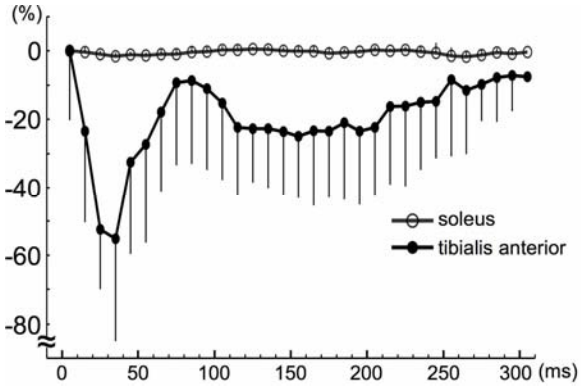


**Fig. 2 :** *The graph of percent changes of signal intensity on DWI. Tibialis anterior muscle was contracted by the electrical stimulation and soleus muscle was that of control.*

**Discussion :** High time resolution dynamic DW-EPI was performed in order to estimate the deformation of the muscle during electrically stimulated contraction. The DWI showed excellent sensibility to visualize even tissue contraction using electrical threshold intensity. High ADC values of 30 ms after stimulation and the decrease of the DWI signal intensity at the tibialis anterior muscle 20-50 ms after later indicated that the DWI could also capture rapid tissue deformation. The results suggest that DWI can be used for various analysis of dynamic tissue deformation. It may even reveal information about the electric conduction of the heart.