Detection of Muscular Deformation using Motion Sensitizing Gradients

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Introduction

Similar to the structural organization of the nerves skeletal muscle tissue consists of fibers. Therefore diffusion tensor imaging (DTI) is a suitable tool to investigate muscle structure. We have reported that the signal intensity in diffusion weighted magnetic resonance imaging (DWI) using echo planar imaging (EPI) is decreased in skeletal muscle contraction [1] as well as in heart muscle contraction [2]. This phenomenon is crucial for the investigation of the apparatus diffusion coefficient (ADC) of water and the determination of the fiber direction in the muscle from DTI. In this study we demonstrate that deformation of the muscle increases the ADC, which is equivalent to signal decrease in DWI. DWIs were measured with single shot EPI applying a motion sensitizing gradients to remove the motion artifacts in phase encoding direction

Material & Methods

Six healthy volunteers were asked to lie in prone position and underwent MRI of the left lower leg with single shot diffusion EPIs and gradient echo, respectively. A Signa LX 1.5 T (CN/I, GEMS) and tow 5-inch surface coils configured as a dual phased array coil were used. The scanning parameters of the DWIs were chosen as follows: 96x96 matrix, 50 ms TE, 6 mm slice thickness, 12 mm FOV, non average and 64 KHz receiver band width. Different motion sensitizing gradients of 10 ms duration and 0-4 gauss/cm strength (b-factors 0, 30, 100, 400, 910, 1610 s/mm^2) were used in x, y and z direction. Motion sensitizing gradients (b=1610) in 6 different directions were used for DTI. Scanning parameters of the axial slice gradient echo image were: 256x256 matrix, TR/TE=17/4 ms, FA=10 degree. The slice location was set 9 cm below the tibial bone head, where pressure was applied to the left side of the gastrocnemius muscle (Fig. 2(a)). Pressure was applied to the muscle with the piston of a 10ml syringe (see Fig.1 below) in which water was injected by an MR injector (MEDRAD Inc., USA). The latter provided controlled water injection with 1.5 ml/sec, causing the piston to press the muscle at a constant speed of 4.8 mm/sec. DWIs were obtained during this process. The ADC and diffusion tensor images were calculated using MRVision software (MRVision co., USA).

Results

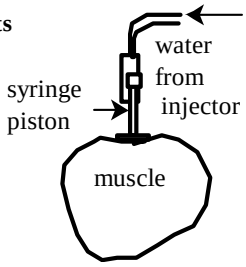

Fig. 1: Syringe piston press the muscle.

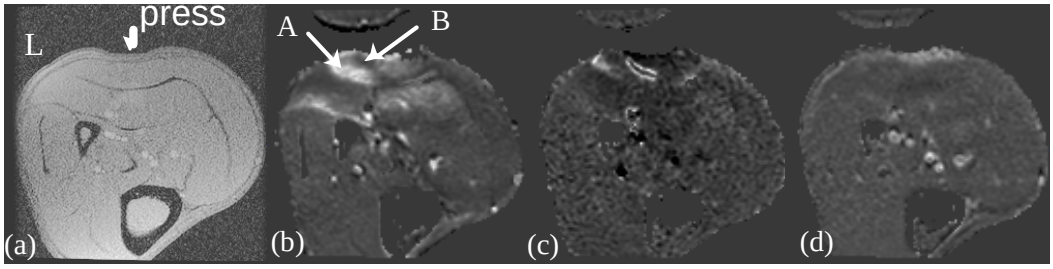

Fig. 2: Gradient echo image acquired during pressure → exertion (a) and according ADC images applying gradient pulses in x (b), y(c), and z(d) direction, respectively.

Figure 2 displays the obtained gradient echo image (Fig.2 (a)) and the DWIs (Fig.2 (b)-(d)). The ADC of the lateral gastrocnemius muscle and the soleus muscle obtained with the sensitizing gradient applied in x-direction was found to be increased by the pressure deformation (Fig.1 (b)). However, this increase did not significantly exceed the ADC of the images measured with the gradient pulse set in y or z direction, respectively (Fig.1 (c) and (d)). ADC values were higher distal from the pressure point (Fig.2 (b) A) than proximal (Fig.2 (b) B). A conventional diffusion tensor image showed that most of the muscle fibers were orientated along the z-axis. However, the main component of the largest Eigenvector was oriented in x-direction. The components (-0.2, 0.1, 0.9) of the largest Eigenvector in typical data of the study presented changed to (0.8, 0.3, 0.5) in areas, which showed high ADC in the DWIs.

Discussion

The increase of the ADC gained during muscle deformation differed from that gained without pressure exertion. The signal reduction in the DWIs of the first derived from intra-voxel incoherent motion (IVIM) of the water in tissue, rather than from water diffusion. Reese showed that muscle deformation increases the ADC (≡ DWI signal decrease) [3]. However, the detected ADC in the gastrocnemius muscle was higher in distal areas than in proximal areas. The same applies to the soleus muscle. We therefore assume that the signal reduction in DWI may not be directly caused by the deformation of tissue. The diffusion tensor Eigenvector components indicated that the IVIM takes place along the x-axis, which is orthogonal to the muscle fiber orientation and the direction of the applied pressure. We suggest that the increased ADC may indicate the extension of IVIM, possibly corresponding to degree of displacement of the muscle fibers, which in turns could reflect the microstructure in the muscle.

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