Time dependence of the diffusional kurtosis in the human calf muscle

Anja Maria Marschar, Tristan Anselm Kuder, Bram Stieltjes, and Frederik Bernd Laut

Department of Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany

Quantitative Imaging Based Disease Characterization, German Cancer Research Center (DKFZ), Heidelberg, Germany

Introduction

The diffusional kurtosis ($K_{app}$) describes the deviation of the diffusion propagator in tissue from a Gaussian function [1]. It is usually measured in combination with the apparent diffusion coefficient ($D_{app}$) and yields additional information on the tissue structure in the human body. It has been measured in several organs, for example in the brain [2] and prostate [3], and was shown to be a valuable parameter to describe diseased tissue, e.g. in prostate cancer [3]. The aim of this work was to perform measurements of $K_{app}$, including its dependence on the diffusion time, in healthy muscle tissue to establish a basis of comparison for the investigation of muscle diseases, e.g., muscle dystrophy.

Materials and Methods

A stimulated echo acquisition mode sequence [4] was used to measure diffusion weighted images (DWIs) in the human calf muscle at 1.5 Tesla (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany). The parameters were TE = 63 ms (for mixing time TM = 100 ms) or TE = 46 ms (for TM = 500 ms) or TE = 38 ms (for TM = 1000 ms), TR = 2.8 s, BW = 1804 Hz/px, matrix 64 x 64, resolution 6.9 mm, slice thickness 10 mm, 3 averages. Three orthogonal diffusion gradient directions were used with the following b-values: 0, 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 6000 s/mm² (for TM = 100 ms); 0, 1000, 2000, 3000, 4000, 5000, 5500, 6000, 6500, 7000, 7500, 8000, 8500, 9000, 9500, 10000 s/mm² (for TM = 500 and 1000 ms). $D_{app}$ and $K_{app}$ values were fitted with the following formula as proposed in [1] with the background noise $\eta$: $S = \sqrt{\frac{\eta^2}{2}} + (S_0 \exp(-bD_{app} + \frac{1}{6} b^2 D_{app}^2 K_{app}))^2$. The DWIs were smoothed with a Gaussian filter with a half width of 1.5 voxels. For the quantitative evaluation, regions of interests were placed in the muscle tissue omitting regions near skin, bones and vessels.

Results

Fig. 1 shows maps of $D_{app}$ and $K_{app}$ which both depend on the diffusion direction. Fig. 2 and 3 show the time-dependence of the ROI-averaged values of $D_{app}$ and $K_{app}$. The z-direction is approximately parallel to the fiber direction. In z-direction the $D_{app}$-values are higher and the $K_{app}$-values are smaller compared to x- and y-direction. $D_{app}$ decreases moderately with increasing TM while $K_{app}$ decreases strongly.

Discussion

The drop of $D_{app}$ with increasing diffusion time was already observed in [5] and absolute values are in agreement with the values presented in [5]. To our knowledge, the time dependence of the kurtosis in muscle tissue has not been investigated to date. Interestingly, a much larger anisotropy can be observed for $D_{app}$ than for $K_{app}$. $K_{app}$ is almost isotropic. For small mixing times (100 ms), the diffusion process is mainly located in either the intracellular or the extracellular compartment, as muscle cells typically have a diameter of about 50 μm [6]. At this time scale, the myofibrils of about 1 μm [6] diameter are not detectable, but the cell membrane causes a restriction. At longer mixing time (1000 ms), the kurtosis decreases, which may be attributed to an effectively free water exchange between intra- and extracellular space at this long time scale. Compared to a kurtosis value of 1.1 in white matter tissue of the brain [2], the kurtosis in muscle tissue is much smaller. There seems to be a fundamental difference between brain tissue and muscle tissue. In brain tissue, for small diffusion time, it is probably justified to assume the presence of two well-separated compartments with different diffusion coefficients, caused by the hydrophobic myelin sheet, which results in large $K_{app}$-values [1]. In muscle tissue, however, such an almost impermeable layer is not present, and this may well explain the low $K_{app}$ in muscle when compared to white matter.

References