Time dependence of the diffusional kurtosis in the human calf muscle

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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 η: $S = \sqrt{\eta^2 + \left(S_0 \exp\left(-bD_{app} + \frac{1}{6}b^2D_{app}^2K_{app}\right)\right)^2}$. 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.

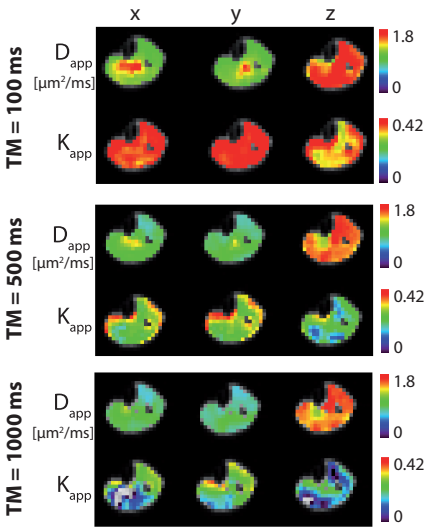

Fig.1: Maps of D_{app} and K_{app} in the human calf muscle for different mixing times TM and diffusion directions. The z-direction is oriented along the body symmetry axis in the lab system.

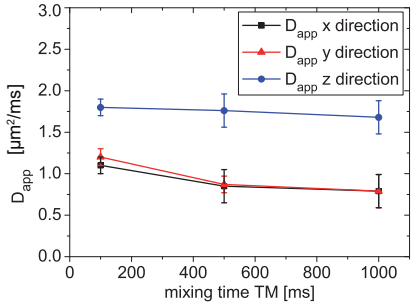

Fig.2: Time dependence of D_{app} in the human calf muscle.

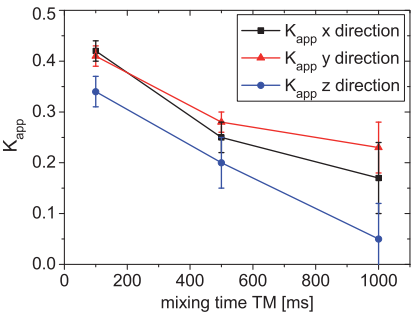

Fig.3: Time dependence of K_{app} in the human calf muscle.

References

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