Relationship between the transverse proton relaxation and the filament overlap in human skeletal muscles

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Introduction The measurement of the proton T_2-relaxation time is of special interest for investigating the physiological activity of skeletal muscles by MRI. It has been shown that the apparent ^{1}H-NMR T_2-time increases during exercise of skeletal muscles (1-3). However, the physiological cause of the effect has not yet competely been understood. Simple variations of the degree of contraction in resting muscles should already cause changes of the T_2 decay. If the condition of rest were properly maintained, such a simple approach would allow the T_2 response to microanatomical changes of the muscle fibers to be distinguished from metabolically induced physiological variations. The purpose of this study is to examine this hypothesis by T_2 resolved MR images of the upper arm acquired with two different elbow flexions.

Methods T_2-times were determined in upper arm muscles of 6 healthy adult volunteers at two distinct flexion states of the elbow (denoted in the following as position ① and ②, respectively, as shown in fig.1). For high resolution sampling of the T_2 signal decay a spin echo EPI sequence was used with 29 echo times (TE) logarithmically incremented from 12 to 90 ms at the approximate position demarcated in fig.1 (dashed box). The forearm position was altered 20 times between positions ① and ②. A statistical analysis based on a Wilcoxon signed-rank test was used for calculating confidential intervals and the significance of the T_2 changes (ΔT_2). To cover the muscle volume by several image slices a turbo spin-echo (TSE) experiment was applied incorporating 6 distinct echo times of 11, 22, 34, 45, 56 and 79 ms. 6 axial slices were acquired numbered in ascending order from distal to proximal end of the arm (see fig. 1). The experiments were repeated 10 times with interchanging arm positions between ① and ②. Scans were performed on a 1.5 T scanner (Siemens Magnetom Sonata, Erlangen, Germany) using a standard extremity coil. Acquisition parameters for both protocols were: TR = 2s, 128 x 128 matrix, 256 x 256 mm (spin echo EPI) and 150 x 150 mm (TSE) FoV, 10 mm slice thickness.

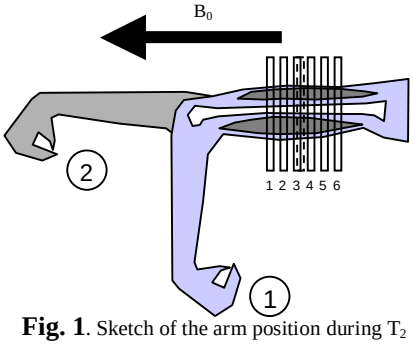

Fig. 1. Sketch of the arm position during T_2 examinations of the biceps and triceps. The boxes 1 to 6 indicate the locations of the axial slices in the TSE experiments; the dashed box shows the approximated slice position during the EPI experiment.

Results T_2 was determined with values ranging from 24 to 30 ms within all spin echo EPI studies. The medians of ΔT_2 of all volunteers were determined with 1.2 and 1.3 ms for biceps and triceps, respectively. Their confidence intervals suggest with 0.5 to1.7 ms (biceps) and -2.6 to -1.1 ms (triceps) that both T_2 changes are significantly ($P < 0.05$) different from zero, whereby the direction of the T_2 change corresponds to the change in the contraction state of each muscle while the arm is bent as demonstrated in figs. 2 and 3. The triceps acts as an extensor and thus contract in position ① and extend in position ② in contrast to the biceps. The alternation of the arm position consistently reflects the T_2 increase and decrease with muscle contraction and extension.

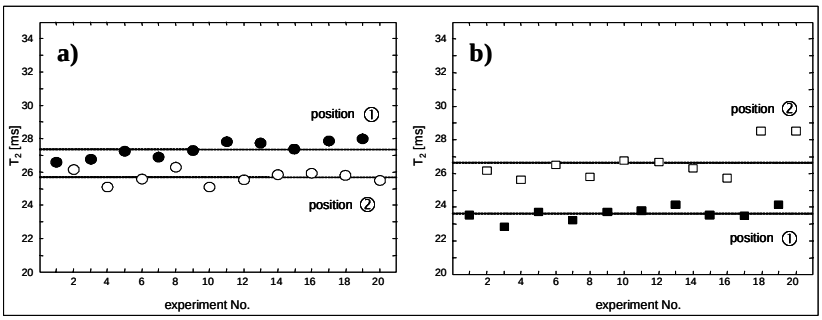

Fig. 2: T_2 alterations determined by spin echo EPI experiments in the course of the repeatedly performed elbow flexions of volunteer 6 for biceps **(a)** and triceps **(b)**. The gray bars indicate a mean error estimate based on the standard deviation of the data.

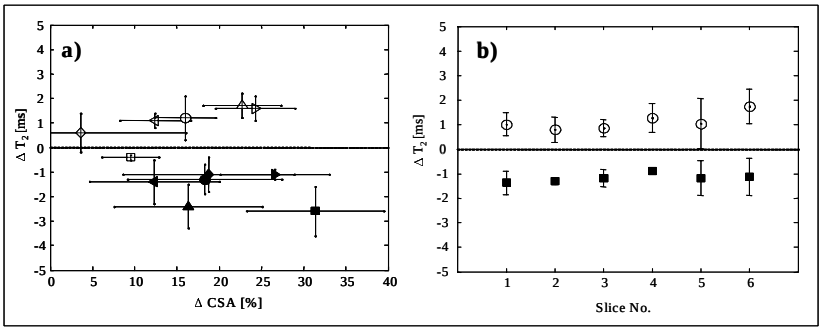

Fig. 3 a) ΔT_2 (EPI) of biceps and triceps of 6 subjects versus the change of the anatomical cross sectional area (ΔCSA) of the muscles, which are due to elbow flexion. **b)** Mean ΔT_2 values calculated from 10 TSE experiments with interchanging arm position (from ② to ①) of the biceps (open symbols) and triceps (solid symbols). The positions of the axial image slices are given on the *x*-coordinate with numbers corresponding to Fig.1.

Discussion Since the examined muscles were not involved in any work a metabolically induced change of T_2 can be excluded. Thus, we can assign the observed T_2 alternations to changes of the microanatomy of the muscle occurring during contraction. In this context we designate relevant anatomical changes to a variation of sarcomere length and filament overlap (4). Since the measured T_2 component (< 30ms) is attributed to intracellular water, we gain some information about the degree of motion of water in vicinity to the sarcomeres. One can speculate that a shortening of the sarcomere length is correlated with a release of attached water due to a reduction of hydrophilic surfaces and hydrogen bridges. Further studies using quantitative ^{1}H-NMR spectroscopy are required to gain deeper insight into the mechanism of intracellular water relaxation of living human muscles. However, the described experiments demonstrate the sensitivity of the transverse proton relaxation time in skeletal muscles to anatomical changes on a microscopic level.

Conclusion The proton-T_2 relaxation time is significantly longer in a contracted skeletal muscle than in its extended state. This demonstrates the sensitivity of the transverse proton relaxation time in skeletal muscles to anatomical changes on a microscopic level. The shown can be qualitatively attributed to morphological changes occurring inside the muscle fibers during muscle contraction.

References

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