**Original Research**

# Alterations of the Proton-$T_2$ Time in Relaxed Skeletal Muscle Induced by Passive Extremity Flexions

Jens Rump, MS,[1] Jürgen Braun, PhD,[2] Sebastian Papazoglou, MS,[1] Matthias Taupitz, MD,[1] and Ingolf Sack, PhD[1]*

**Purpose:** To demonstrate reciprocal changes of the apparent proton-$T_2$ time in the biceps and triceps due to passive contraction and extension of the muscle fibers.

**Materials and Methods:** The contraction state of the upper arm muscles of six healthy volunteers was passively changed by alternating the forearm position between the straight-arm position and an elbow flexion of 90°. The relaxation of the muscle during passive contraction and extension was measured with the use of muscle electromyography (EMG) experiments. Spin-echo (SE) MRI with increasing echo times (TEs) of 12–90 msec was used to acquire the averaged signal decay of the segmented biceps and triceps. The apparent $T_2$ was deduced using monoexponential least-square fitting.

**Results:** The median $T_2$ alterations in biceps and triceps among all volunteers were found to be 1.2 and –1.3 msec in the straight and bent forearm positions, respectively. The confidence intervals (0.5 to 1.7 msec in biceps, and –2.6 to –1.1 msec in triceps) clearly indicate that proton-$T_2$ in MR images is significantly ($P < 0.05$) prolonged with muscle contraction.

**Conclusion:** The observed increase of the proton-$T_2$ time was correlated with a passive contraction of skeletal muscle fibers. This passive effect can be attributed to changes in the intracellular water mobility corresponding to the well-known "active" $T_2$ increase that occurs after stimulation of muscle.

**Key Words:** skeletal muscle MRI; relaxometry; $T_2$; muscle contraction; water mobility; diffusion
**J. Magn. Reson. Imaging 2006;23:541–546.**


THE MEASUREMENT of the proton transverse relaxation time ($T_2$) in skeletal muscle is particular useful for investigating muscle activity by NMR. It is known that the proton-$T_2$ time increases during exercise of the skeletal muscles (1). This effect has become an important factor in $T_2$-sensitive MRI, in which signal intensity can be correlated to muscle recruitment during different motor tasks (2–4). Most of the literature data show that $T_2$ examinations on the timescale of conventional imaging protocols (10–200 msec) yield a monoexponential $T_2$ relaxation with values between 26 and 33 msec for resting in vivo skeletal muscle (2–9). This apparent muscle $T_2$ was found to increase up to 30% depending on the intensity and dynamics of the exercise involved (6–11). Although the physiological cause of the effect is not entirely understood, it is being exploited as a correlative means of measuring muscle activity in sports and rehabilitation medicine (12–15).

Intense research during the last few years has illuminated the relationship between the biomolecular environment of water protons and their $T_2$ relaxation in muscles. From $^1$H-spectroscopy it is known that the $T_2$ relaxation of muscle tissue displays a multiexponential decay that consists of two (16), three (17), or more (18) distinct $T_2$ components. Some investigators also observed a biexponential muscle $T_2$ by MRI that consisted of one short $T_2$ ($T_2$-S) corresponding to the apparent $T_2$, and one additional minor (<10%) and long (>100 msec) relaxing $T_2$ component ($T_2$-L) (5,8,19–21). This multicomponent $T_2$ decay is widely ascribed to anatomical compartmentation of water molecules, i.e., the existence of extra- and intracellular water in the extra- and intravascular spaces (16–18,20,22). Since the blood-volume fraction is low (2–3%) in skeletal muscles (23), the compartmentation model suggests that the vast majority of the $^1$H-NMR signal is related to the extravascular spaces. Correspondingly, the activity-induced increase of the apparent $T_2$ is also observable in the absence of blood flow (24,25). On the other hand, the $T_2$-L component varies with changes in the blood oxygenation (20,26). Since blood volume and oxygenation state are related to muscle work, the $T_2$-L component is sensitive to muscle activation (26,27) in a manner similar to that of a blood oxygen level-dependent (BOLD)-

[1]Institute of Radiology, Charité-University Medicine Berlin, Berlin, Germany.
[2]Institute of Medical Informatics, Charité-University Medicine Berlin, Berlin, Germany.
Contract grant sponsor: German Science Foundation; Contract grant number: Sa/901–2.
*Address reprint requests to: I.S., Institute of Radiology, Charité-University Medicine Berlin, Humboldt University Berlin, Schumannstr. 20/21, 10117 Berlin, Germany. E-mail: ingolf.sack@charite.de
Received December 9, 2005; Accepted December 28, 2005.
DOI 10.1002/jmri.20534
Published online 2 March 2006 in Wiley InterScience (www.interscience.wiley.com).