# Multi-component $T_2$* mapping in the calf muscle during plantar flexion using a multi-echo radial GRE sequence

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**Target audience** Researchers in MR physics and muscle physiology

**Purpose** Recently, muscle functional MR imaging using spin-spin relaxation ($T_2$) mapping has been proposed to assess muscle fatigue and to investigate pathological changes in muscle diseases [1-3]. However, due to the motion-sensitivity of typically applied sequences, e.g. spin-echo echo planar imaging (SE-EPI), the method is limited to pre- and post-exercise measurements. The aim of the present study was to apply a radial multi-echo gradient-echo (GRE) sequence during dynamic exercising for continuous quantitation of the effective transverse relaxation time constant ($T_2$*) enabled by the increased robustness of radial trajectories against motion artefacts [4]. As $T_2$* is sensitive to blood volume and oxygenation [5] its continuous monitoring should provide further insights into the mechanisms of muscle fatigue. Therefore, load-induced $T_2$*-changes were determined based on mono-exponential and multi-component signal fitting of data obtained in a human calf during plantar flexion.

**Methods** The muscle functional $T_2$* study was carried out in a healthy volunteer (male, 24 years old) using a previously described MR compatible pedal ergometer [6]. MR data were collected on a clinical 3 T whole-body MR scanner (TIM Trio, Siemens Healthcare, Germany) using a flexible double-tuned $^1H/^{31}P$ transmit/receive coil (RAPID Biomedical GmbH, Würzburg-Rimpar, Germany). A series of transverse $T_2$*-weighted images with linearly increasing echo times (GRE sequence, radial *k*-space sampling [4], 233 spokes, FOV = 144 × 144 mm², 1.0 × 1.0 mm² in-plane resolution, four 10 mm-thick slices, in-phase $TE_{1-6}$ = 2.46-14.8 ms, ΔTE = 2.46 ms, TR = 76.9 ms, TA = 18 sec) was acquired prior to (NAS = 4), during (NAS = 16) and post-exercise (NAS = 20). Spokes acquired during exercise were compared with a corresponding mean baseline spoke using 1D correlation [4]. Spokes yielding a correlation coefficient less than 0.98 during exercise were excluded from this "self-gated" image reconstruction to reduce motion artifacts. Plantar flexion was performed over a time period of 4.8 min resulting in total exhaustion. $T_2$*-maps were calculated offline using MATLAB by pixel-wise mono-exponential fitting of the signal decays in the acquired series of $T_2$*-weighted images. Median pre- and post-load $T_2$*-values were determined based on ROIs of the *M. gastrocnemius medialis* (GM), *M. gastrocnemius lateralis* (GL) and *M. soleus* (SOL), which were outlined on the first pre-exercise $T_2$*-weighted image (slice 3). Non-negative least-squares (NNLS) analysis was performed for the GM by applying multi-component fitting using $T_2$*-values in the range of 0.01 ms and 100 ms.

**Results** Fig. 1 shows multi-slice $T_2$*-maps acquired pre, during (NAS = 18) and post exercise (NAS = 20). High in-plane resolution of 1.0 × 1.0 mm² enables a clear distinction of activated muscles from the surrounding tissue. A clear shift toward higher $T_2$*-values is visible in GM and GL, whereas $T_2$* in the SOL remains nearly constant. Tab. 1 lists the ROI-specific median $T_2$*-values pre- and post-load. Fig. 2 shows NNLS results of the GM, where two main $T_2$*-components were detected. The fast component (2-5 ms) shows an exercise-induced increase and the slow component (20-30 ms) a shift toward longer $T_2$*-values (up to 40 ms) in the $T_2$*-spectra (see Fig. 2, right). However, at the beginning of the exercise (NAS = 5 - 7) we observed artificial $T_2$* shortenings which arose from motion-induced image artefacts due to insufficient numbers of spokes included in the image reconstruction.

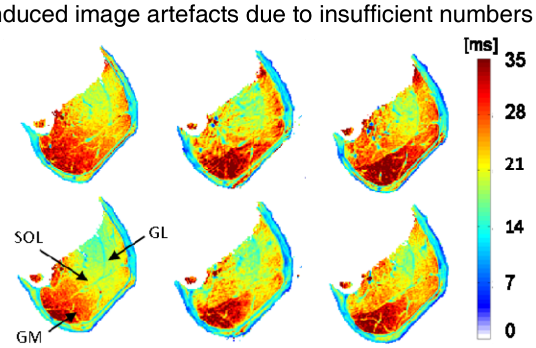


***Fig. 1*** *$T_2$*-maps obtained with a radial GRE imaging pre, during and post exercise (from left to right).*

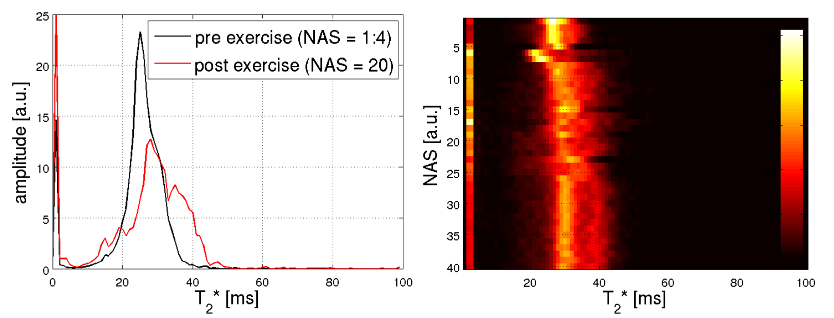


***Fig. 2*** *NNLS $T_2$*-spectra of the GM calculated based on pre (black) and post exercise data (red, left) as well as the entire dynamic series (right).*

**Discussion and Conclusion** This work demonstrate $T_2$*-quantitation in human calf muscles during dynamic exercise by mono- and multi-component fitting, showing the feasibility of muscle functional $T_2$*-mapping based on self-gated radial GRE imaging. Although motion related artefacts could not be avoided completely, $T_2$*-values clearly increased during and post exercise in muscles stressed during plantar flexion. Future modifications of the exercise protocol may improve image quality during exercise, e.g., by introducing short breaks in the exercise during non-deflected foot position.

***Tab. 1*** *Pre and post-exercise $T_2$*-values.*

| ROI | median $T_2$* ± SD prior to exercise [ms] | median $T_2$* ± SD post exercise [ms] |
|---|---|---|
| GM | 26.4 ± 3.1 | 29.8 ± 5.1 |
| GL | 23.2 ± 1.6 | 25.7 ± 2.5 |
| SOL | 23.2 ± 2.0 | 22.1 ± 2.4 |

**References** **1.** Louie EA. Magn Reson Med 2009;61:560-569. **2.** Tawara N. Magn Reson Med Sci 2011;10:85-91. **3.** Hiepe P. Proc ISMRM 21 (2013), #3512. **4.** Krämer M. J Magn Reson Imaging 2013, E-Pup ahead of print. **5.** Damon BM. Magn Reson Med 2007; 57:670–679. **6.** Gussew A. Biomed Tech (Berl) 2012, Sep 4.