Application of a SAGE Sequence During Isometric Contractions in Skeletal Muscle

Christopher P. Elder[1,2], Jack T. Skinner[1,3], Theodore F. Towse[2,3], Nathan D. Bryant[1,3], and Bruce M. Damon[1,3]

[1]*Vanderbilt University Institute of Imaging Science (VUIIS), Vanderbilt University, Nashville, TN, United States,* [2]*Physical Medicine and Rehabilitation, Vanderbilt University, Nashville, TN, United States,* [3]*Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, United States*

Target Audience: Researchers and clinicians with an interest in BOLD effects in skeletal muscle and in methods for dynamic quantification of tissue relaxation rates.

Purpose: The time-courses of MR relaxation rates have traditionally been assessed using echo planar imaging (EPI) based dynamic measurements of R_2* and R_2 from separate image acquisitions. Subtraction of these rates yields an estimate of R_2', which can be used for image-based calculation of muscle oxyhemoglobin saturation[1]. This approach requires subjects to repeat functional tasks such as contractions or cuff occlusion. Recently, an EPI based multiple spin- and gradient-echo (SAGE) method has been developed for brain perfusion imaging[2,3] that permits the simultaneous measurement of R_2* and R_2. We applied the SAGE sequence to measurements of relaxation rates in skeletal muscle during maximal and submaximal isometric dorsiflexion contractions.

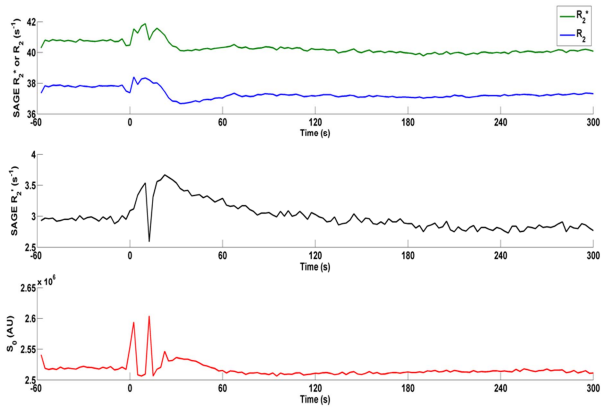

Fig. 2: SAGE R_2* and R_2 relaxation rates (upper panel), deoxyhemoglobin concentration, (middle panel), and S_0 (lower panel) during 60s baseline, 10s maximal isometric dorsiflexion contractions and post-contraction recovery averaged for all 5 subjects. (SD omitted for clarity)

Methods: With local IRB approval, SAGE, multi-gradient echo (MGE), and multi-spin echo data (MSE) were acquired from the legs of 5 subjects [4 female, Age=29(4)years, Height=165.4(4.3)cm, Mass=62.0(11.9)kg] using a 3T Intera Achieva MRI (Philips Healthcare, Cleveland, OH) and an 8 channel knee coil. SAGE imaging parameters were: TR=2.5s, TE=4.9,14,29,38,47, FOV=180x180mm^2, Voxel Size = 2.81x2.81x7.6mm^3. R_2 and R_2* from the SAGE acquisition were compared to those from MGE (TR=2.5s, TE=2.5ms, ESP=2.5ms, NE=30) and MSE (TR=2.5s, TE=10.77ms, ESP=10.77ms, NE=8) acquisitions. Subjects then performed two 10s duration maximal voluntary isometric dorsiflexion contractions and one 120s duration submaximal isometric dorsiflexion contraction (40%) while SAGE data were acquired. On a separate day, near-infrared data were acquired (model 96208; ISS, Inc., Champaign, IL) from the tibialis anterior muscle of 3 of the 5 subjects [2 female] while the isometric contraction protocol was repeated.

Results and Discussion: There was fairly good agreement between relaxation rate measurements derived from EPI SAGE and those derived from MGE and MSE sequences. SAGE R_2*=40.23 [35.59, 45.45] (mean [95% confidence interval]); MGE R_2*=37.35 [37.13, 37.57]; SAGE R_2=37.50 [32.90 42.10]; and MSE R_2=32.80 [31.62, 33.97]. It is notable that agreement was good even when comparing SAGE EPI rates to the non-EPI multi-echo rates. The post-contraction decrease in R_2* and R_2 characteristic of the muscle BOLD effect is clearly visible (Fig 1) with a 1.6% decrease in R_2* occurring 25.0s post-contraction and a 3.0% decrease in R_2 occurring 22.5s post-contraction. The data in figure 2 suggest that the magnitude and kinetics of the R_2' are influenced by a combination of changes in proton density and deoxyhemoglobin. At present, we were unable to achieve such results for submaximal contractions, however, patient populations such as those with diabetes may tolerate brief maximal contractions better than longer submaximal contractions. Additional data collection will allow more quantitative analysis of the observations in the present study.

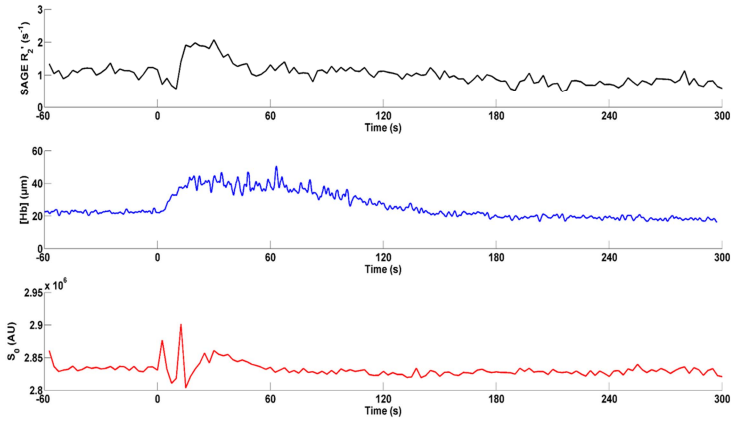

Fig. 2: R_2' relaxation rates (upper panel), deoxyhemoglobin concentration (middle panel) and S_0 (lower panel) during 60s baseline, 10s maximal dorsiflexion contractions and post-contraction recovery in a single subject.

Conclusion: Baseline SAGE R_2* and R_2 measurements generally agree with more conventional multi-echo measurements. SAGE allows simultaneous measurement of changes in R_2* and R_2 related to the BOLD effect in skeletal muscle induced by isometric contractions. These simultaneous measurements allow a more direct calculation of R_2' that is related to the change in muscle oxygen saturation when maximal isometric contractions are performed.

References: 1. Elder CP, *et al*. *Magn Reson Med* 2010; 64:852-861. 2. Schmiedeskamp H, *et al*. *Magn Reson Med* 2010; 63:959-969. 3. Schmiedeskamp H, *et al*. *Magn Reson Med* 2012; 68:30-40.