An MR-compatible solution for simultaneous electrical muscle stimulation and MR imaging at 3T

Alireza Akbari[1], Conrad P. Rockel[1], Dinesh A. Kumbhare[1,2], and Michael D. Noseworthy[1,3]
[1]*School of Biomedical Engineering, McMaster University, Hamilton, Ontario, Canada,* [2]*Physical Medicine and Rehabilitation, McMaster University, Hamilton, Ontario, Canada,* [3]*Electrical and Computer Engineering, McMaster University, Hamilton, Ontario, Canada*

Introduction: Electrical muscle stimulation is a known approach for producing quantitative and reproducible muscle activation. Activation could be accomplished through nerve stimulation or direct motor point stimulation on the muscle. In MRI applications, the difference between the two stimulation methods is important as they differ in electrode placement. In the former method, electrodes are placed over the nerve that innervates the target muscle and thus their effect on MR image quality is much less than the latter method where the electrodes are located on the muscle motor points (which may fall within the imaging FOV). Almost 20 years ago simultaneous ^{31}P spectroscopy and nerve stimulation was done to study muscle metabolism with basic pulse-acquire surface coil localized spectroscopy [1,2]. However, newer MRI techniques such as blood oxygen level dependent (BOLD) and diffusion tensor imaging (DTI) are now more routinely used for the assessment of dynamic muscle physiology. It would be useful if the application of simultaneous muscle stimulation to these imaging techniques could be performed, especially in the case of direct muscle stimulation where the presence of the electrodes could pose artifacts in the MR images. And, more importantly, improperly designed electrode leads could result in burns. Thus the purpose of this work was to design a simple MRI-compatible solution that delivers safe electrical stimulation pulses from a commercially available EMG/stimulator unit located in the MRI control room to a subject in the magnet bore; enabling simultaneous electrical muscle stimulation and MR imaging.

Methods: *Instrumentation Components:* A commercial EMG unit (XLTEK, NeuroMax 1004) was used for generating stimulation pulses. Standard MR-compatible ECG electrodes (Cleartrace REF2700-003) along with clip electrodes (Invivo Adult Quadtrode MRI ECG Cable) were used for stimulation through the skin. Two sets of 9m long coaxial cables were used to relay the stimulation pulses from the EMG unit through the waveguide to the electrodes. The setup is shown in **Fig.1**.
Phantom Setup/Test: All experiments were performed using a GE 3T (General Electric Healthcare, Milwaukee WI). A spherical phantom was used to test for RF heating and image distortion due to electric stimulations. Prior to phantom imaging, the 2 stimulating electrodes were placed beside each other with their conductive gels touching since the plastic surface does not conduct electricity and we wanted to ensure stimulation pulses would have a closed circuit for this test. Temperature changes due to RF and gradients were monitored using 2 probes from a MRI-compatible optical thermometry system (ReFlex-4 RFX273A, Neoptix, Quebec, Canada) placed under each electrode. A series of stimulation pulses at frequencies ranging from 0.5 to 50 Hz were delivered while the phantom was imaged using a gradient intensive pulse sequence (DTI with 50 mT/m peak amplitude at a slew-rate of 200 mT/m/s) and a 32ch head coil (MR Instruments INC.).
Subject Setup: An *in vivo* test was done on a 29-year-old healthy male volunteer. The stimulation electrodes were placed on the two heads of the gastrocnemius medialis muscle for direct muscle stimulation. BOLD images of the gastrocnemius medialis muscle were obtained using an 8 channel knee coil (Invivo 3T HD T/R Knee Array) before stimulation and during stimulation (Pulse width: 0.1 ms, Amp: 35 mA, freq: 40 Hz) and also without the presence of electrodes. BOLD image quality was compared between the following: without electrodes, with electrodes (no stimulation) and with electrodes during scanning. Mean BOLD image SNR, and potential artifacts were evaluated on the centre slice between stimulator electrodes.

Results and Discussion: The temperature remained constant during DTI scanning, and over all EMG stimulator frequency tests. No artifacts due to electrode presence or stimulation contaminated any of the muscle BOLD images. Geometric change was clearly observed (and expected) due to electrically induced contraction (**Fig.2**). Local artifactual geometric distortions were not significant on BOLD or DTI scans around the electrode sites. The SNR measurements at the centre slice without the electrodes was 116.3, where the SNR was 127.3 at the electrode site. In the presence of electrodes the centre slice SNR decreased to 109.6 (i.e. 6% drop), while that nearest the electrode dropped to 99.4. In the center of the calf muscle, where BOLD imaging was done, an SNR drop of 6% was measured due to presence of electrodes. In this work, MR-compatible ECG electrodes and clip electrodes were used because standard EMG electrode cables are not MR-compatible. However, these leads have an impedance of 12 kOhm each, which restricts the maximum stimulus power delivered to the muscle. Future work will involve investigation of lower impedance EMG leads for delivering more powerful muscle stimuli.

Conclusion: We were able to conduct simultaneous BOLD MRI and EMG stimulation with no significant interference and heating issues using a simple set-up. This method enables reliable quantitative and repeatable activation of muscle.

References:
[1] Blei ML *et al.* (1993) *PNAS* 90:7396-7400.
[2] Jeneson JA, et al. (1997) *Mol Cell Biochem* 174:17-22.

Figure 1 The EMG unit along with the electrodes and the other components

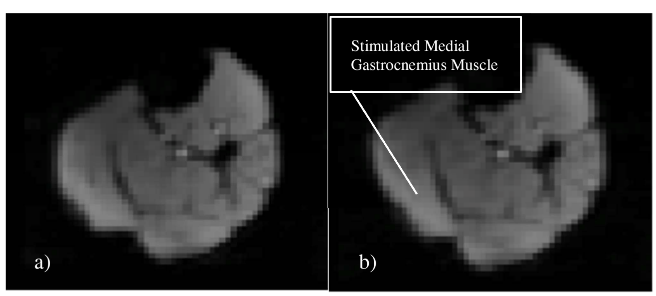

Figure 2 BOLD images of cross section of the leg. a) before stimulation of the medial gastrocnemius b) after stimulation of the medial gastrocnemius