Development of MR Compatible Muscle Stimulation Device: Deformation and Velocity Imaging of Rat Muscle Contraction.

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Purpose: It is critical to develop a muscle-skeletal (MSK) model of diseases such as dystrophy, sarcopenia, cachexia to understand the pathophysiology as well as to develop imaging biomarkers of disease to monitor progression and response to interventions. The rat muscle has been shown to be ideal for modeling these disease states under controlled conditions [1]. While structural imaging including diffusion tensor imaging has been performed to elucidate architectural changes in rat muscle model [2], dynamic functional imaging of the rat muscle is still a challenging unresolved problem because of electronic noise generated by stimulation circuitry. The ability to characterize structure and function of the MSK system in a non-invasive, in-vivo manner, will allow the development of muscle disease models with the potential to assess progression and response to interventions longitudinally.

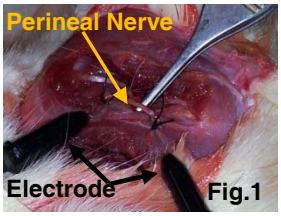
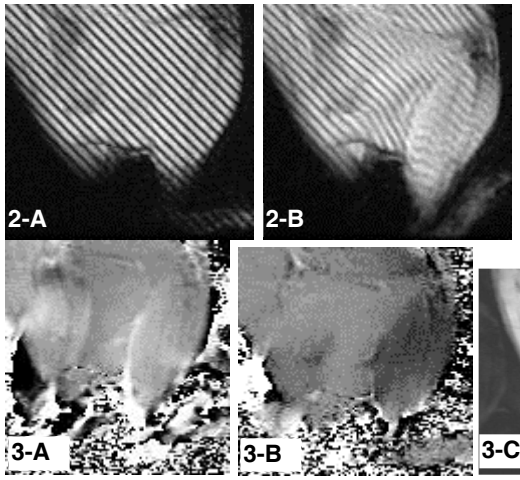
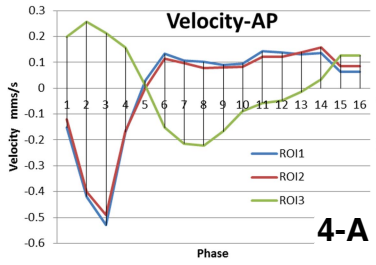


Fig.1

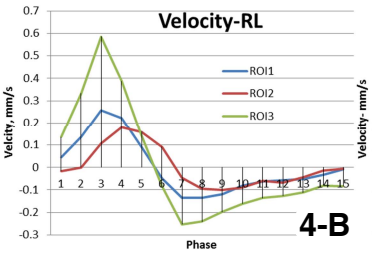
Aim: To develop an MR-compatible animal (rat) model system that will allow studying of muscle dynamics using gated spin-tag and phase-contrast velocity-encoding, with controlled muscle activity using external stimulation system.

Methods: A surgical incision was first made in the lateral anterior portion of the biceps femoris muscle in the hind limb of a rat, to expose the common perineal nerve below the bifurcation. MR-compatible platinum electrodes were then attached to this nerve and surgically fixed with sutures (Fig.1). A GRASS (S8800, Quincy MA) stimulation system was utilized to produce a train of 0.2ms pulses at 60Hz frequency, for a train length of 500~800ms, with 0.5 pulse train/s [3]. The voltage level at which tetanic contraction could be achieved was first determined, and then the voltage of the pulse train was modulated from zero level to the tetanic to produce well-controlled motion of the hind limb muscle without eliciting muscle fatigue. Several electronic circuits were needed to be built in order to filter out the noise and for the amplitude modulation of voltage. The imaging sequence and modulation were triggered synchronously to the beginning of the pulse train. Five 18-mo-old male Wistar rats were scanned on a 1.5-T GE whole-body scanner in a wrist coil with the animal on its side and the stimulated hind leg on the anterior side. Gated Spin tag images (standard fGRE spin-tag sequence, 6ms TE, 18ms TR, 9cm FOV, 256x160 matrix, 3mm thick, 4Av, 30bpm, 5mm tag spacing, ~2mnts) and VE-PC (water) imaging sequence (16.5ms TR, 7.7ms TE, 20º FA, 4 Av, 122Hz/pixel bandwidth, 10 cm/s velocity encoding in three directions, 4 views per segment, 22 phases, 2 excitations, 256x160 matrix, 9cm FOV, 1 slice, and ~2.44mnts scan time) in coronal orientations was used to acquire tissue deformation and velocity encoded dynamic images of the leg. Velocity was calculated in 2D after the phase images were corrected for phase shading artifacts.

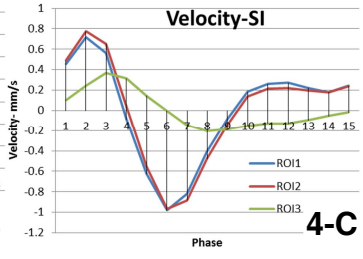




4-A



4-B



4-C

Results: Fig. 2 shows the spin-tag images in the initial relaxed (2.A) and in a later stimulated (2.B) state – the distortion of the tag lines can be easily visualized, and which are able to demarcate different muscles by their different displacements. Fig. 3-A and B show VE-PC images at again two different phases of the contraction cycle. Fig. 3-C shows the magnitude images of the VE-PC image and three ROIs placed in the lower leg. The velocity profiles as a function of the dynamic cycle is shown in Fig. 4-A, B and C, for the three directions (SI, RL, AP – these are for the magnet axis, since the rat was placed on its side and coronal images were acquired) for three ROIs placed in the soleus (ROI1), gastrocnemius (ROI2) and the hamstring (ROI3).

Discussion and Conclusions: Acquisition of dynamic MR images of the rat leg muscle required careful consideration of instrumentation to eliminate electronic noise and MR- artifacts as well the muscle physiology. The high frequency pulse train at 100 Hz caused a series of jerky motions each lasting 100 ms. The low frequency modulation at 1Hz was able to convert this jerk into a smooth change in plantarflexion angle with the pulse train. The visualization of the spin tags and their deformation shows that dynamic imaging of muscle tissue deformation is possible. VE-PC images quantified velocity changes as a function of the stimulation pulse highlighting the behavior of the hamstrings and the triceps surae muscles. **References:** [1] Bollheimer LC, Biogerontology. 2012 Oct 14. [Epub ahead of print]; [2] Van Donkelaar et al. J Anat. 1999 January; 194(Pt 1): 79–88.[3] Drost et al. Pflugers Arch-Eur J Physio(2003) .