Introduction. Magnetic Resonance is already widely used in musculoskeletal imaging to provide structural information about muscles and for the differentiation of focal lesions. Functional imaging of the muscle currently follows two approaches: perfusion/oxygenation imaging and contraction imaging using cine MRI. Contraction imaging can be based on real-time imaging or on cyclic voluntary movements that are correctly synchronized to the acquisition, however, the overall temporal resolution is low. In this work, we present a new method for accurate, quantitative measurement of muscle contraction speed and displacement with a temporal resolution of few milliseconds. This allows the direct assessment of the reaction time of muscle fibers, contraction speed and displacement. We termed this method MR Electromyography (MR-EMG) since the response of the muscle fiber to an external electrical stimulus is imaged. MR-EMG thus provides complementary information to conventional electromyography, for similar application fields.

Materials and Methods. A healthy volunteer was prepared with the application of saline electrodes on the lateral side of the quadriceps femoris (QF) muscle in order to stimulate the rectus femoris (RF) and the vastus lateralis (VL). Said electrodes were connected to a commercial symmetric sine wave electrical muscle stimulator (EMS) device through a custom electronic switch controlled by an optical pulse. The stimulation type was set to unmodulated, thus delivering a constant 11-kHz sinusoidal electrical stimulus. The amplitude of the stimulus was manually adjusted to the minimum required voltage for tetanic muscle contraction. A SPAMM-tagged [1] cine gradient echo MRI sequence was adapted to deliver a trigger pulse after the tagging block, preceding the cine acquisition block, and a second pulse to indicate the end of the cine acquisition. The triggers were used by the electronic switch to toggle the stimulus delivery (fig. 1). The cine acquisition block acquired one k-space line per phase and was adjusted to last 200ms, followed by 300ms of recovery time. MR acquisitions were performed on a parasagittal 2D slice comprising a section of the RF of the VL, with a spatial resolution of 0.76x0.76x8mm³ and a temporal resolution of 5.7ms (matrix size 256x256, flip angle 10°). The tagged images were subsequently processed to extract the displacement information in different areas of the muscle with a computer-assisted manual procedure.

Results. MR-EMG nicely depicted the contraction pattern of the different heads of the QF, thus providing morphological information about the direction of the muscle fibers (fig. 2). A quantitative analysis showed different displacements in different sections, varying in total amount, contraction speed and reaction time. In particular, the distal part of both the VL and the RF were faster with respect to the beginning of the contraction (reaction time of 1 frame, 5.7ms), where the proximal part of the RF was the one contracting last (reaction time of 6 frames, 34.2ms, fig. 3).

Discussion. MR-EMG offers a new promising tool for the analysis of muscle function, yielding qualitative and quantitative information about the contraction speed and patterns. This allows the study of the electromechanical response of the muscle fibers, in a similar and complementary fashion to conventional EMG. For the evaluation of focal lesions of traumatic or neoplastic nature, the qualitative visualization can be useful to assess the affected area of the muscle. In contrast, quantitative measurements provide information about the general health and performance of muscle fibers and can be used for monitoring muscular effects of neurodegenerative diseases, dystrophies, and to assess effects of training and rehabilitation.


Fig. 1: Synchronization between imaging and muscle contraction.

Fig. 2: Tag images at t=22.8, 45.6, 68.4 and 91.2ms. Lines are drawn to highlight the displacement in one illustrative region.

Fig. 3: Displacement of different areas of the quadriceps femoris.