Mapping of Movements in the Dynamically Contacting Human Triceps Surae Muscles using a Computer Controlled Hydraulic Foot-Pedal Device with Velocity Encoded Phase Contrast MRI

D. Shin[1], R. Kinugasa[2], C. Mishra[2], J. Hodgson[1], V. Edgerton[1], and S. Sinha[2]

[1]University of California, Los Angeles, CA, United States, [2]University of California, San Diego, CA, United States

Introduction:

In vivo dynamics of muscle-tendon movement has been studied extensively under the isometric contraction mode using ultrasonography, VE-PC-MRI, and DENSE techniques. We have performed numerous isometric contraction experiments using velocity encoded phase contrast MRI (VE-PC-MRI) and reported several important findings[1,2,3,4]. We are now moving toward dynamic contraction experiments under active and passive conditions through the development of a novel MR-compatible muscle testing apparatus. This step forward is an important one because it allows one to look at the morphological/functional changes in the muscle-tendon system as they occur during normal body movement, e.g. walking and running. For the first time in magnetic environment, we are demonstrating the feasibility of performing dynamics muscle contractions in vivo and accurately mapping muscle-tendon movement through VE-PC-MRI experiments. We highlight clear differences in structural and functional behavior of muscle-tendon system, thereby suggesting the different mechanics involved for creating motion under the two contraction modes (dynamic vs. isometric).

Materials and Methods:

1) Testing Apparatus: The muscle testing apparatus (Fig. 1) consists of driving and actuating modules. The former includes a programmable linear motor (resolution: ±0.0003 inches, max. force: 495 lbs) and a water hydraulic cylinder, both of which are placed in the control room outside the magnetic environment. The latter consists of a leg housing platform with a rotatable foot pedal and another water hydraulic cylinder for conversion of linear motion into ankle rotation. All components in the actuating module were custom-made to ensure MR-compatibility. A carbon-fiber plate was placed at the base of the foot pedal with an optical strain gage attached on its distal side to monitor muscle activation level during the experiments. Distilled water was used as the pressure medium between the two modules via high-pressure tubing. All hydraulic components were vacuum-rated to ensure leak-free operation of the apparatus.

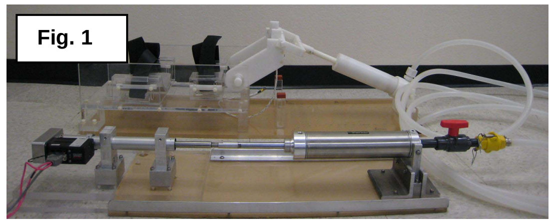

Fig. 1

Fig. 2

2) PC-MRI Data Acquisition: Four healthy human subjects (age 25.2 ± 4 years, body mass 68.4 ± 3 kg and height 172 ± 2.3 cm) were recruited for this study. PC-MR imaging was performed first under the isometric contraction mode at 20% MVC, then under the active dynamic contraction on a separate day. The dynamic range of ankle rotation was 20^o (plantarflexion), -10^o (dorsiflexion) with respect to the relaxation ankle position, moving at the tangential velocity of 8 in/s. The same oblique sagittal slice was prescribed for both modes for consistency as well as for imaging of the midsection of the medial gastrocnemius (MG). Eight equally spaced ROIs were chosen along the MG muscle (Fig. 2) and their tracking behavior was compared between two contraction modes.

Results and Discussion: 1) Velocity distributions of 8 ROIS were similar within the contraction mode but significantly different between modes. Specifically, the velocity patterns were altered and the peak velocity was much higher during the dynamic contraction (6.92 cm/s vs. 2.85 cm/s). 2) The spatial strain distribution was also different between the two modes, suggesting that the fiber activation level and the recruitment pattern were affected in the dynamic contraction mode.

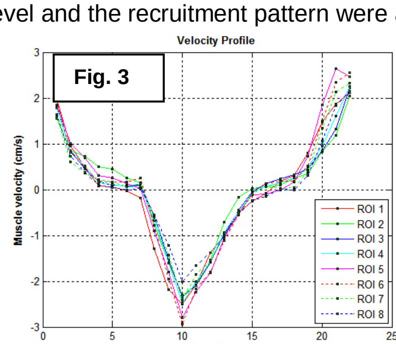

Fig. 3

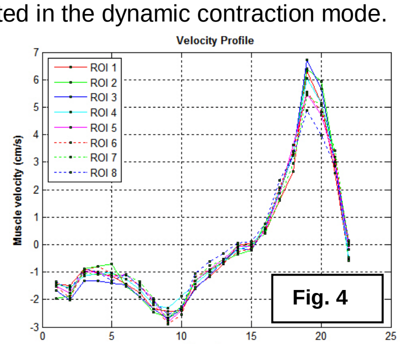

Fig. 4

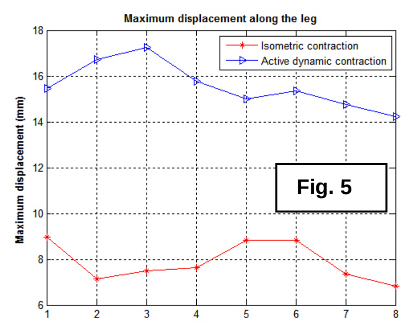

Fig. 5

Conclusions:

The new hydraulic foot-pedal device was successfully utilized to create the dynamic and active muscle contractions inside the MRI bore. The PC-MRI data acquisition and post processing of 8 ROIS in the MG region have revealed significantly different displacement/velocity behavior, suggesting that the new dynamic mode may involve different muscle mechanics. Given that the ankle movement in the dynamic mode closely mimics that occurring in the human joint motion in vivo, further investigations are expected to provide valuable information regarding muscle-tendon biomechanics previously undetectable under the isometric contraction mode.

References:

1. Sinha S et al. J Magn Reson Imaging 20(6):1008-19,2004. 2. Finni T et al. J Appl Physiol 95: 829-837, 2003. 3. Hodgson JA et al. J Morphol 267: 584-601, 2006. 6. 4. D Shin et al. Presented at Fifteenth ISMRM Meeting in 2007.