Preliminary Database of Thigh Muscle Stiffness using Magnetic Resonance Elastography

S. F. Bensamoun[1], S. ringleb[1], Q. Chen[1], T. Hulshizer[2], P. Rossman[2], R. Ehman[2], K-N. An[1]

[1]Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, Rochester, Minnesota, United States, [2]Department of Radiology, Mayo Clinic, Rochester, Minnesota, United States

Introduction

The biopsy, electromyography (EMG) and sonoelastography are invasive and non-invasive techniques allowing for quantification of muscle composition, activity and stiffness, respectively. MRE is a novel non-invasive phase contrast MR technique capable of visualizing small displacements (on the order of microns) from applied shear waves. The stiffness of the soft tissue can be calculated from the measured wave. When using MRE to quantify the stiffness of the thigh muscles, the biggest challenge is to induce waves in the muscle when a large amount of subcutaneous fat is present. The purpose of this study is to show the efficiency of a pneumatic driver to induce waves in the vastus lateralis (VL), vastus medialis (VM) and sartorius (Sr) muscles in healthy volunteers with a large amount of subcutaneous fat when the muscles were relaxed.

Methods

Five healthy volunteers (5 females, mean BMI 22.08 ± 1.15) participated in this MRE study. The volunteers lay supine in a 1.5T General Electric Signa MRI with the right leg resting in a custom MR compatible leg press, capable of measuring the applied load. The pneumatic driver was positioned on the thigh 1/3 of the distance from the patellar tendon to the greater trocanter. The pneumatic driver consisted of a remote pressure driver (i.e., a large active loudspeaker) connected to a long hose. A smaller silicone tube was wrapped around the subject's thigh, clamped on the lateral side and connected to the remote pressure driver (Fig. 1). This system created a time varying pressure wave, which expand or contract the tube around the thigh with the remote driver. After the pneumatic driver was in place, a custom built Helmoltz coil was placed over the thigh. Shear waves were propagating through the thigh muscles at 90Hz (f). Oblique scan planes passing through the VL, VM and Sr were selected from an axial image (Fig. 2). MRE images were collected with a gradient echo technique with TR/TE 350 ms/minimum full with a 256x64 acquisition matrix and a 24cm field of view. Each scan took 3 minutes and 30 seconds to acquire. The wavelength (λ) was measured in each of the four offsets and the stiffness was calculated ($\mu=\rho*\lambda^2*f^2$, where ρ=1000 kg/m^3). The reported stiffness was the average of all four offsets. To measure the wave length, a profile was drawn along the direction of the propagating wave in each phase image (Fig. 3).

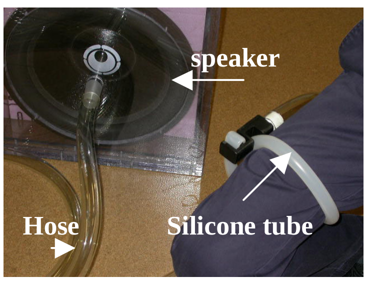


Fig. 1: Pneumatic driver

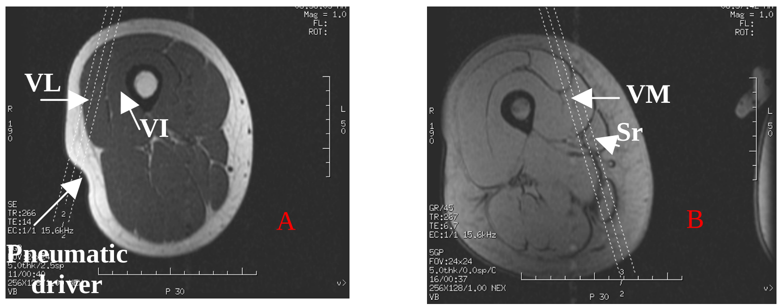


Fig. 2 : Axial scout representing the thigh muscles localization in the lateral (A) and medial (B) side.

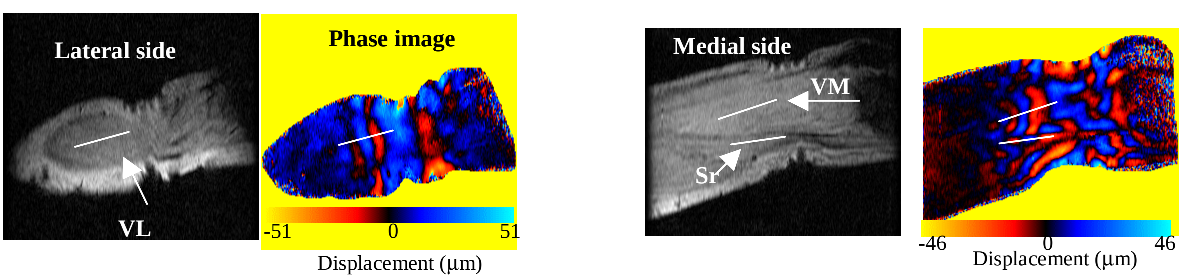
Results

A mechanical driver was previously used, however the waves did not propagate through the subcutaneous fat. The pneumatic driver enables the propagation of the shear waves into different thigh muscles (VL, VM and Sr). The shear modului measured in the vastus lateralis (VL), the vastus medialis (VM) and the sartorius (Sr) were 4.45 ± 0.318kPa (VL), 4.17 ± 0.92kPa (VM) and 6.78 ± 1.74kPa (Sr). Moreover, the shapes of the waves were influenced by the fiber orientations. Round waves were observed within the sartorius (longitudinal fibers), while elliptical waves were seen within the vastus medialis (unipennate fibers). The muscle boundaries were identified in the phase image because the waves did not cross the apeunorosis membrane.

Discussion

This study demonstrated that the MRE technique is able to measure the muscle thigh stiffness. While a number of MRE studies were performed on skeletal muscles [1,2,3] (lower leg and biceps) none of them investigated the thigh muscles. This work provides a data base for this thigh muscles. The sartorius muscle shows a higher stiffness than the vasti muscles. This may be due to the longitudinal fiber orientation compared to the unipennate shape of the vasti. Therefore, the wave length seems to be influenced by the fiber orientations. Similarly, the biceps brachii, which is a bipennate muscle, exhibited a higher muscle stiffness (17.9 ± 5.5kPa and 23.8±6.68kPa) than the other muscles [3], which are composed of different fiber orientations. Finally, the MRE technique could replace invasive procedures (e.g., biopsy) that are currently used to understand changes that occur with pathologies, such as Graves Disease.

Fig 3



Reference

[1] Dresner et al., JMRI 13(2):269-76, 2001. [2] Jenkyn et al., J Biomech. 36(12):1917-21, 2003. [3] Uffmann et al., NMR Biomed. 17(4):181-90, 2004.

Acknowledgments This study was funded by NIH Grant # and EB00812, EB01981 and CA91959, Association Française contre les Myopathies and the Philip foundation.