Mechanical Properties of Relaxed and Contracted Thigh Muscles using Magnetic Resonance Elastography

1 Sabine Bensamoun, 1 Stacie Ringleb, 1 Qingshan Chen, 2 Richard Ehman, 1 Kai-Nan An
1 Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, Rochester, MN 55905
2 Department of Radiology, Mayo Clinic College of Medicine, Rochester, MN 55905

INTRODUCTION
The determination of the mechanical properties of muscle in passive and active conditions may characterize the physiological changes within the muscle [1]. Thus, the measurement of the in vivo mechanical properties of muscles is clinically necessary in order to understand the transformations that occur in muscle with pathologies and treatments. A few techniques (palpation, sonoelastography, elastography) allow measurement of the in vivo stiffness of soft tissues but, they are restricted in depth and field of view. Magnetic Resonance Elastography (MRE) is a non-invasive phase contrast MR technique capable of quantifying the in vivo mechanical properties and imaging the entire spatial distribution of muscle elasticity [2]. The purpose of this study was to measure the mechanical properties of the vastus lateralis (VL), vastus medialis (VM) and sartorius (Sr) muscles in a relaxed and contracted position.

METHODS
Fourteen volunteers (4 males and 10 females, mean age 25.2 ± 1.78) 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. Shear waves were applied to the thigh muscles with a mechanical (n=7 VL, n=10 VM, n=9 Sr) or pneumatic driver (n=5 VL, n=4 VM, n=4 Sr). Each driver was positioned on the thigh 1/3 of the distance from the patellar tendon to the greater trochanter. The mechanical driver was composed of a coil of copper wire with a hollow aluminum core driven with an alternative current of variable potential, induced shear waves into the thigh muscles at 120Hz. The pneumatic driver was composed of a thin silicone tube connected to a remote pressure driver (i.e., a large active loudspeaker). This system created a time varying pressure wave, which caused the tube around the thigh to expand and contract with the remote driver at 90 Hz. A custom-made Helmholtz surface coil was placed around the thigh. Axial images were obtained and oblique scan planes passing through the VL, VM and Sr were selected from these images. MRE data were collected with a gradient echo technique. The wavelength (λ) was measured in each of the four offsets and the stiffness was calculated (μ = ρ*λ²*P², where ρ = 1000 kg/m³).

RESULTS AND DISCUSSION
Figure 1 showed shear waves propagating in the vastus medialis (VM) and sartorius (Sr) muscles.

Fig. 2. Representation of the muscle stiffness in a relaxed and contracted positions

The shear modulus measured at rest (Fig. 2) in the vastus lateralis, vastus medialis and sartorius were 3.73 ± 0.85kPa (VL), 3.91 ± 1.15kPa (VM) and 7.53 ± 1.66kPa (Sr). The stiffness of the sartorius is significantly higher than the vastis stiffness. This may indicate that that the propagation of the waves was influenced by the muscle fiber orientation. The fiber orientation is unipennate in the vasti, while it is longitudinal in the sartorius.

During a thigh contraction of 10% MVC, the stiffnesses of the VL and the VM were 6.11 ± 1.15kPa (P<0.1) and 4.83 ± 1.68kPa, respectively. A faster increase of stiffness was measured for the VL than for the VM. This may be due to a larger percentage of fast fibers in the VL enabling a faster contraction.

With a level of 20% MVC, the stiffnesses of the VL and the VM were 8.49 ± 4.02kPa and 6.40 ± 1.79kPa (P<0.1), respectively. For both levels of contraction, the stiffness of the sartorius muscle did not exhibit any changes. This may be due to the leg press, which solicits the knee extensors while the sartorius flexes the knee.

CONCLUSIONS
We concluded that the MRE technique is able to quantify the stiffness of thigh muscles. Furthermore, the wave length was sensitive to the morphology and fiber composition in each muscle. The MRE technique could be a helpful means to non-invasively improve diagnoses and to understand the effects of pathologies such as Graves Disease which effects proximal muscle strength by changing the composition of the muscle fibers [3].

REFERENCES

ACKNOWLEDGEMENTS
This study was funded by NIH Grant # and EB00812, EB01981 and CA91959 and Association Française contre les Myopathies (AFM). Special thanks to Thomas Hulshizer and Philip Rossman of the MR Research Laboratory for their technical assistance.