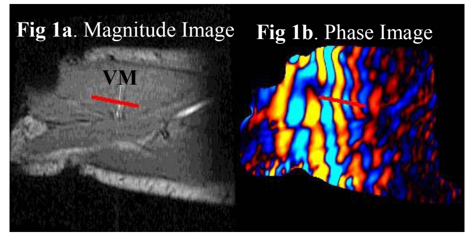
Mechanical properties of thigh muscle from childhood to adulthood with Magnetic Resonance Elastography (MRE) technique

L. Debernard[1], L. Robert[2], F. Charleux[2], and S. F. Bensamoun[1]

[1]Biomécanique et Bioingénierie, UMR CNRS 6600, Université de Technologie de Compiègne, Centre de Recherches de Royallieu, Compiègne, France, [2]ACRIM-Polyclinique Saint Côme, Compiègne, France

Introduction

Muscle tissue is strongly solicited during all the life. The structural and functional properties of the muscle can be affected by its perpetual stretches and contractile activities but also by specific muscle pathologies. Imaging techniques can determine the muscle composition and morphological properties but no quantification of the mechanical properties is recorded with such imaging techniques. Magnetic Resonance Elastography technique is capable of giving the morphological and the mechanical parameters for the same exam, allowing a complete characterization of the muscle tissue. The purpose of this study is to characterize the Vastus Medialis muscle stiffness from childhood to adulthood.



Methods

Seven children (6 boys and 1 girl, mean age = 10.9 ± 0.6), nine young adults (5 males and 4 females, mean age = 26.4 ± 1.7) and ten middle-aged adults (3 males and 7 females, mean age = 55.2 ± 2.39) underwent a MRE test. The experimental protocol was already published by Bensamoun et al. (1) and is briefly summarized here. The subject lays supine on a leg press inside a 1.5T MRI machine (GE) with the right leg resting in a custom MR compatible leg press, capable of measuring the applied load. Then, a pneumatic driver consisted of a remote pressure driver connected to a long hose was wrapped and clamped around the subject's thigh. Shear waves were induced through the thigh muscles at 90Hz (*f*). MRE images were collected with a gradient echo technique, a 256x64 acquisition matrix and a 24cm field of view. Four offsets were recorded and the scan time was decreased for children using a TR/TE of 100 ms/minimum full instead of the 200 ms/minimum full used for the adult groups.

MRE technique provides anatomical images of the VM muscle (fig. 1a) as well as phase images (fig. 1b) showing the shear wave displacement inside the muscle. A red profile was manually placed in the direction of the wave propagation allowing to measure two mechanical parameters: the muscle shear modulus (μ) obtained from the wavelength (λ), with the following equation ($\mu = \rho\, \lambda^2 f^2$, with ρ=1000 kg/m^3 the muscle density), and the attenuation coefficient (α) calculated from the shear wave displacement amplitude in function of the distance. An exponential fitting curve $Ae^{-(\alpha d)}$ is used to determine the attenuation coefficient, with A and d representing the displacement amplitude value and the distance along the profile, respectively. The mechanical parameters (μ and α) were measured when the VM muscle was relaxed and contracted (10% and 20% MVC) for each group. The Cross-Sectional Area (CSA) for each subject was calculated so as to normalize the shear modulus. Statistical analysis was performed with ANOVA and t tests.

Fig 2

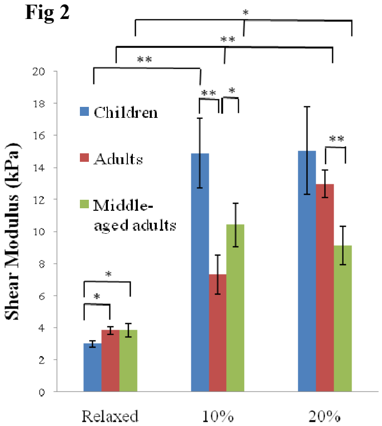
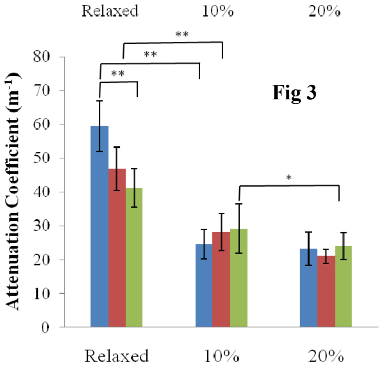


Fig 3



Results

The CSA calculated for the children, young and middle-aged adults were 12.15 ± 1.27 cm^2, 22.38 ± 1.36 cm^2 and 18.52 ± 1.46 cm^2, respectively.

Figure 2 showed the evolution of the shear modulus (μ) in function of the level of contraction from childhood to adulthood. Between the relaxed and 10% MVC, all the groups showed a significant ($p<0.05$) increase of μ, while between 10% and 20% MVC the muscle stiffness behavior is different for each group. Indeed the shear modulus at 20% MVC reached a plateau for the children, decreased significantly ($p<0.1$) for the person in his fifties, and showed a linearly increase ($p<0.05$) for the young adults. In a relaxed state, the children had a significant ($p<0.1$) lower shear modulus (about 1 kPa) compared to adults which have similar stiffness. However, at 10% MVC children revealed the highest μ (14.9 kPa). In addition, the normalization of the shear modulus to CSA showed the same tendency.

The same behavior for the attenuation coefficient (Fig. 3) was found for all ages, i.e a significant ($p<0.05$) decrease between the relaxed state and 10% of MVC which is maintained constant at 20% of MVC. Moreover, at rest a significant ($p<0.05$) difference was found between children and person in his fifties.

Discussion

The results showed that the muscle contractile properties are different in function of age. Indeed, at 10% MVC, person in his fifties as well as children have already reached his maximal stiffness, meaning an important muscle fibers recruitment, compared to young adults that realize a progressive recruitment according to the degree of contraction.

The stiffer muscle exhibited by middle age adults, may be due to fatty tissue infiltration between muscle fibers, to cross-links changes (3) and to an increase of slow fibers, requiring a maximum recruitment of fast fibers to reach a small level of contraction.

The incredible increase of shear modulus produced by children may be due the unorganized muscle structure caused by the fibers growing and the on-going structural organization such as muscle sheath. As a consequence, childhood muscle is unable to recruit in a proper way the fibers to perform a small contraction. Instead, children muscles tend to recruit all the fast fibers leading to a high shear modulus.

This study demonstrated that MRE technique is sensitive enough to detect changes in contractile properties from childhood to adulthood, and it will be extended to persons in his seventies in order to have a complete characterization of VM muscle stiffness through lifetime.

References

[1] Bensamoun et al., JMRI 23(2): 242-7, 2006. [2] Domire et al., J Appl Biomech 25(1): 93-7, 2009. [3] Avery et al., Scand J Med Sci Sports 15(4): 231-40, 2005.