IN SILICO EVALUATION OF THE LATERAL TRANSMISSION OF MUSCLE CONTRACTION FORCE

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Introduction

Aging represents a physiological condition that is usually associated with the reduction of muscle mass and performance. It has been hypothesized that the decline of contraction capability is due also to the impaired ability of a muscle to laterally transmit the generated force. This may be caused by alterations of the extra-cellular matrix (ECM).
The ECM contribution in the lateral transmission of contraction force is here assessed by a numerical approach based on the Finite Element Method (FEM), also considering the effects of aging.

Methods

Geometric and mechanical properties of ECM at the level of muscle bundles have been deduced from biopsies of vastus lateralis in young (mean age 21 y.o.) and elderly (mean age 67 y.o.) subjects [1].

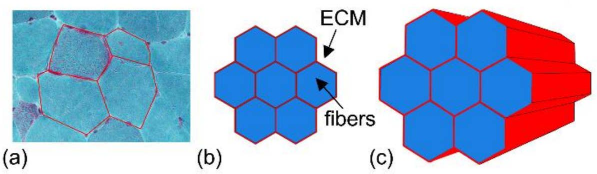

Figure 1: Transverse section of a biopsy sample with ECM outlined in red among muscle fibers (a); Transverse section (b) and 3D view (c) of a simplified geometric reconstruction of a muscle bundle composed of fibers (blue) and ECM (red).

Starting from experimental data, different FE models were built for young and elderly subjects to simulate muscle bundles formed by few fibers connected through the ECM (Fig.1). To describe the contractile behavior of muscle fibers, the three element Hill based formulation developed by Marcucci et al. was adopted [2]. The ECM mechanical behavior was described through an isotropic hyperelastic neo-Hookean constitutive model.
Different numerical analyses were carried out replicating at the scale of a bundle the experimental protocols developed by Huijing et al. [3] and Ramaswamy et al. [4] on whole muscles. These protocols were aimed at assessing the persistence of contraction force transmission following the cut of one or more muscular fibers.

Results and discussion

The results of the analyses referring to the experimental tests performed by Ramaswamy et al. [4] are reported below. In this simulated experiment, the bundle is fixed at the proximal side and in an intermediate section using a yoke apparatus (Fig. 2). The fibers are activated, and the amount of contraction force transmitted at the proximal side is evaluated.

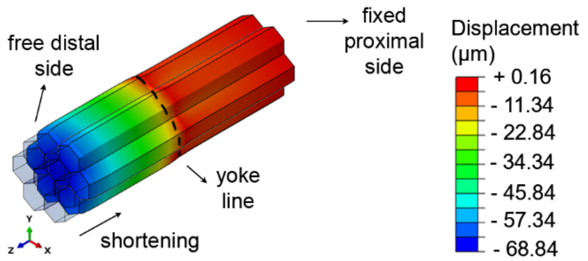

Figure 2: Contour of the longitudinal displacement (z-direction) for the numerical simulation of the yoke apparatus test protocol on a bundle of 1000 µm.

By comparing the results obtained with the FE models for young and elderly subjects, a different drop in the transmitted force is observed, with a higher reduction for the elderly group. The difference is consistent with the maps of the force-length function (Fig. 3), showing that the region of fibers with active stress much lower than the maximum isometric value (<0.8) is more extended in the case of elderly than in the case of young bundles. This can be explained by the lower shear stiffness of ECM for elderly bundles, also related to its higher thickness.

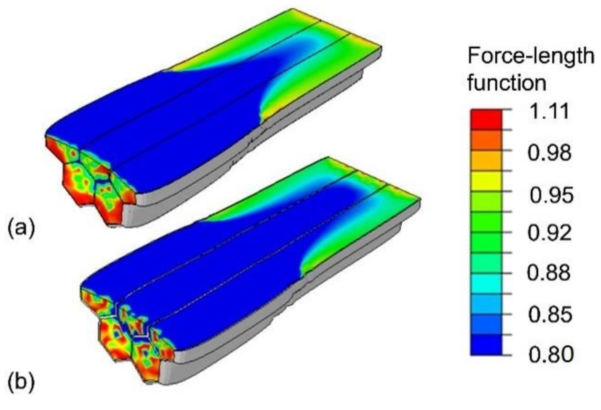

Figure 3: force-length function for young (a) and elderly (b) subjects. The values less than or equal to 0.8 are colored in dark blue.

References

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2. Marcucci et al., Biomech Model Mechanobiol, 16:1833-1843, 2017.
3. Huijing et al, J Exp Biol, 201:682-691, 1998.
4. Ramaswamy et al, J Physiol, 589(5):1195-1208, 2011.