COMPUTATIONAL SIMULATION OF THE ACTIVE BEHAVIOUR OF MOUSE ROTATOR CUFF MUSCLES

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Introduction

The rotator cuff is the group of muscles and tendons that act to stabilize the shoulder and allow for its extensive range of motion. The set of these tissues surrounding the joint keeps the head of the upper arm bone firmly within the shallow socket of the scapula. Due to the frequent lesions among the tendons involved in this joint, there is still a challenge for orthopaedic surgeons to avoid muscle degeneration and chronicity [1]. In this work, a computational model for simulating the passive and active behavior of the infraspinatus and supraspinatus muscles of an animal model is presented. The model considers a detailed implementation of the muscle architecture based on photon confocal microscope images.

Material and Methods

The experimental study was conducted in accordance with the provisions of the European and Spanish legal normative (RD53/2013). Isolated supraspinatus and infraspinatus (n=3) mouse (wild-type (WT, C57BL/6J)) muscles and scapula were prepared to scan using the Zeiss LSM 880 NLO two photon confocal microscope. The computational model was developed in the Comsol Multiphysics finite element software considering the formulation proposed in [2] by means of a strain density energy function:

$$\Psi = \Psi_{vol}(J) + \overline{\Psi_p}(\overline{\boldsymbol{C}}, \boldsymbol{N}) + \overline{\Psi_a}(\overline{\boldsymbol{C}_e}, \overline{\lambda_a}, \boldsymbol{N}) \qquad (1)$$

where J is the determinant of the strain deformation gradient ($\boldsymbol{F}$), $\overline{\boldsymbol{C}}$ is the isochoric part of the right Cauchy-Green deformation tensor, $\overline{\boldsymbol{C}_e}$ is the equivalent for the elastic component in the muscle fiber, $\overline{\lambda_a}$ is the active stretch of the fiber and $\boldsymbol{N}$ is the fiber orientation.

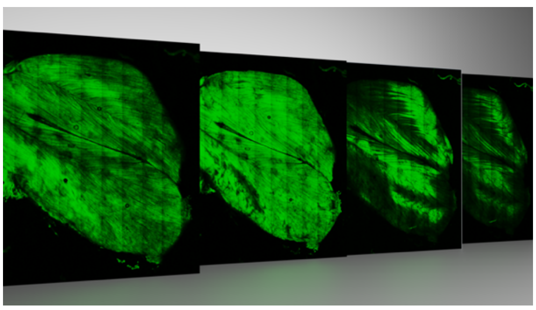

Figure 1: Four cutting planes images using Epiplan-Neofluar 10x0.25 HD M27 obj. HeNe: 633 nm laser.

Results

In Figure 1, the images obtained by the microscope are presented. Those images were used to determine the fiber orientation that allowed to define the anisotropy of the tissue. These orientations were obtained (Figure 2) for the infraspinatus muscle using a flow method analogy in the finite element program. Figure 3 also represents the active stretch along these fibers when muscle is activated isometrically.

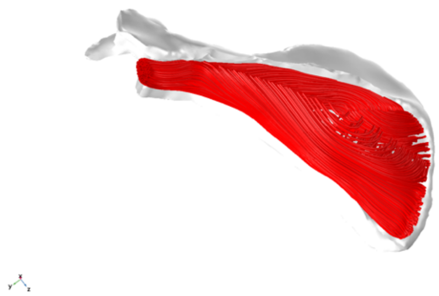

Figure 2: Fiber orientation for the infraspinatus muscle.

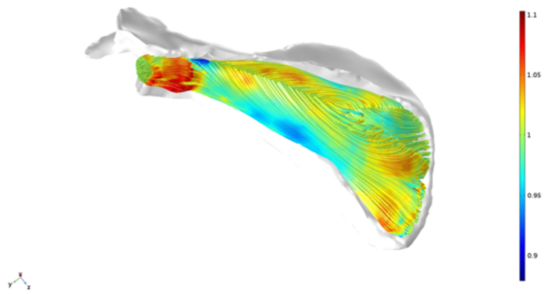

Figure 3: Active stretch plotted along the muscle fibers at the maximum developed force point.

Discussion

The computational model developed is able to reproduce the experimental behavior of the muscles from a previous work regarding the active force at both ends of the tissue. The complex contractile shortening and lengthening pattern of the pennated muscle fibers can be analyzed during different contractile conditions.

References

1. Shirasawa et al, Sci Reports, 7:1, 2017.
2. Hernández-Gascón et al, J Theor Biol, 335:108-118, 2013.

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