XIV Jornada de Jóvenes Investigadores/as del I3A

Computational simulation of muscle fiber contraction: unraveling the structural function of the endomysium

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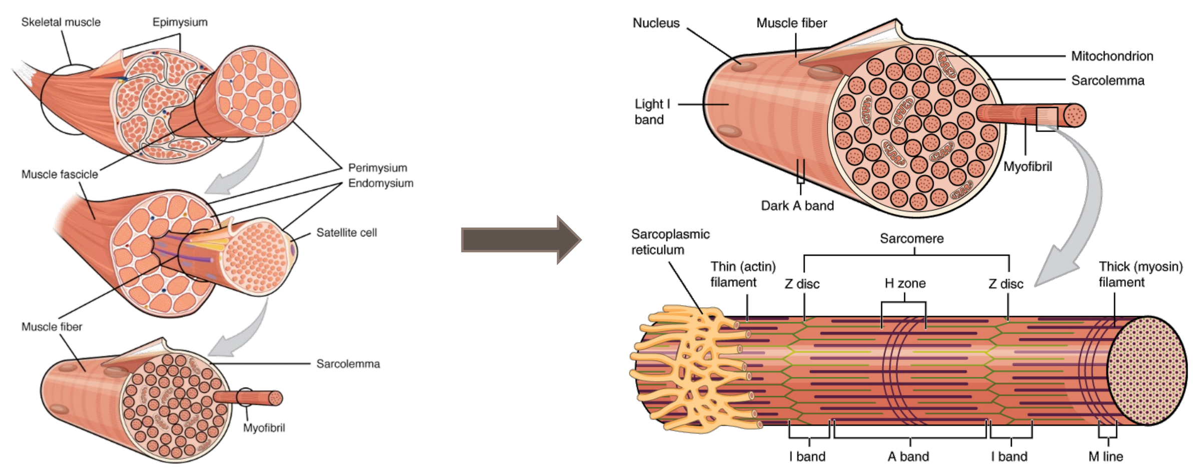
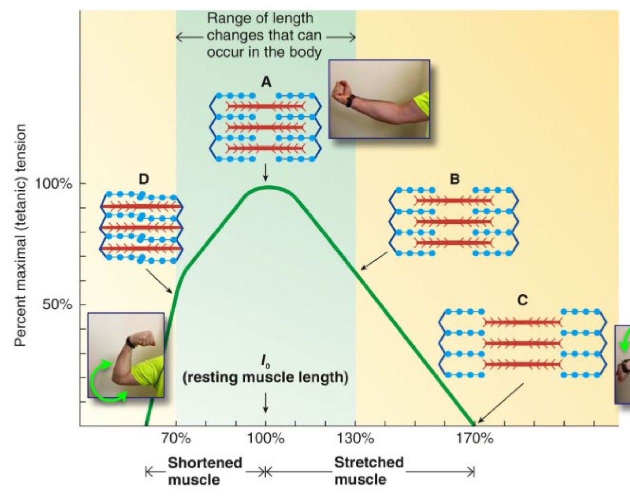
INTRODUCTION



Understanding the variation in the level of active force generated in muscle fibers as a function of different elongations

Analyze the role of the endomysium in active force generation

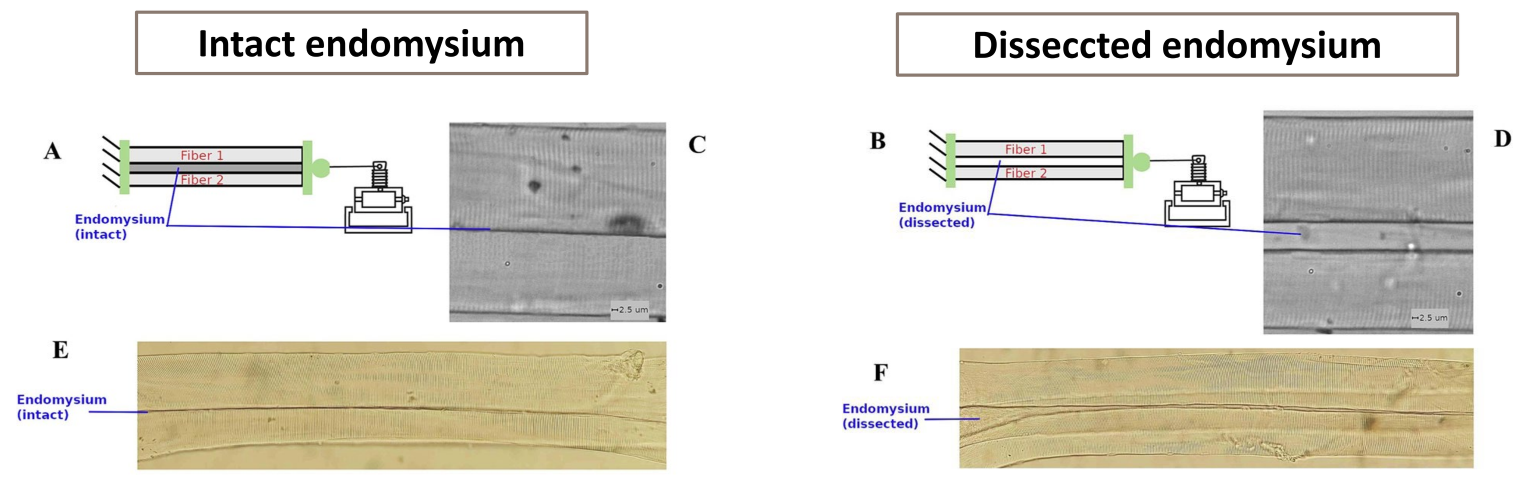
COMPUTATIONAL MODEL



MATERIAL AND METHODS

Experimental test

Following Danesini et al. (2024), fibers from the extensor digitorum longus (EDL) muscles were extracted from two rats. Passive and active forces were measured in two cases:



Hyperelastic model incorporating the active function

Strain energy density function (muscle fiber contraction)

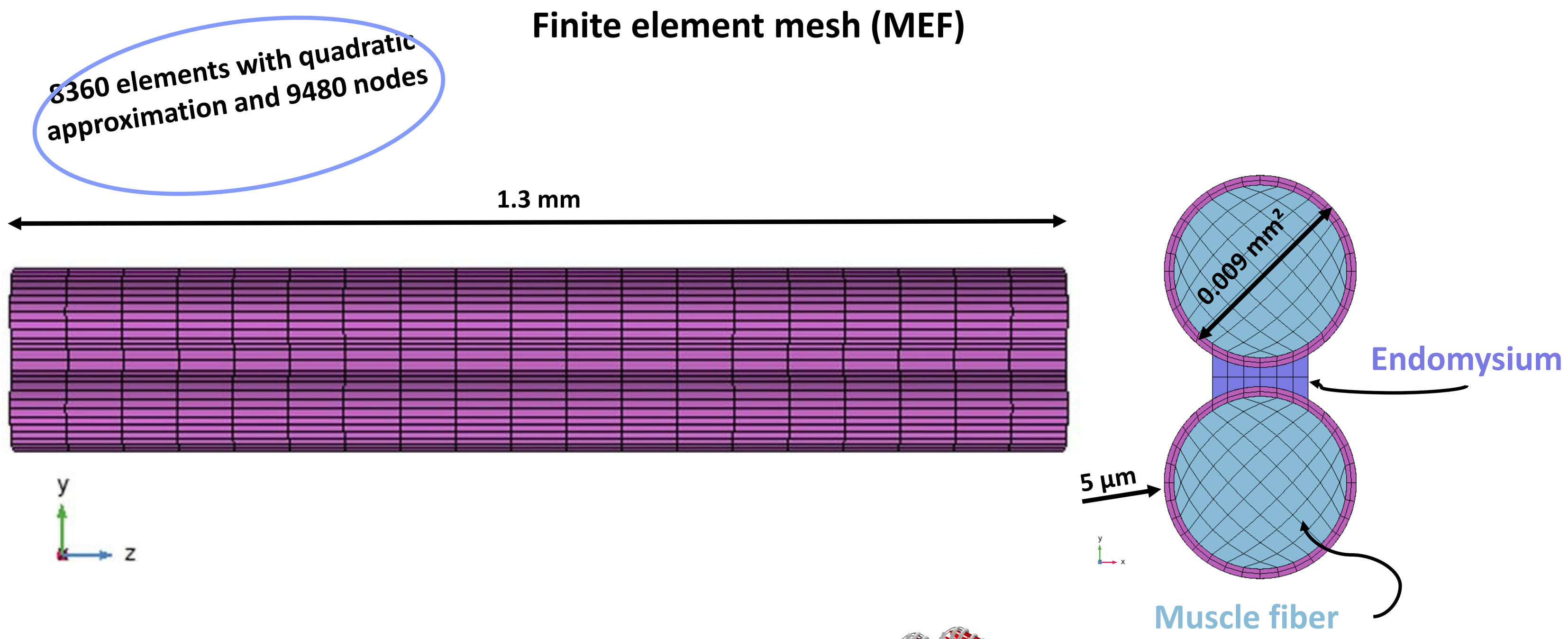
$$\Psi = \Psi_{vol} + \Psi_{endomysium} + \Psi_{fiber}$$

$$\Psi_{\text{endomysium}} = \frac{C_3}{C_4} e^{C_4 (I_4 - I)} \qquad \Psi_{\text{fiber}} = \frac{1}{2} P_0 (J_4 - 1)^2 f_{\text{train}}(t) f_\lambda(\lambda)$$

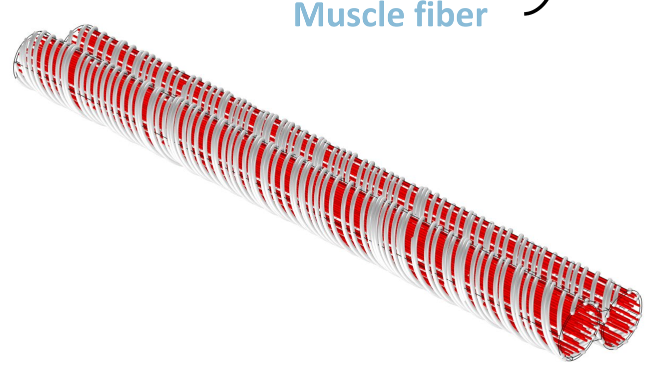
- C_3 = 0.001 MPa
- C_4 = 0.87 MPa
- $I_4 = \lambda^2$

Our computational model:

Finite element mesh (MEF)

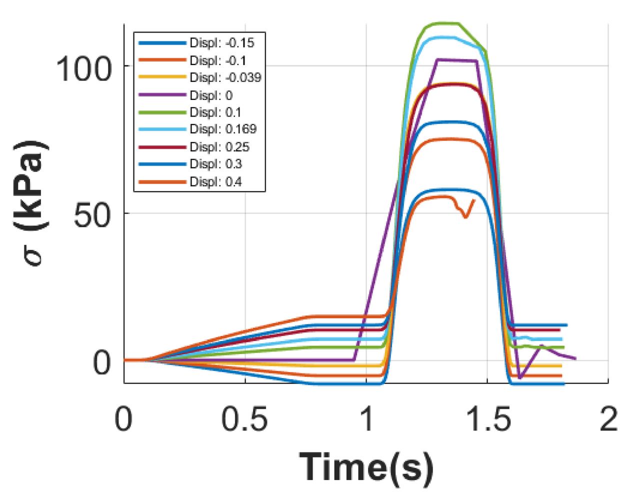


The endomysium was modeled as a **hyperelastic and transversely isotropic material**, with a **preferred collagen fiber orientation at 55º** with respect to the longitudinal axis

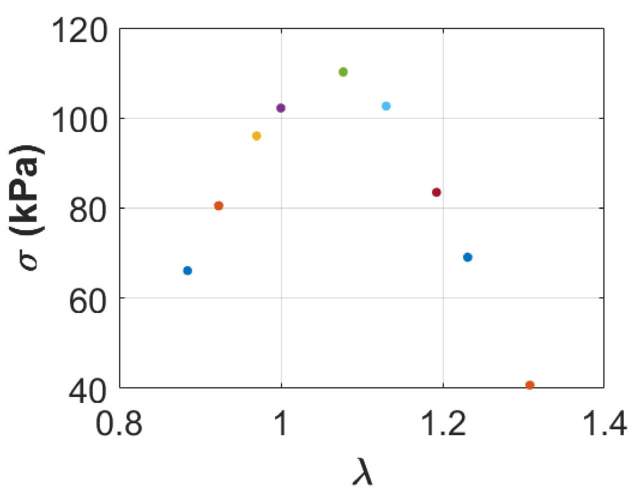


RESULTS

Active stress

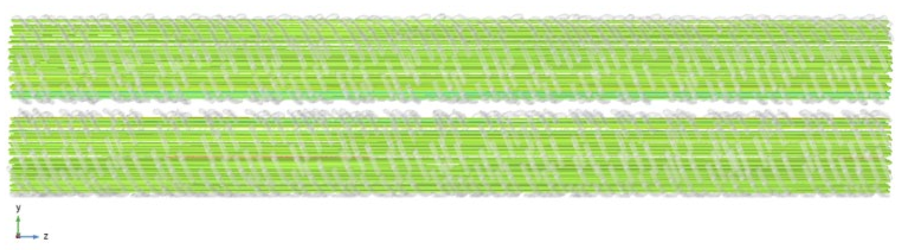


Evolution of the active tension generated by the muscle fiber during activation as a function of elongation



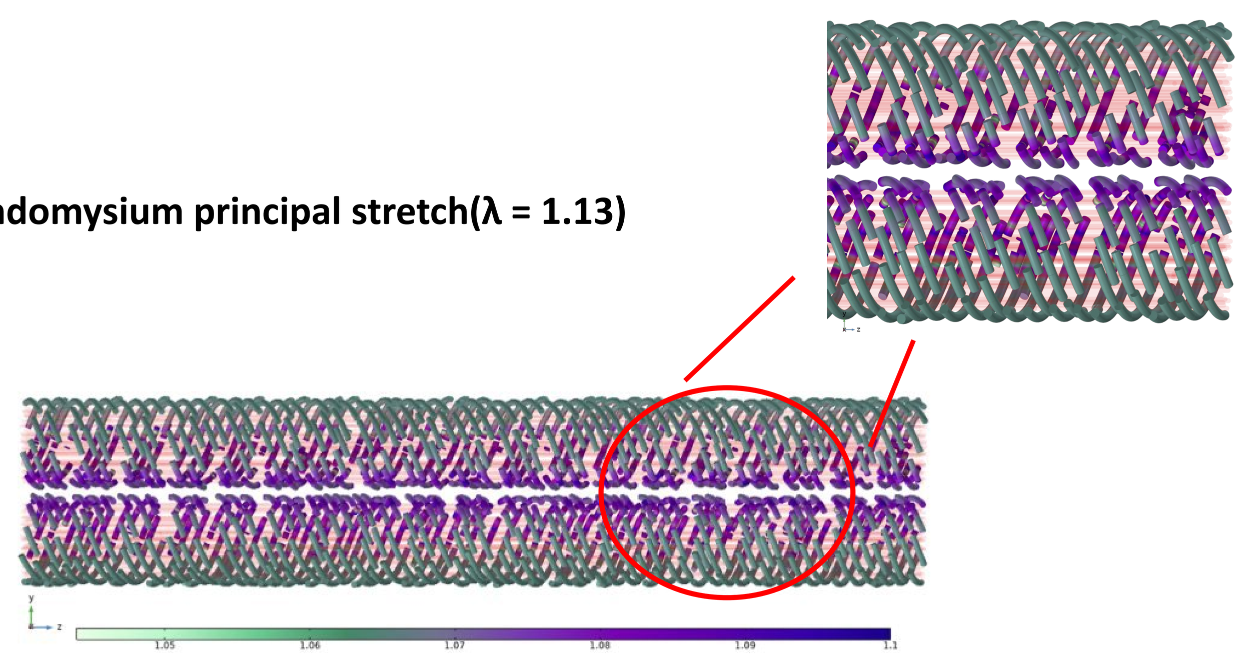
Stress (kPa) generated by the fiber due to the different displacements imposed prior to activation

Muscle fiber's elongation



Muscle fiber active stretch (λ = 1.13)

Fiber endomysium principal stretch(λ = 1.13)



CONCLUSIONS

- The results obtained show that the presence of collagen fibers in the endomysium significantly influences force transmission in muscle tissue.
- Although the formulation used for muscle fiber activation includes the effect of overlap between actin and myosin filaments, this factor does not fully explain the experimentally observed behavior [2].
- The analysis of the total tension generated shows that it reaches its maximum value when the collagen fibers of the endomysium are aligned and subjected to stretch, highlighting its key structural role.

REFERENCES

[1] PURSLOW P.P., Strain-included reorientation of an intramuscular conective tisue network: implications for passive muscle elasticity. J. Biomech. 22:21-31, 1989

[2] DANESINI, P. C., HEIM, M., TOMALKA, A., SIEBERT and T., ATES, F. Endomysium determines active and passive force production in muscle fibers, J. Biomech. Doi: 168:112134, 2024.

[3] GRASA, J., SIERRA, M., LAUZERAL, N., MUÑOZ, M.J., MIANA-MENA, F. J., CALVO, B., Active behavior of abdominal wall muscles: Experimental results and numerical model formulation, J. Mech. Behav. Biomed. Mater. 61, 2016

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