UNDERSTANDING THE BIOMECHANICAL SIGNIFICANCE OF EXTRACELLULAR MATRIX FOR FUNCTIONAL MUSCLE FORCE USING A BIO-INSPIRED ARTIFICIAL MUSCLE

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Introduction

The extracellular matrix (ECM) in muscle fibres consists of three layers: the epimysium, the perimysium, and the endomysium. The ECM structurally maintains the morphology and limits the expansion of skeletal muscle, which affects the functional transmission of muscle force [1],[2]. The biological and biomechanical significance of ECM is not fully understood. This work aims to use a biomimetic approach through modelling an electro-hydraulic synthetic muscle, a Peano-HASEL actuator (PHA) [3], to understand the effect of the ECM on functional muscle force. Specifically identifying the ECM's effect on damping, force-length relationship, and force-velocity relationship.

Methods

A validated 2D finite element model of Peano-HASEL artificial muscle fibre, built in COMSOL Multiphysics 6.1 (Cambridge, UK) [5], was used to evaluate the motion, force-length relationship, and force-velocity relationship. A biomimetic approach was used to design the artificial muscle that mimics the muscle and the constraint that mimics the ECM, which in turn may contribute to understanding the biomechanical significance of ECM. As shown in Figure.1a, muscle fibre is surrounded by the ECM. Similarly, in Figure.1b, a constraint like ECM was introduced into the artificial muscle fibre model. Loads from 0 to 21N (1.5N interval) were applied at point A in the arrow direction.

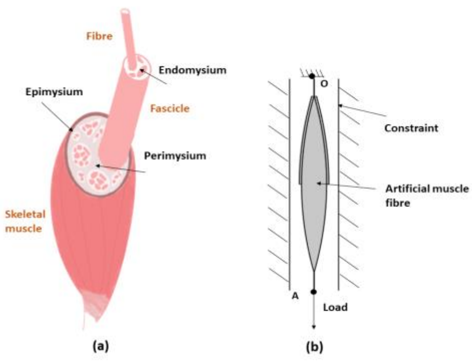

Figure 1: Biomimetic approach (a). Skeletal muscle structure (b). Artificial muscle fibre with ECM

Results

Figure.2 shows the finite element results of artificial muscle fibre models with ECM. Specifically, Figure.2a shows the displacement-time curve under the no-load condition, which shows the damping response of the artificial muscular system to stimulus. As shown in Figure.2a, ECM models oscillate to rest faster than no constraint models, which means less vibration. Figure.2b & 2c show the force-length and force-velocity characteristics, respectively. The output strain and contraction velocity decrease with the tightening of the ECM because the ECM limits fibre expansion, while the output force is not affected.

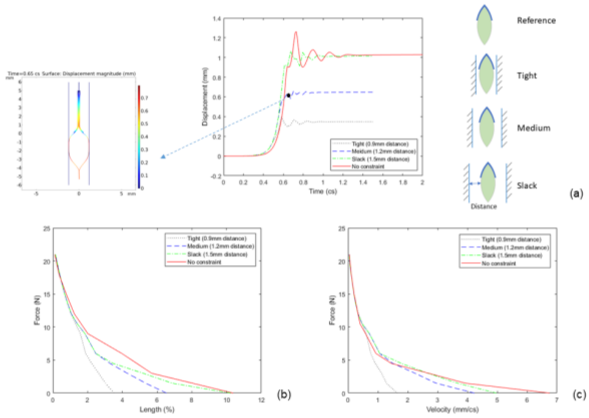

Figure 2: Finite element results of artificial muscle fibre models with ECM (a). Displacement-time curve under no-load condition. Four different conditions used are illustrated on the right. The state of artificial muscle fibre at a specific time is shown on the left. (b). Force-length curve (c). Force-velocity curve

Discussion

The ECM greatly affects damping characteristics, output strain and contraction velocity because the interaction between the artificial muscle fibre and ECM. Specifically, damping ratios of ECM models are 10 times lower; maximum output strains decrease by 4% to 6%; maximum contraction velocities are 1.5 to 5 times lower in comparison with the no constraint model.

Aging causes reduced output force and contraction velocity in the force-velocity curve [4]. The results in this work show that as the extracellular tightens or stiffens, the contraction velocity of the muscle is reduced, indicating the shrink or tightening of the ECM may also lead to changes in force-velocity relationship in aging muscle.

References

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