APONEUROSIS INSPIRED VARIABLE STIFFNESS FOR SOFT ROBOTICS

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Introduction

Biomechanics and Robotics are synergistic disciplines. Soft Robotics is closing the gap between the two by using compliant materials and new technologies [1,4] and may provide avenues to explore biomechanical principles in relatively simpler engineering systems.

Lateral deformation of the aponeurosis during muscular contraction has been shown to affect the stiffness response of the aponeurosis and possibly connected tendons, imbuing them with *variable stiffness* (VS)[2,3]. In Robotics, VS is a desired actuation feature allowing transient and controllable dynamics responses which can facilitate adaptivity to novel interactions [5]. Robotic VS mechanisms, while efficacious, can be complex and heavy, with large form factors [6,7].

We use silicone elements to mimic tendon/aponeurosis and provide static lateral displacement to mimic transverse loading to inform relatively minimalist VS mechanisms in robotic locomotion and provide insight into the biomechanical principles. We investigate the impact of varying lateral displacement and the length of the region laterally loaded on the force-displacement response of the element under tensile loads.

Methods

Silicone elements of shore hardness 40 (Cure on Mold Max 40) are molded with geometry: 100mm x 20mm x 4mm. L is the length of the tendon 100mm. Each element has tabs on either side of its width of length, l, that can be clamped and displaced using a continuous stretching mechanism. We vary lateral displacement, d, from 0 – 15mm in 5mm increments and load the element in longitudinal tension with a mechanical testing machine (Instron 3344) to 75% strain of the reference configuration, measuring longitudinal force production, F_{lo}.

Results

Our data shows *decreasing* force production observed for *increasing* d (Fig.1, Table.1). The low strain, "toe" region was largely unaffected by the lateral deformation, with changes seen at higher strains. The reference stiffness is increased with a larger l and the effect of lateral displacement on stiffness is also enhanced.

Discussion

In biological literature, the measurements are made on or very close to the aponeurosis and show a stiffness *increase* with d [4,5]. Future work will look to isolate the aponeurosis region to understand further our observations.

In comparison to biological tendon/aponuerosis tissue, with high anisotropy and multi scale dynamics, silicone is isotropic and relatively simple. This may have a large effect on the impact of lateral loading.

In conclusion, our data suggest that laterally loading silicone elements may be useful for variable stiffness in robotics, but indicate an inverse trend in this change when compared to biological analogs.

Figure and Tables

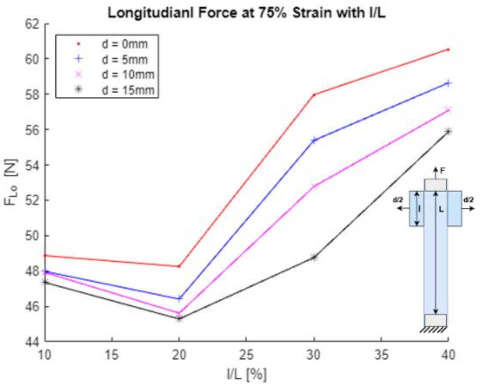

Figure 1: The maximum F_{lo} developed for each l/L tested. There is an overall increase in force, indicative of increasing stiffness and as d is increased this maximum force is lowered.

l/L	$F_{max}(d = 0mm)$	$F_{max}(d = 15mm)$
40%	60.5464 N	55.8956 N
30%	57.9772 N	48.7578 N
20%	48.2521 N	45.2853 N
10%	48.8686 N	47.3551 N

Table 1: Variations in maximum force production (at 75% longitudinal strain) for tested l/L ratios at the two extremes of lateral displacement.

References

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