SUBMAXIMAL SOLEUS FORCE LENGTH CHARACTERISTICS WITH AGING

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Introduction

Older adults use more energy to walk than young adults. Age-related changes in muscle-tendon units (MTU) could cause reduced muscle power and force economy. For example, reduced Achilles tendon stiffness in older adults leads to shorter, less economical muscle operating lengths [1]. But the muscle itself may also be a factor; loss of type 2 fiber percentage and muscle mass as well as increased connective tissue stiffness could all contribute to a reduced force output per muscle activation in old versus young adults and lead to increased metabolic energy expenditure. Comparative literature has shown that in healthy, young muscle there is a leftward shift of optimal muscle length with increasing activation [2] affording a potential mechanism to keep muscles operating in proximity to optimal length (l_0) despite an average shortening against series elastic tissues during more demanding tasks (e.g., faster walking). Here, we sought to examine whether this activation dependent shift in optimal length is retained in aged human soleus muscle. We hypothesized that older adults would have stiffer muscles and a smaller leftward shift in optimal length with increasing activation.

Methods

Two young (1M, 1F, 20 ± 1.4 years), and two older adults (1M, 1F, 66.5 ± 2.1 years) performed a minimum of 3 plantarflexion (PF) contractions at 5 ankle joint angles (20°PF, 10°PF, 0°, 15° dorsiflexion (DF), maxDF) and 4 activations (0, 33, 66, 100% of max voluntary contraction [MVC]). Torque at the ankle was measured using a dynamometer while prone with the knee bent 120° to isolate the soleus muscle. Muscle activity and muscle lengths of the soleus were measured using electromyography (EMG) and ultrasound respectively. MVC were performed with visual torque feedback while 33% and 66% contractions were performed with EMG feedback. Two minutes of rest were taken between every contraction. For the passive curve, torque and length were measured in increments of 5° from 10°PF to maxDF after 45 seconds of resting in this position to mitigate history-dependent effects. Soleus active muscle force (F_{sol}^{act}) was calculated as follows.

$$F_{sol}^{act} = \frac{\tau_{total} - \tau_{pedal}}{r_{ank} \cdot \cos(\theta_{penn})} - F_{sol}^{pass}$$

τ_{total} is total torque, τ_{pedal} is pedal torque, r_{ank} is ankle moment arm, θ_{penn} is pennation angle, and F_{sol}^{pass} is passive force at the length during contraction. A 2nd order polynomial was least squares curve fit to the data for the active curves, and an exponential curve for the passive data [2]. Muscle stiffness was calculated as the slope at l_0.

Results and Discussion

As expected, the normalized muscle stiffness was greater for older adults (Y: 0.118, O: 0.541). Contrary to our hypothesis, both Y and O adults exhibited a rightward shift in l_0 at the highest activations (Y:100%: 1.0, 66%: 0.896, 33%: 0.888, O: 100%: 1.0, 66%: 0.903, 33%: 0.943). The location of l_0 is highly dependent on the curve fitting method and the amount of data on the descending limb. Previous literature has reported some participants cannot reach the descending limb which could explain our observed opposite shift in l_0 compared to other studies [2]. By combining data from more participants and further refining our fitting procedure, we hope to verify our measured shifts in l_0. The absolute force-length curves for the older group had lower maximum force (Y: 6155.5 N, O: 2904.1 N) and shorter optimal length (Y: 49.5 mm, O: 40.65 mm). Lower maximum force with aging has been reported previously.

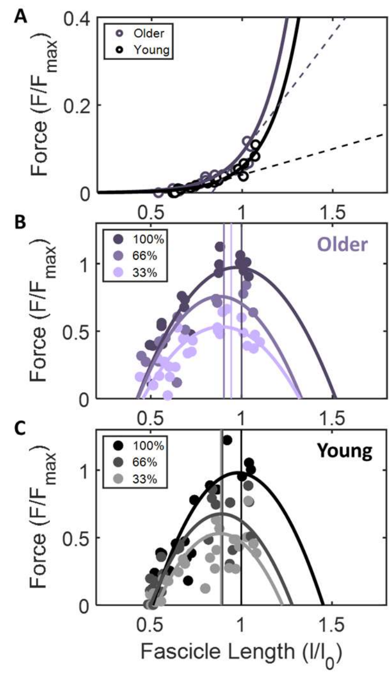

Figure 1. A. Average passive force-length curve of young (black) and older (purple) adults. The dashed lines represent respective muscle stiffness. B. Average force-length curves for 100%, 66%, and 33% activation from older adults. The vertical lines represent l_0 at respective activation. C. Average force-length curves for 100%, 66%, and 33% activation from young adults. The vertical lines represent l_0 at respective activation.

Based on these preliminary data, we conclude older adults have more stiff muscles and altered activation dependent shifts in l_0 compared to young.

Significance

Characterizing age-related shifts in muscle FL curves is a critical aspect to understanding the increase in energy cost of walking for older adults and may inform training interventions and the design of assistive devices to address the mechanical and metabolic effects of aging.

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