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Estimating Skeletal Muscle Forces in vivo: A Shear Wave Elastography Approach

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INTRODUCTION:

Modelling and simulation of skeletal muscles are essential to understand neuromuscular diseases better and to improve treatment strategies. However model validation with direct muscle force measurements at the respective tendons intra-operatively [e.g. 1] is not straightforward and not feasible for many scenarios in particular for healthy muscles.

Ultrasound shear wave elastography (SWE) was shown to represent in vivo active [2] and passive [3] muscle mechanics.

We hypothesized that changes in mechanical properties of the Biceps Brachii muscle (BB) can be detected with SWE both in passive state and during isometric ramp contractions. We investigated whether SWE can reveal individual muscle mechanics in relation to joint function.

MATERIALS AND METHODS:

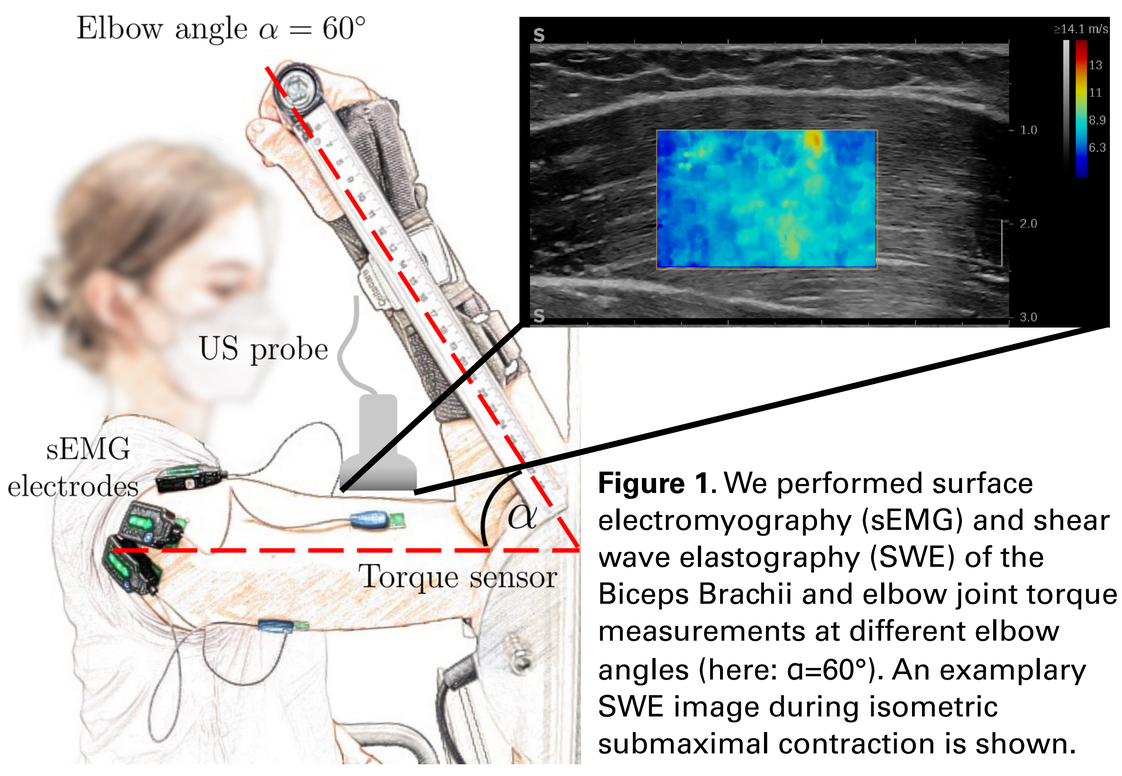

Figure 1. We performed surface electromyography (sEMG) and shear wave elastography (SWE) of the Biceps Brachii and elbow joint torque measurements at different elbow angles (here: α=60°). An examplary SWE image during isometric submaximal contraction is shown.

- SWE, surface electromyography (sEMG) of the BB, and isometric elbow torque measurements at 60°, 90°, 120°, 150°, and 180° elbow angles (Fig. 1)
- 14 healthy volunteers (7 females, 28.07 ± 5.06 years)
- Measurements at rest, during maximum voluntary contractions (MVC), and isometric ramp contractions (up to 25%, 50%, 75% of MVC torque) were performed.
- BB length was measured using B-mode ultrasound (US) imaging

RESULTS:

BB muscle length increased with increasing elbow angle from flexion to extension ($p<0.001$)

Passive shear elastic modulus increased with increasing elbow angle from flexion to extension ($p<0.001$)

During sub-maximal isometric contractions, both elbow angle and activity level affected shear elastic modulus significantly ($p<0.001$, Fig. 2)

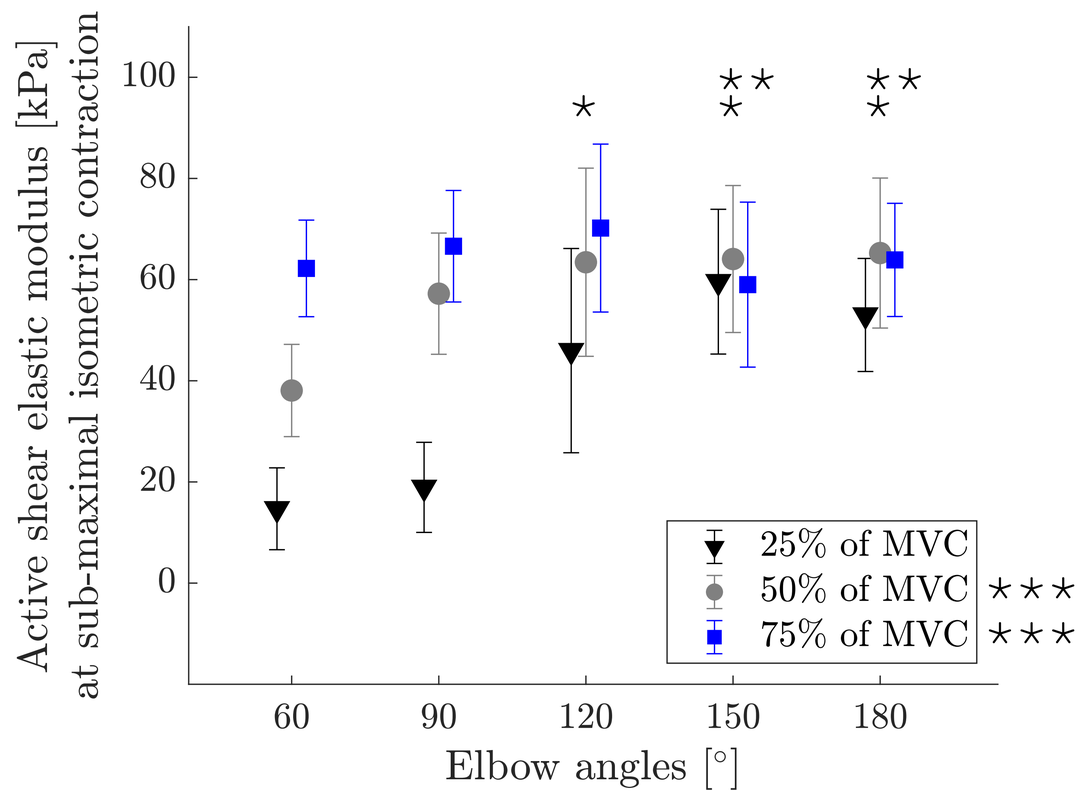

Figure 2. Average active shear elastic modulus at 25%, 50%, and 75% isometric contractions for different elbow angles (60°-180°).
2-way ANOVA results ($p<0.05$): *, ** indicate significantly different values from 60° and 90° elbow angles respectively. *** indicate significantly different values from 25% activity level.

DISCUSSION:

Passive mechanical muscle properties were characterized using SWE. We found that at active state, SWE reflects different activity levels while indicating muscle length dependent characteristics. The present study relates joint torque with the SWE of an individual muscle. Direct force measurements [e.g. 1] will allow further developement and validation of SWE as an index of muscle force.

CONCLUSIONS:

1. Passive shear elastic modulus of the BB increased with increasing muscle length
2. Active shear elastic modulus of the BB increased with increasing elbow torque at shorter muscle lengths
3. SWE revealed muscle length dependent active muscle mechanical properties

Ongoing work: Understand the contribution of individual muscles to the resulting joint torque and relate direct muscle force measurements with muscle's shear elastic modulus.

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