Empirical Quantification and Modeling of Muscle Deformation: Toward Ultrasound-Driven Assistive Device Control

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Motivation

- **Intuitive control of high-DoF assistive devices** remains an open problem
- Control systems using surface EMG are limited by the sensor's noisy and aggregate nature and by poor overall understanding of neurological motor control [1]
- **Muscle deformation** represents an **alternative control signal** that can be measured in a **highly localized manner** via ultrasound to allow for robust extraction of **multiple independent control signals**

Challenges

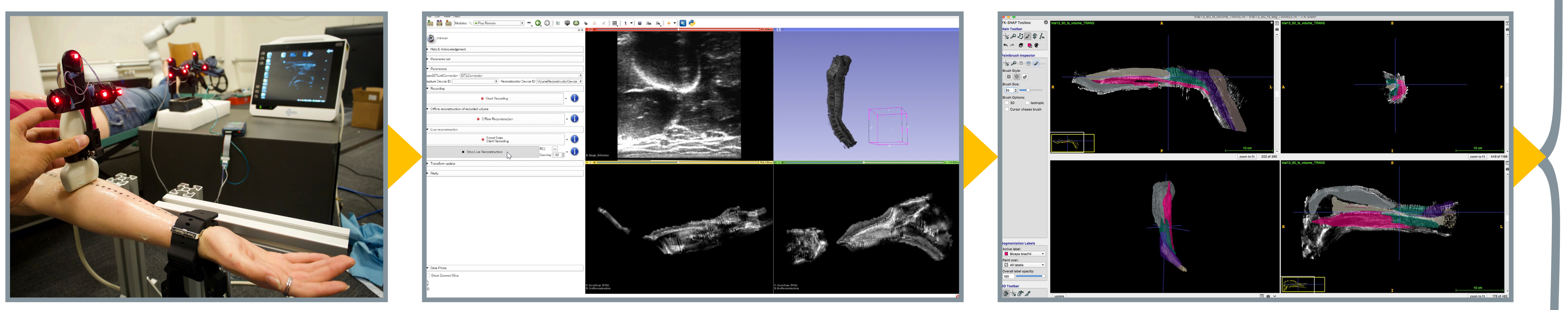
- **Substantial muscle deformation** occurs during both **force exertion** and **changes in kinematic configuration**, complicating model generation
- **No data exists** with which to study these deformation signal sources independently, but **both must be considered** to use deformation as a control signal

Approach

- Generate **factorial set of volumetric scans** of the arm under multiple elbow angles and loading conditions to allow for **separable analysis of force- and configuration-associated muscle deformation**
- Examine volumetric changes along the full length of the arm to **assess potential device control signals**, including muscle cross-sectional area (CSA), thickness (T), and eccentricity (E)

Muscle Volume Extraction

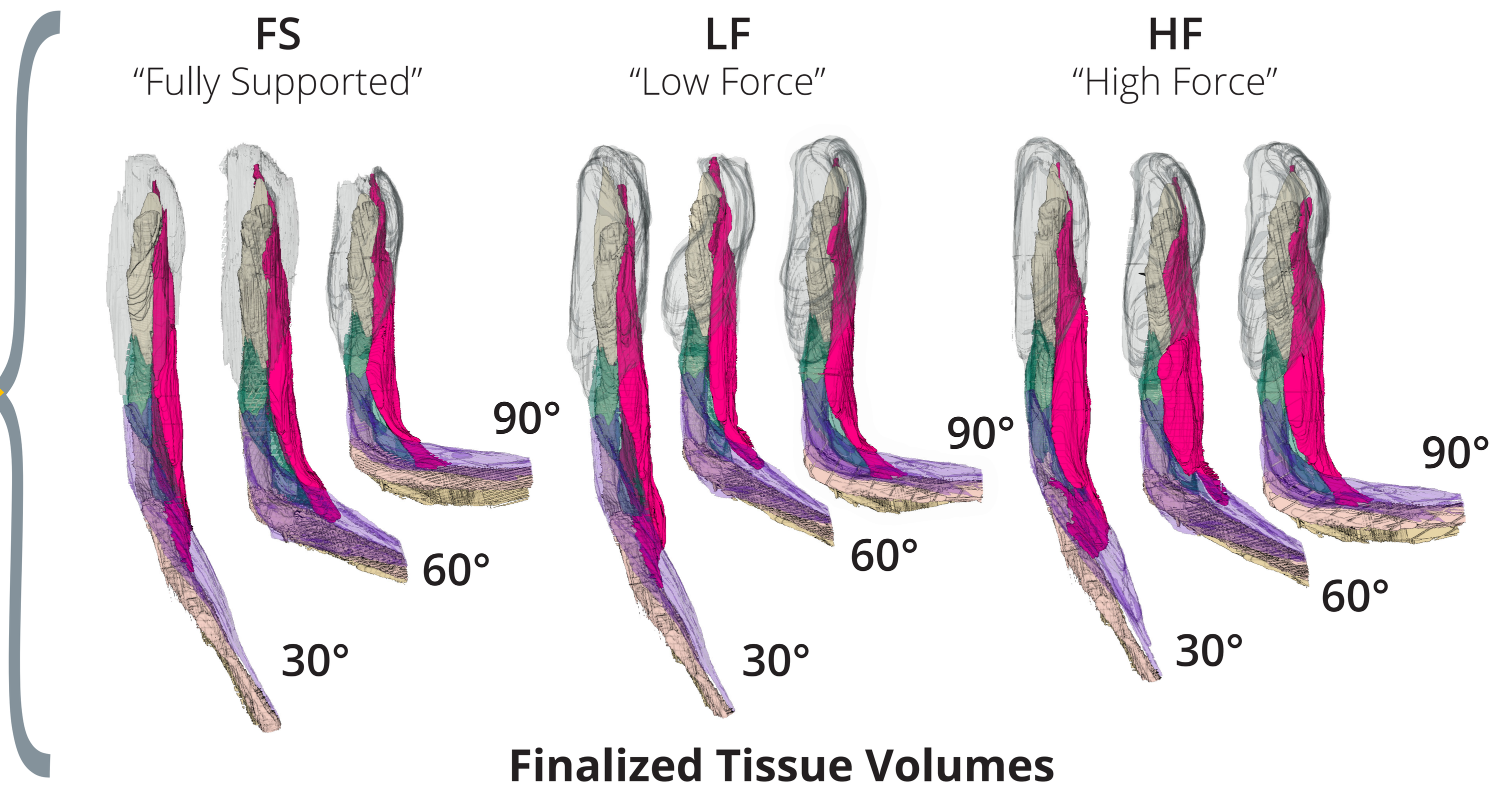
Data Processing Pipeline



Raw Data Collection via Ultrasound & Motion Capture

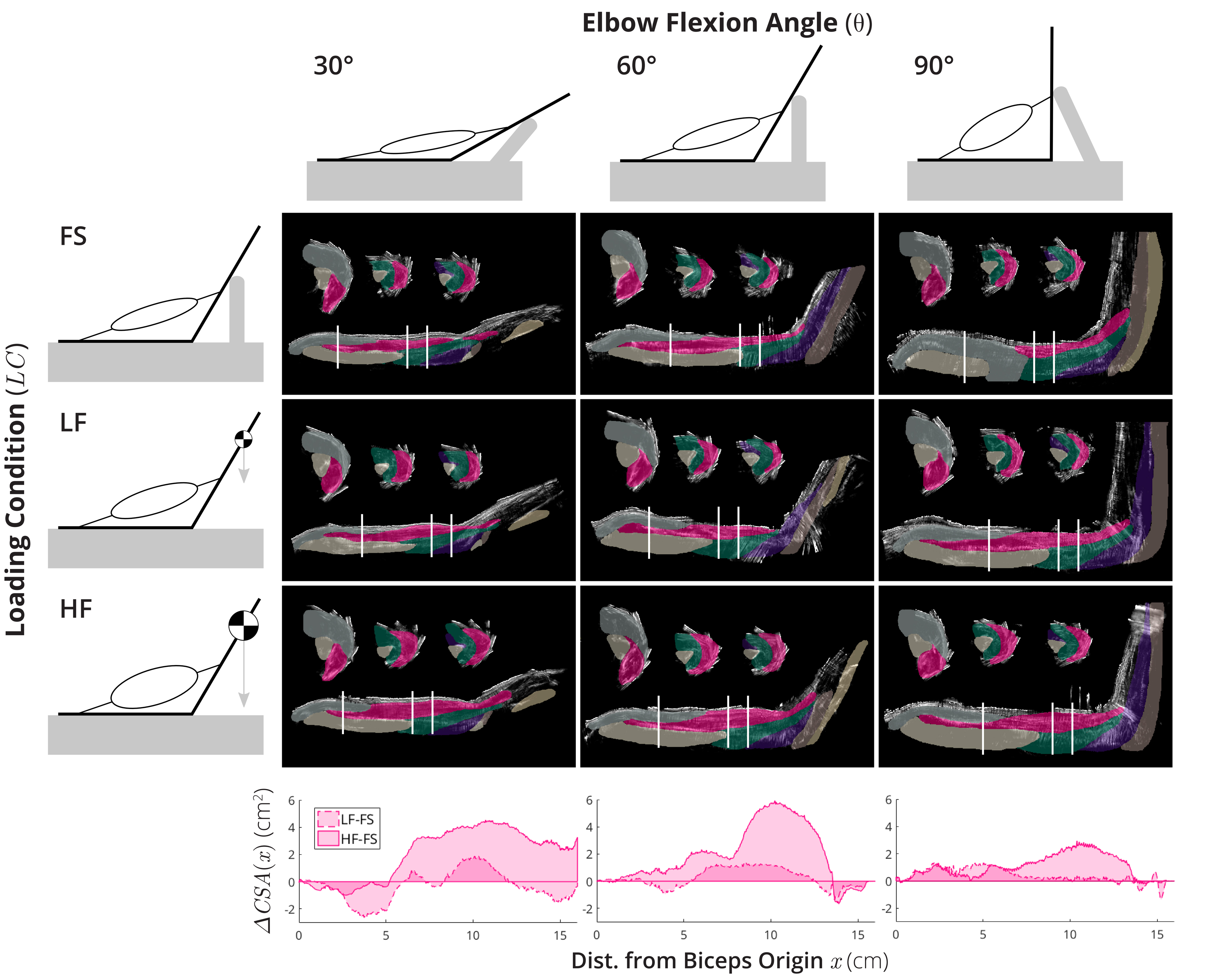
Volumetric Reconstruction via PLUS Toolkit [2]–[4]

Tissue Segmentation in ITK-SNAP [5]



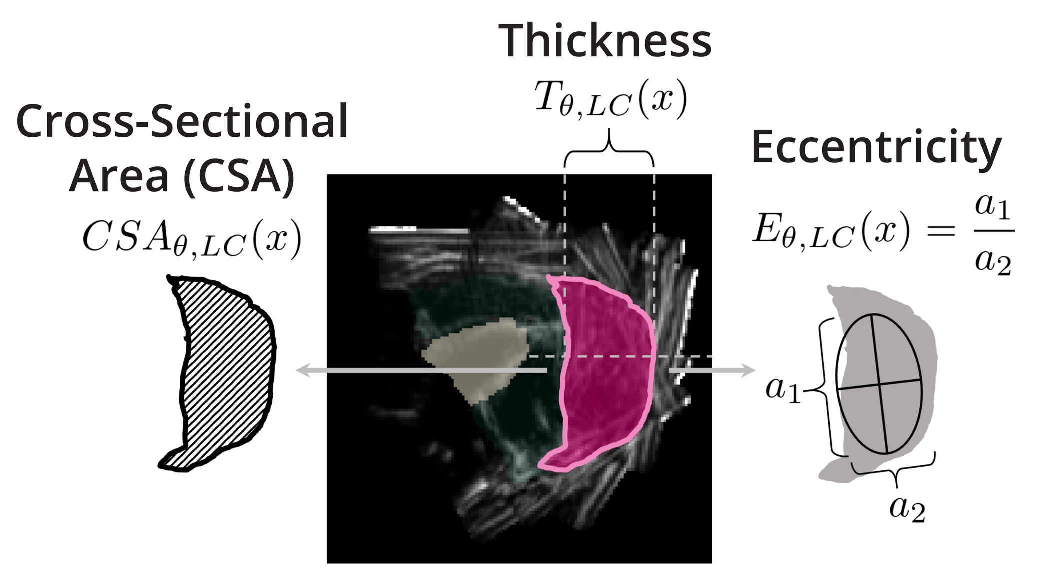
Finalized Tissue Volumes

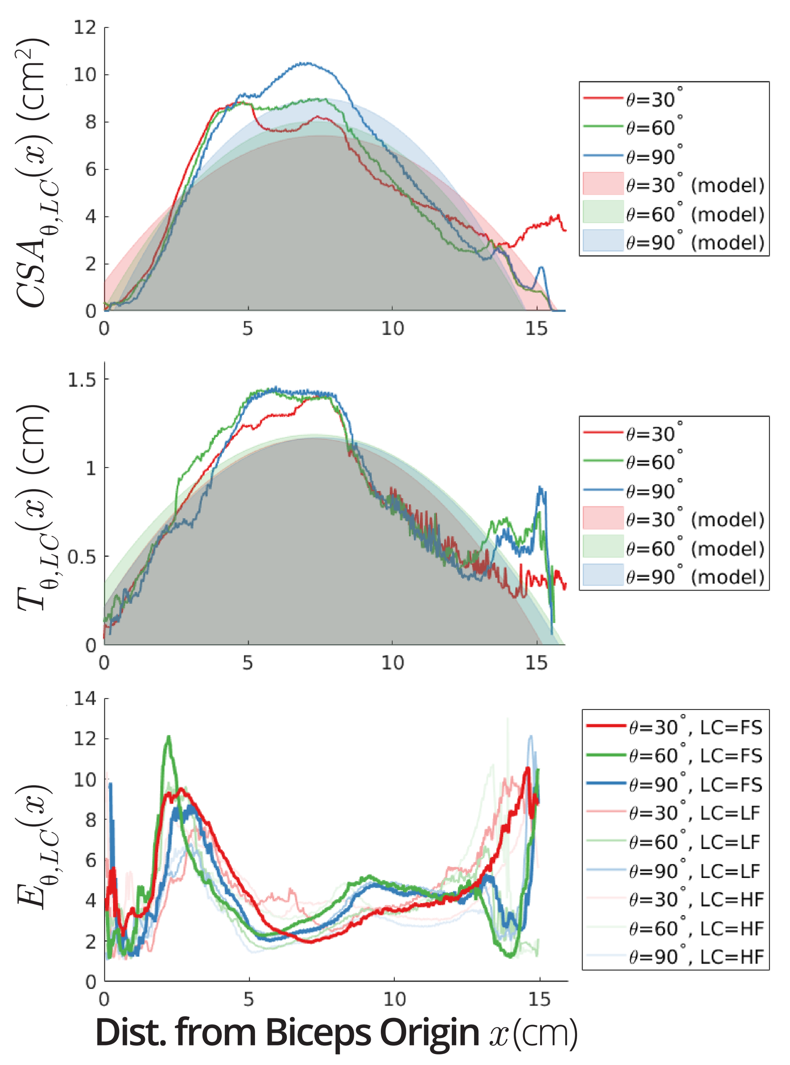
Preliminary Deformation Data & Analysis



The location of **maximal change in CSA under loading** is approximately consistent across elbow angles, suggesting an **optimal location from which to extract a control signal** using a static ultrasound probe.

Deformation Characterization





Changes in width of the fitted CSA quadratic **reflect compression of the muscle** as elbow angle increases.

In the future, a model of eccentricity could be used to **predict CSA from one-dimensional thickness data**.

Download the full data set at `hart.berkeley.edu/datasets`

Conclusions & Future Work

- Data show **force- and configuration-associated deformation of similar magnitudes**, confirming **the necessity of modeling both signal sources** when using the deformation signal for device control
- Segmentation of tissue structures remains a major bottleneck → working to speed up process using semi-automated image registration techniques [6] and fully-automated neural networks [7]
- Ultimately, hope to use **multiple deformation signals simultaneously** for high-DoF assistive device control

Acknowledgments / Sponsors / References

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