Human Musculoskeletal Dynamics Modeling:

Current Research and Objectives

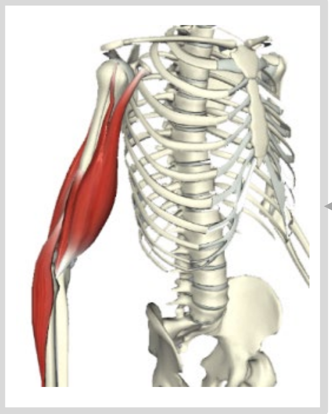
Laura Hallock
Ruzena Bajcsy
CNEP Conference
2017.12.07

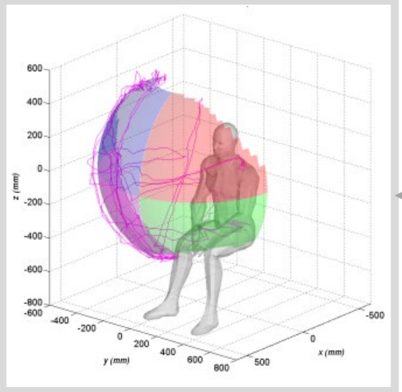
HART Lab
Human-Assistive Robotic Technologies

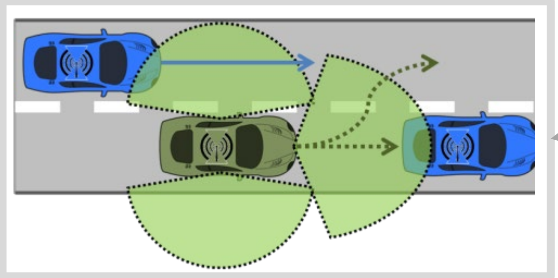
Human-Assistive Robotic Technologies (HART) Lab

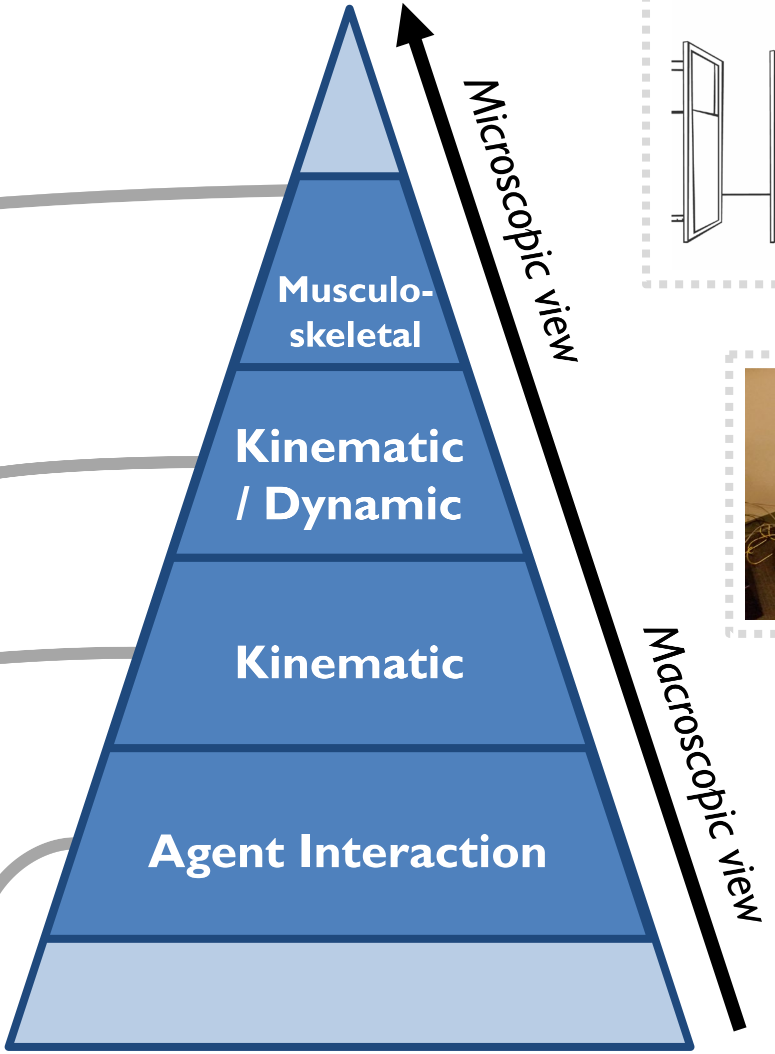
OVERVIEW

HART Lab Ecosystem

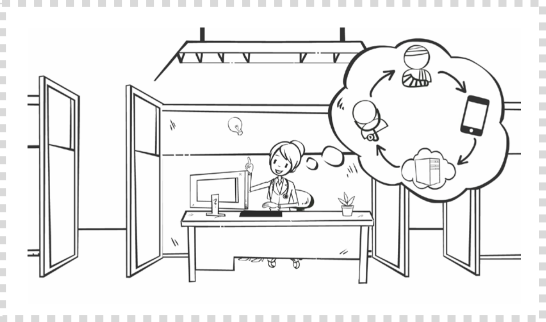








Levels of human modeling abstraction



People (Musculoskeletal Modeling)

UC Berkeley


R. Bajcsy


R. Matthew


L. Hallock


S. Seko


J. Zhang


A. Kato


A. Sy


S. Sharma


I. McDonald


D. Ho


Y. Tuo


L. Howard


S. Nair


P. Kiran

Stanford


O. Khatib

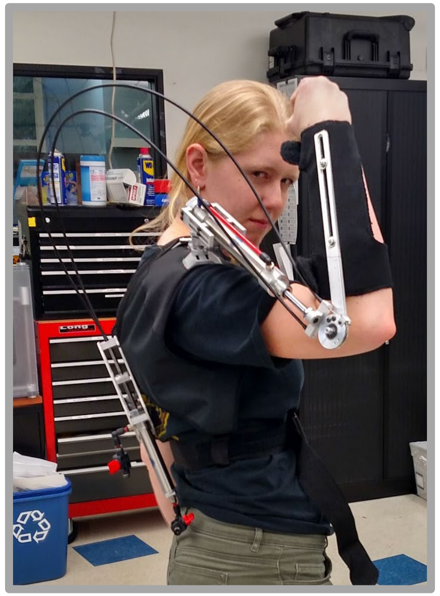

S. Menon


T. Migimatsu

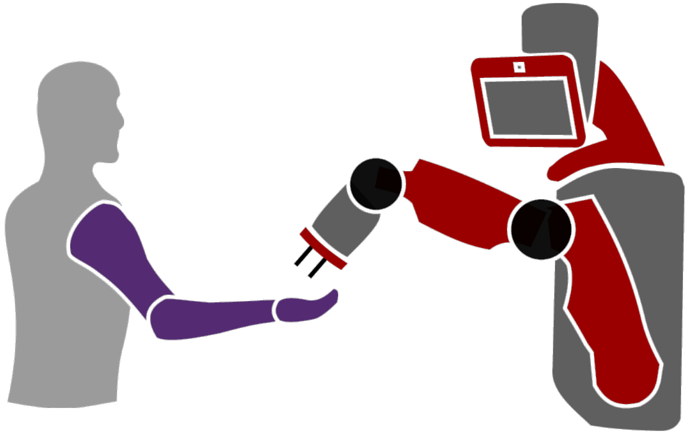
Why model musculoskeletal dynamics?

Human dynamics modeling is essential for many applications.

- understanding forces imperative in physical HRI
- non-physiological models cannot sufficiently predict dynamics



APEX Gamma exoskeleton,
HART Lab 2016



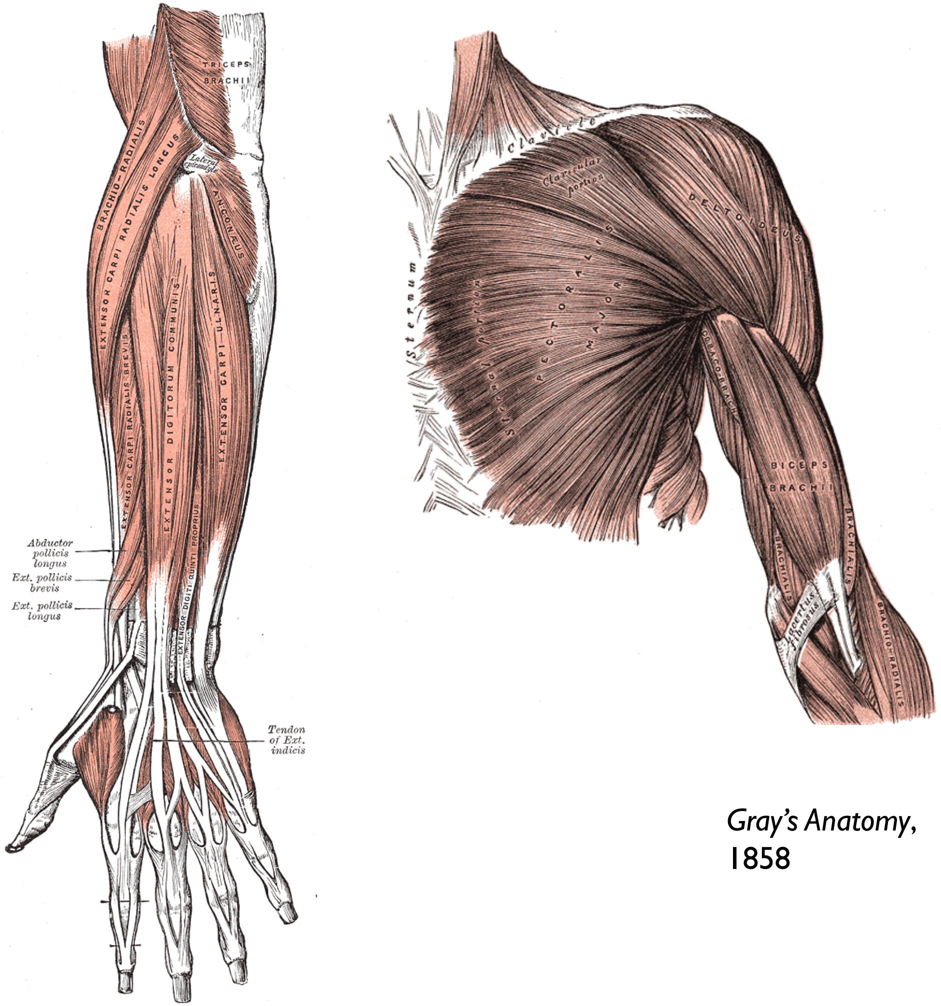
Why model musculoskeletal dynamics?

Human dynamics modeling is essential for many applications.

- understanding forces imperative in physical HRI
- non-physiological models cannot sufficiently predict dynamics

It’s also difficult.

- complex dynamical system (how many DoF?)
- morphological variation
- limited sensing (esp. non-invasive)



Gray’s Anatomy, 1858

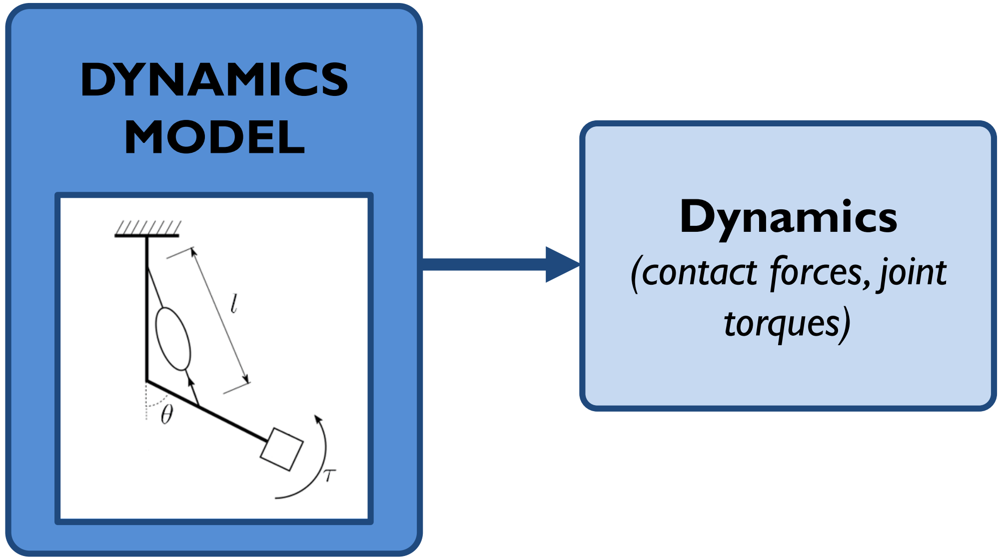
Objective

We seek to **develop models to predict human arm dynamics** that

- have appropriate level of abstraction (**as simple as possible** while accommodating **dynamically- and medically-relevant pathologies**)
- are trainable/customizable using **non-invasive sensing** (MRI, ultrasound, EMG, AMG, etc.)
- can be used in assistive device control system using **non-invasive, wearable sensing** (EMG, AMG, *ultrasound*)

Objective: Predictive Upper-Limb Model

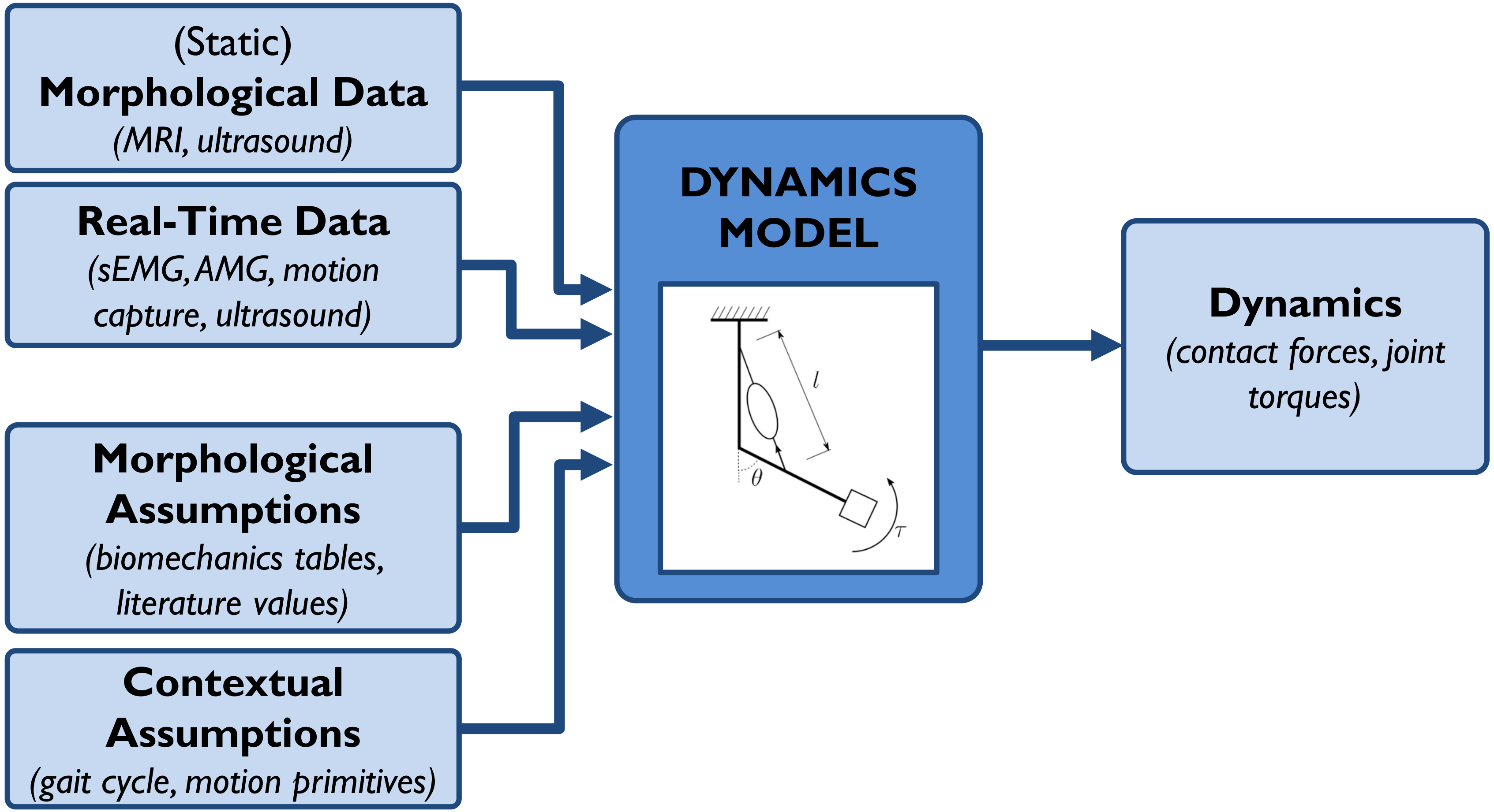
- predicts contact forces / joint torques of interest
- accommodates musculoskeletal pathology
  - injury
  - disease (e.g., MD)
- individualized
- computationally tractable



DYNAMICS MODEL

Dynamics
(contact forces, joint torques)

Existing Human Dynamics Models



(Static)
Morphological Data
(MRI, ultrasound)

Real-Time Data
(sEMG, AMG, motion capture, ultrasound)

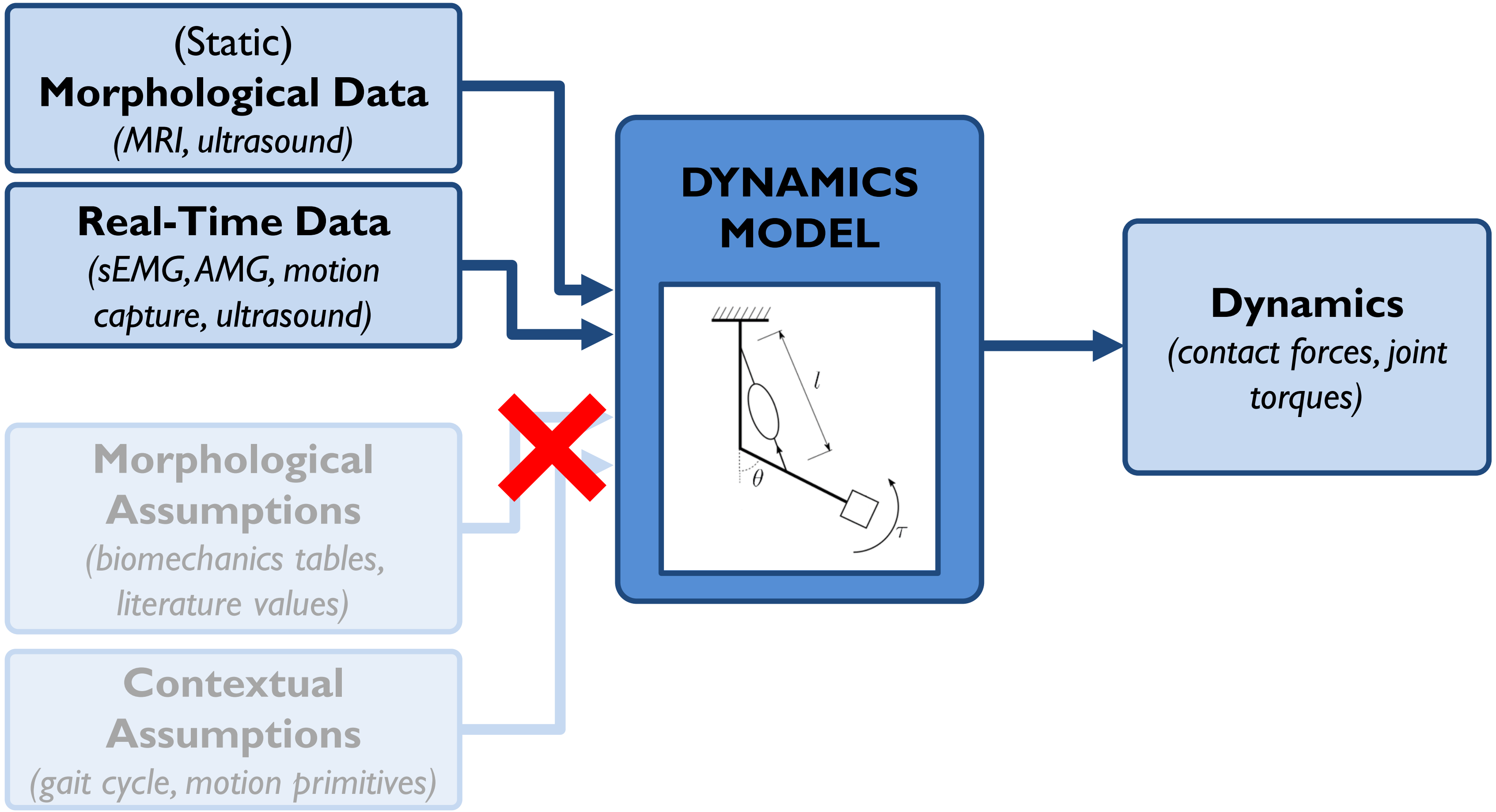
Morphological Assumptions
(biomechanics tables, literature values)

Contextual Assumptions
(gait cycle, motion primitives)

DYNAMICS MODEL

Dynamics
(contact forces, joint torques)

Our Objective



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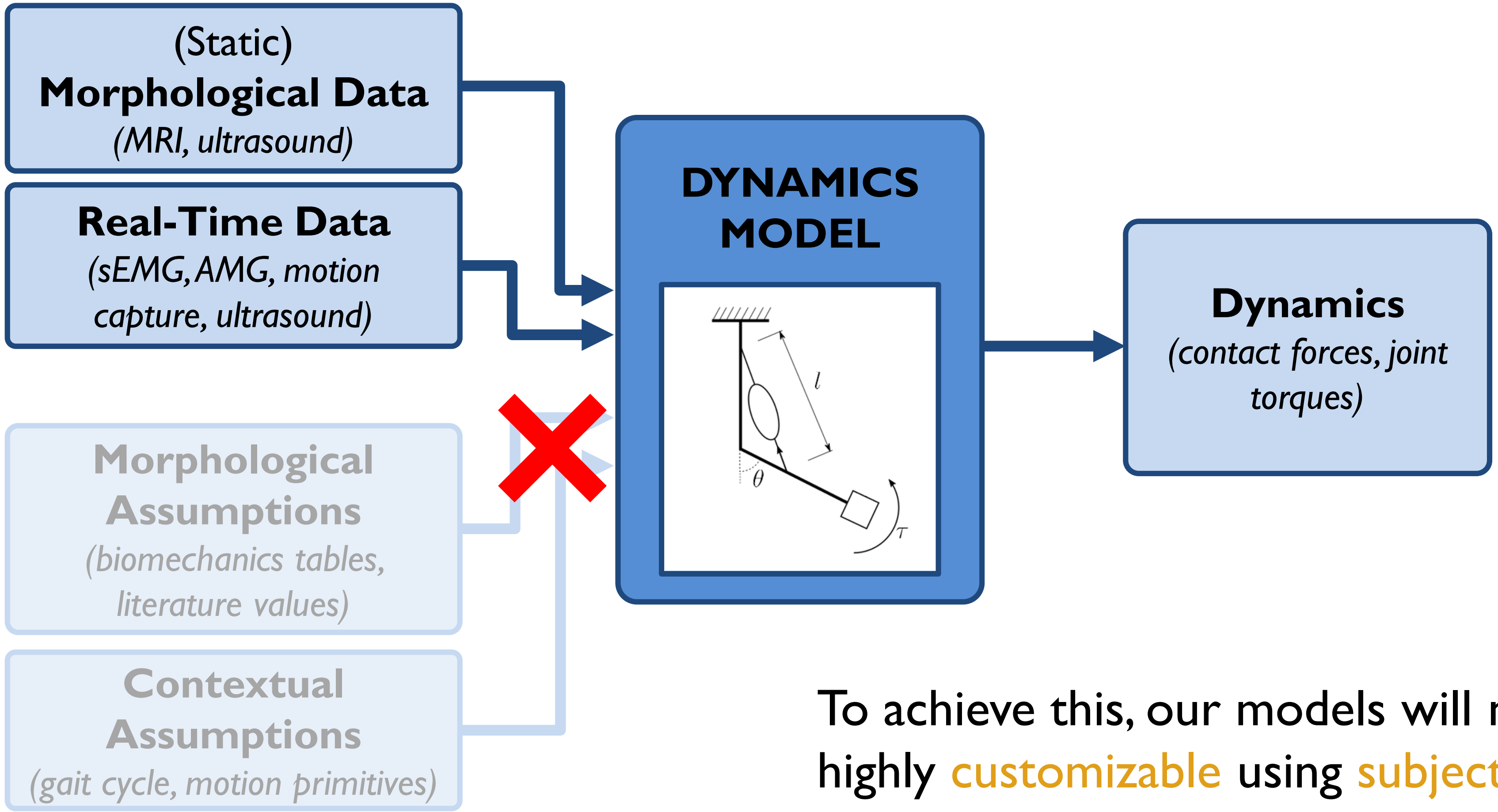

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DYNAMICS MODEL

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(contact forces, joint torques)

To achieve this, our models will need to be highly customizable using subject-specific data.

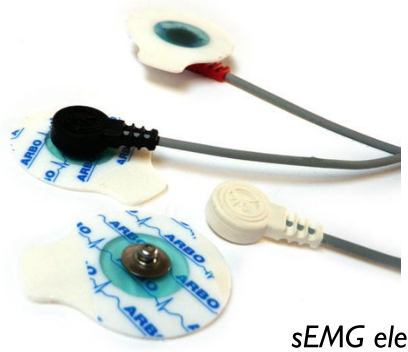
Possible Sensing Modalities

sEMG (surface electromyography)

- sensitive, noisy
- aggregate
- based on neurological signals (*neurological disorder* → *poor signal*)
- well-explored
- industry standard

AMG (acoustic myography)

- improved SNR
- aggregate
- based on physiological signals
- novel

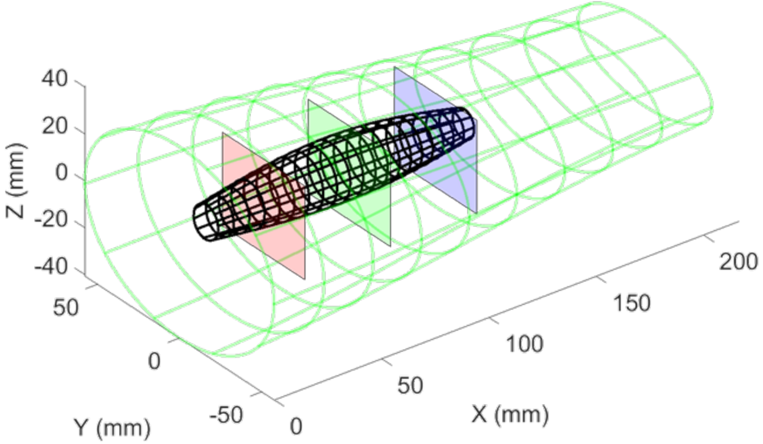

sEMG electrodes

CURO

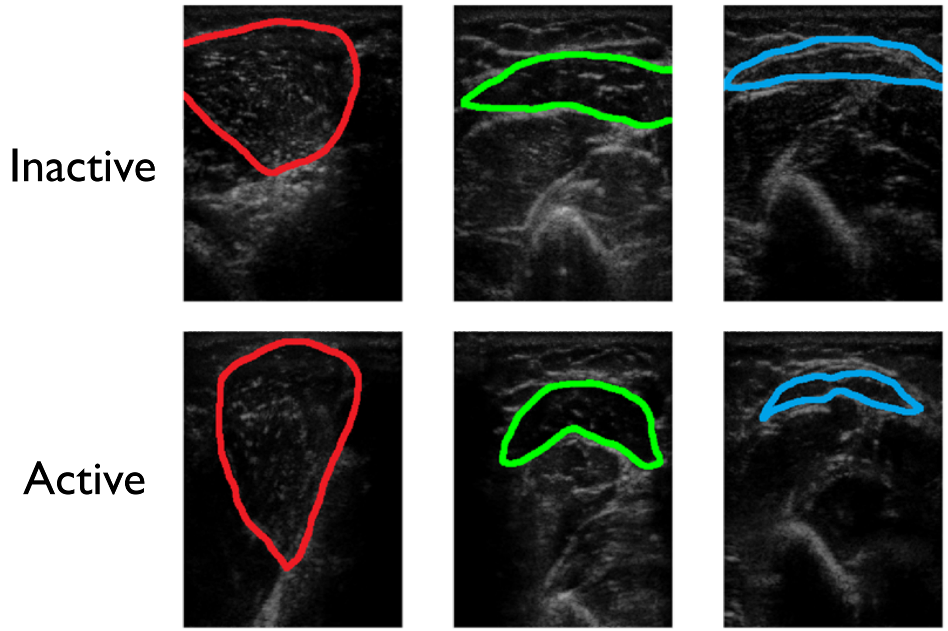
Possible Sensing Modalities

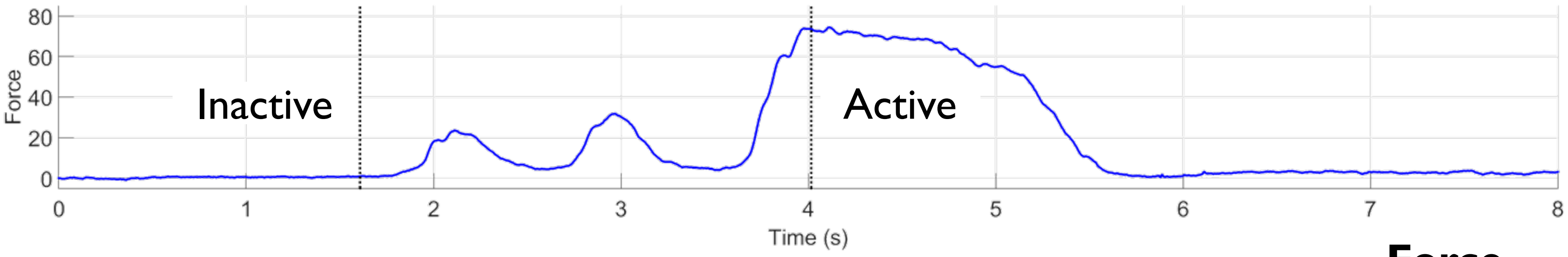
Ultrasound

3D View



Muscle Cross-Section





Force

Possible Sensing Modalities → **Models**

- **Option 1**: geometric models (MRI, ultrasound)
  - – no ready "wearable" signal sources
  - + highly localized
  - – more computationally intensive?

- **Option 2**: stress-strain/elasticity models (AMG, cine DENSE)
  - + AMG as "wearable" signal source
  - – less localized

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}

TODAY

- **Option 2**: stress-strain/elasticity models (AMG, cine DENSE)
  - \+ AMG as "wearable" signal source
  - – less localized

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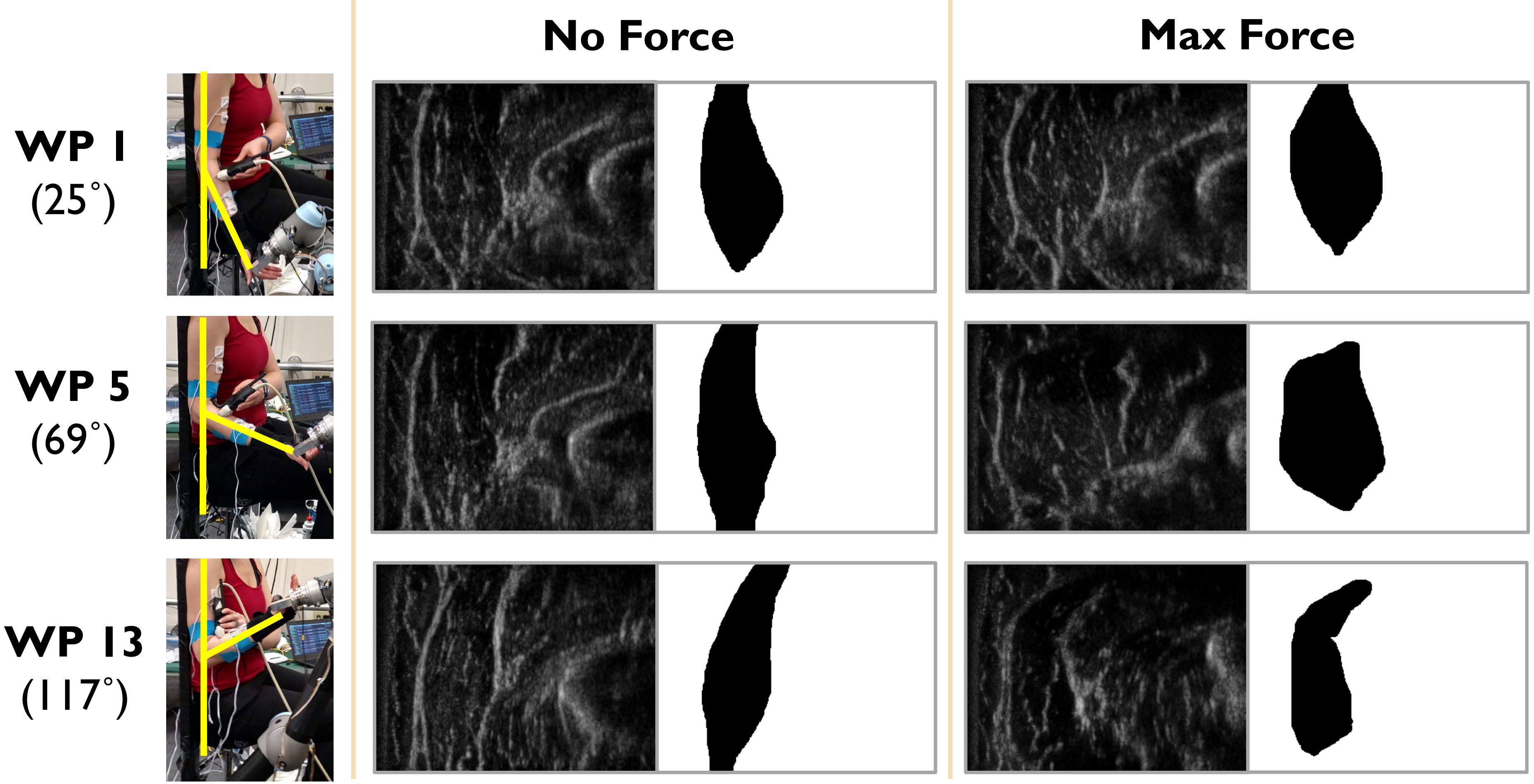
Muscle Deformation Analysis via Ultrasound

Ultrasound Data Revisited



Key Questions

- Can we differentiate muscle deformation associated with **kinematic configuration** from deformation associated with **force output**?
- If we account for pure configuration-associated deformation, can we infer a **clean relationship between force and deformation** that can be used as a control signal?

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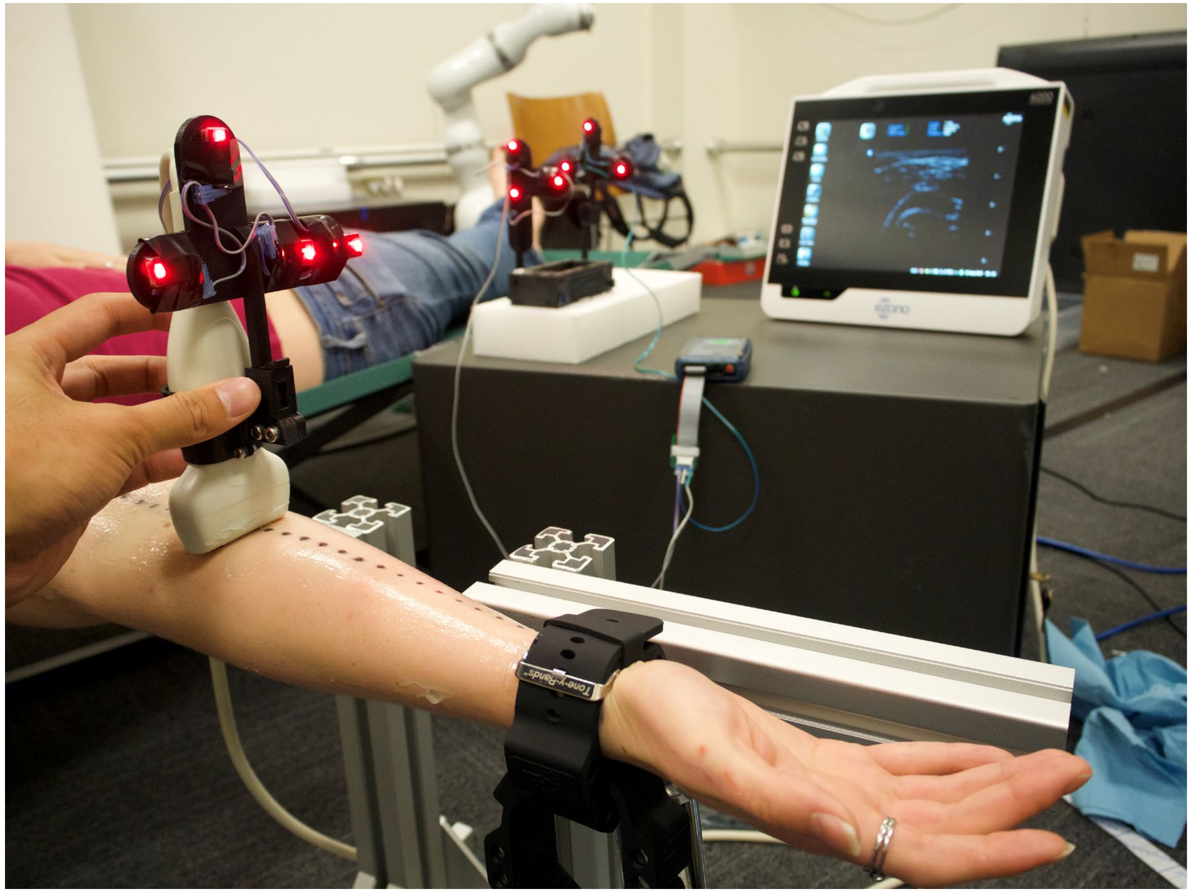
To answer these questions, we need a **factorial set of muscle scans** to compare across both joint positions and loading conditions.

Approach

Model target: elbow flexors (*biceps brachii*, *brachialis*, *brachioradialis*)

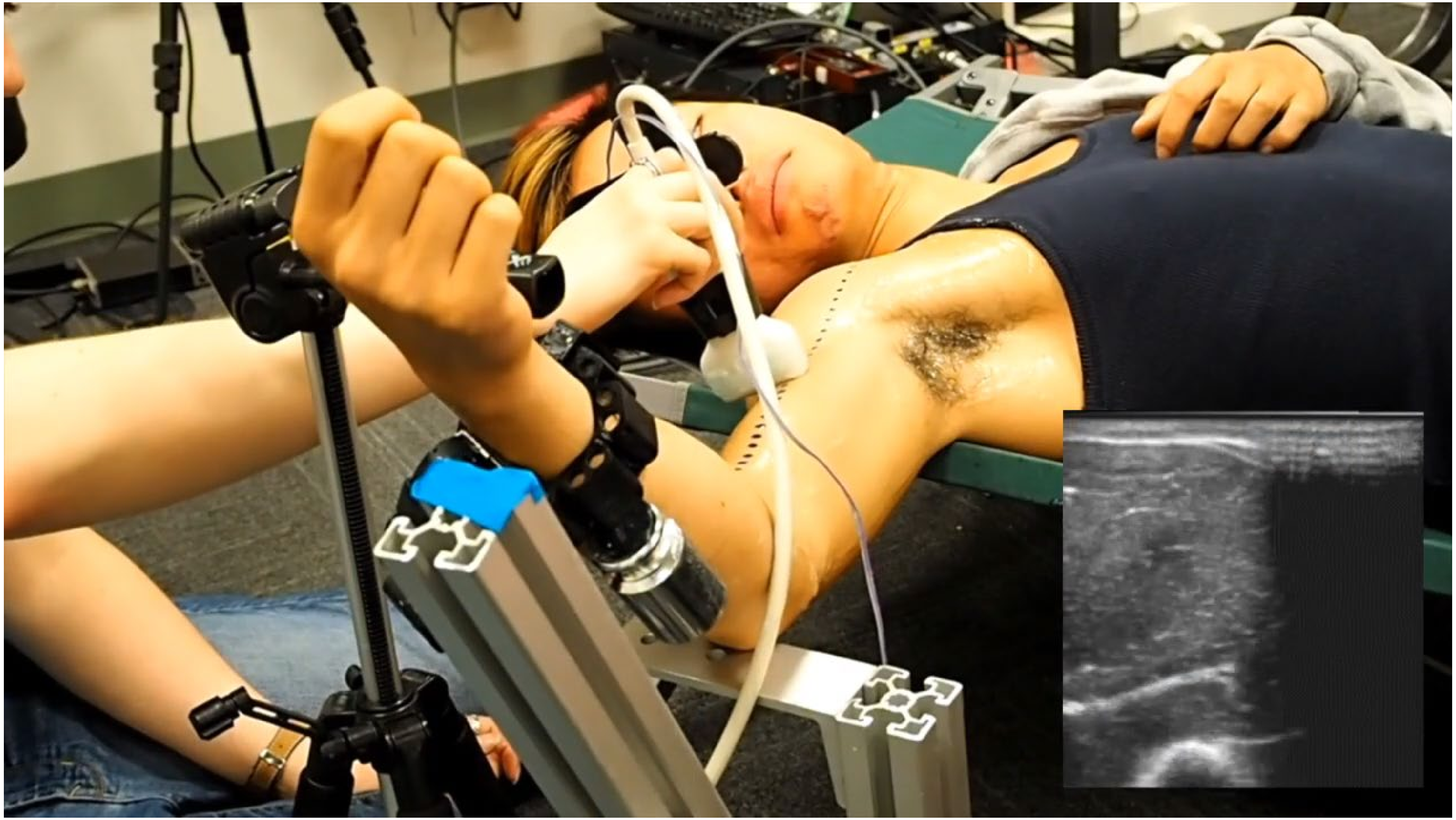
Data set:

- 3 subjects (1 F, 2 M)
- full arm ultrasound volumetric scan
- 4 elbow flexion angles, 0–90°
- 5 loading conditions
  - fully supported
  - gravity compensation only
  - light wrist weight (~225g)
  - medium wrist weight (~725g)
  - heavy wrist weight (~950g)

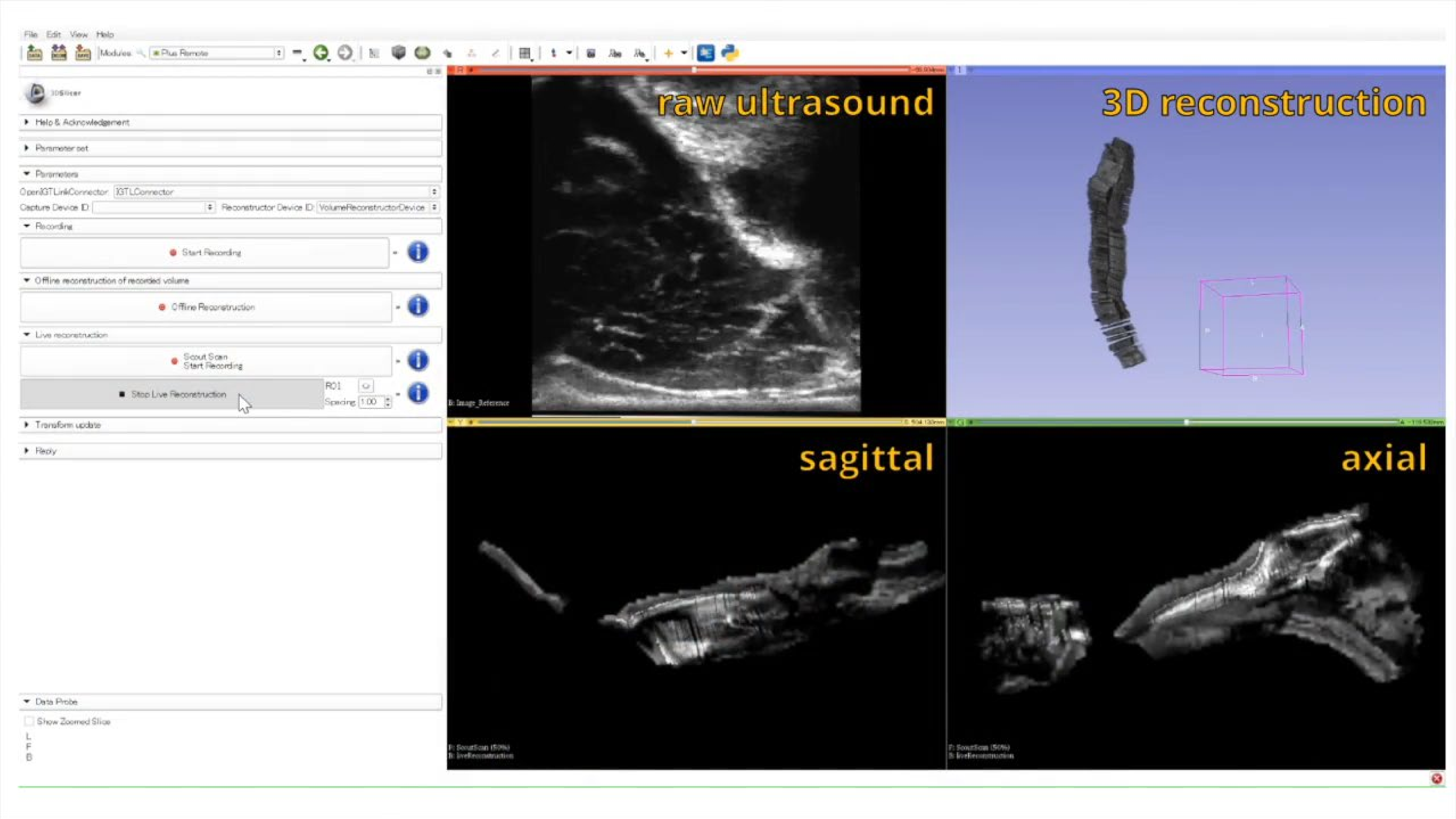


Ultrasound volumetric data collection, HART Lab 2017

Data Collection and Processing



Data Collection and Processing: PLUS/3DSlicer


OpenIGTLinkConnector: IGTLConnector

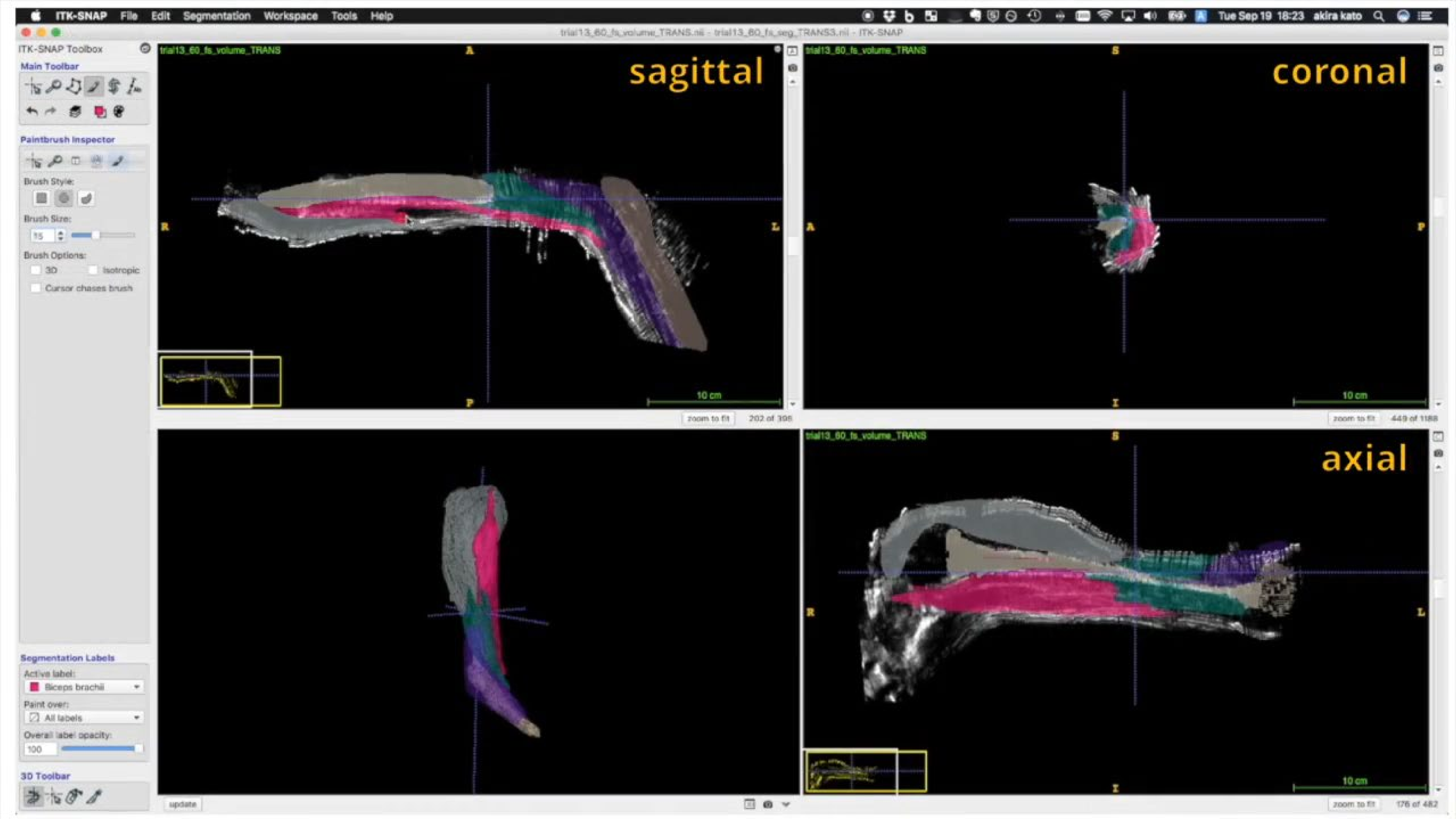
Capture Device ID:

Reconstructor Device ID: VolumeReconstructorDevice

ROI

Spacing: 1.00

Data Collection and Processing: ITK-SNAP



trial13_60_fs_volume_TRANS.nii - trial13_60_fs_seg_TRANS3.nii - ITK-SNAP

Brush Size: 15

Brush Options: ☐ 3D ☐ Isotropic ☐ Cursor chases brush

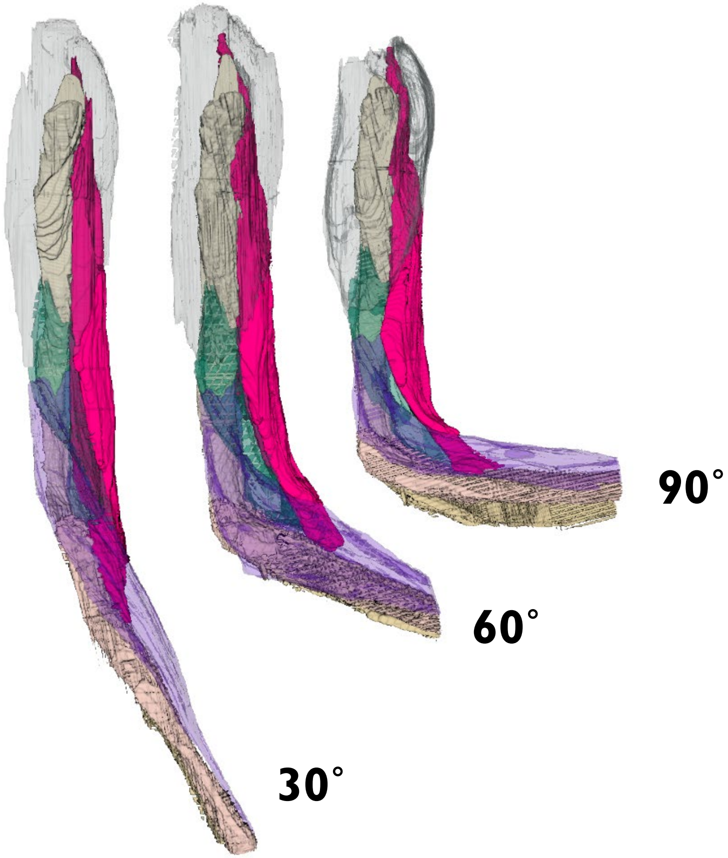
Active label: Biceps brachii

Paint over: All labels

Overall label opacity: 100

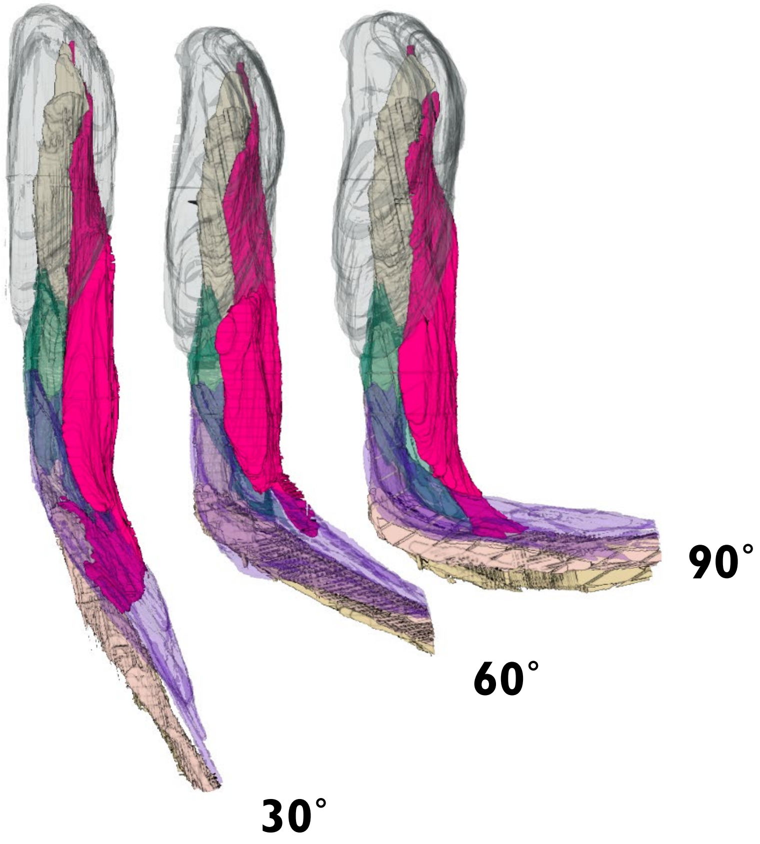
Preliminary Results

FS
("Fully Supported")

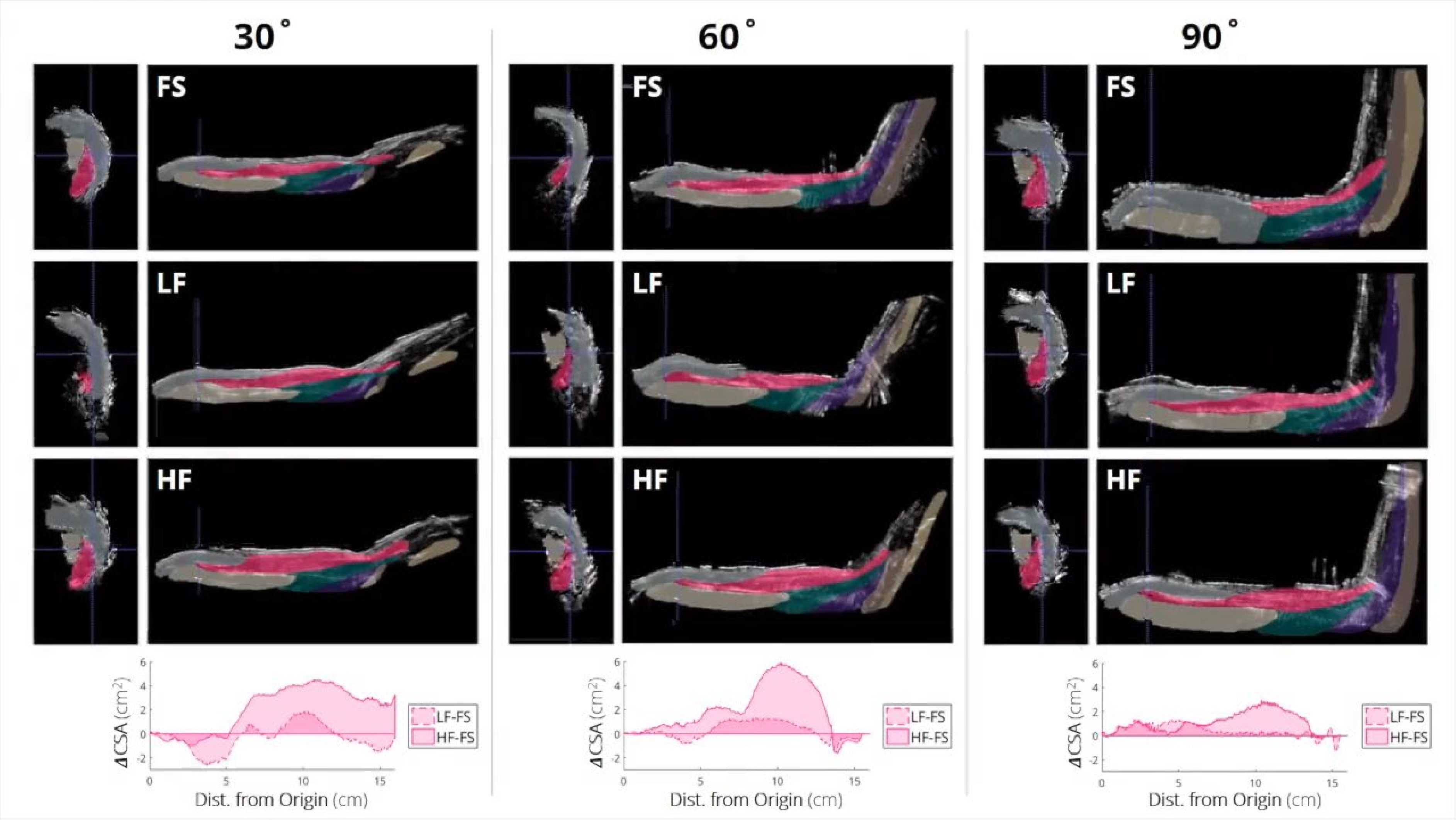


LF
("Low Force")

HF
("High Force")



Preliminary Results



Preliminary Results

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

Laura A. Hallock, Akira Kato, and Ruzena Bajcsy

HART Lab
Human-Assistive Robotic Technologies

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ICRA 2018

Next Steps

- Impose and validate one or more **deformation models**:
  - cross-sectional area (CSA) changes
  - volume changes
  - superquadric models
  - shape models
  - FEM

- Refine experimental procedures to allow **clean comparison of force conditions across angles**

- Speed up / automate **segmentation pipeline**

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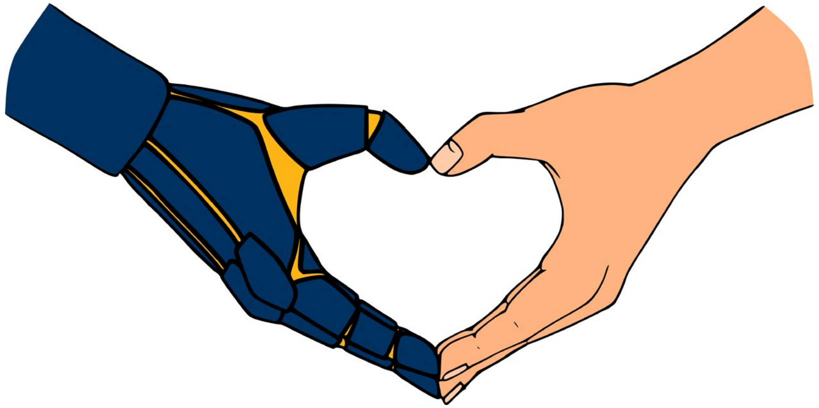
CONCLUSIONS

Conclusions

By examining localized deformation models of human arm muscle morphology, we seek to generate a modeling framework that **surpasses existing models in predictive accuracy and detail** while remaining **computationally tractable** and **useful in a wide range of applications**.



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Papers

Conference Papers

L.A. Hallock, A. Kato, and R. Bajcsy. "Empirical Quantification and Modeling of Muscle Deformation: Toward Ultrasound-Driven Assistive Device Control." *IEEE International Conference on Robotics and Automation (ICRA)*, 2018. (under review)

L.A. Hallock, R.P. Matthew, S. Seko, and R. Bajcsy. "Sensor-Driven Musculoskeletal Dynamic Modeling." *International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2016. (late-breaking report)

Technical Reports

L.A. Hallock, R.P. Matthew, S. Seko, and R. Bajcsy. (2016) "Sensor-Driven Musculoskeletal Dynamic Modeling." UC Berkeley EECS, Tech. Rep. UCB/EECS-2016-66.

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