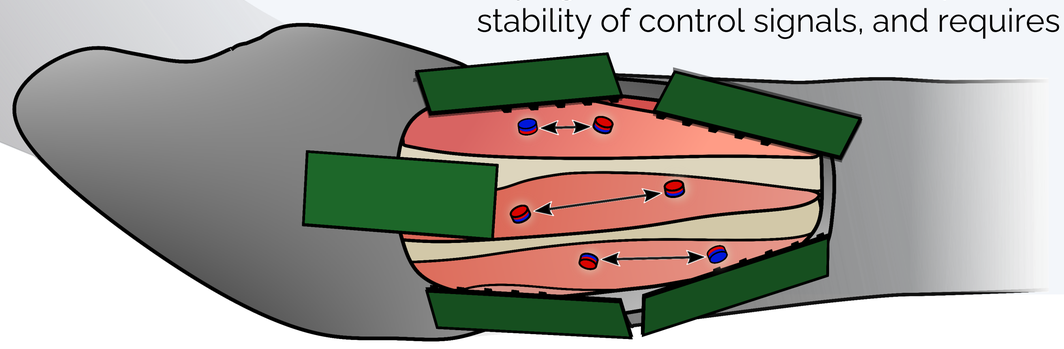
Optimizing the myokinetic interface: a finite element model to predict displacement in amputated muscles

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Many novel strategies for prosthetic control rely on **muscle deformation** during contractions[1,2]. Among these, the **myokinetic interface**[3,4] decodes the user intent by monitoring the displacement of implanted magnets in the muscles. Identifying the most suitable implantation sites for the magnets in advance is crucial to ensure adequate range and stability of control signals, and requires a preoperative estimation of the muscle deformation during contraction.



Here, we developed a Finite Element Model (**FEM**) of pennate muscles

- Calibrated and validated using anatomical geometries of **intact muscles** and in vivo measurements from able-bodied subjects.
- The model performance was further assessed on three **transected muscles** by comparing simulations with in vivo data from a participant with transradial amputation.

Finite Element Model of muscle

- **Muscle**: modeled as a combination of passive elastic (F_e) and active (F_a) material properties[5]. Fiber contribution depends on fiber direction **M** and contraction level γ.
- **Tendon**: modeled as an elastic component (distributed springs)
- Isometric **contraction**.
- **Geometry:** obtained from a 3D CAD of the human forearm.

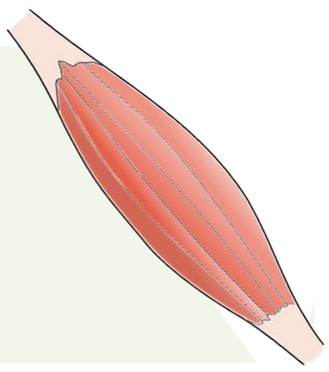
$$\mathbf{F} = \mathbf{F_e F_a}$$

$$\mathbf{F_a} = (1-\gamma)\mathbf{M} + \frac{1}{\sqrt{(1-\gamma)}}(\mathbf{I} - \mathbf{M})$$

$$\psi = \psi_{iso} + \psi_{ani}$$

$$\psi_{iso(F)} = -\mu\frac{I_{max}}{2}\log\left(1 - \frac{I_1 - 3}{I_{max}}\right)$$

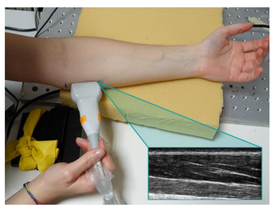
$$\psi_{ani(F)} = \alpha\beta\left(I_4^{\frac{1}{\beta}} - 1\right)^2$$

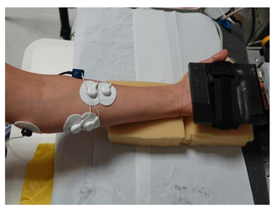


Intact muscle

Calibration

- Aimed at determining the values of the material parameter.
- Conducted using the intact geometry of Flexor Carpi Radialis (FCU) muscle.
- Variation in **pennation angle** and **force** generated during different contraction intensities were monitored and compared with in vivo experimental data, using an ultrasound probe and a load cell.





Results

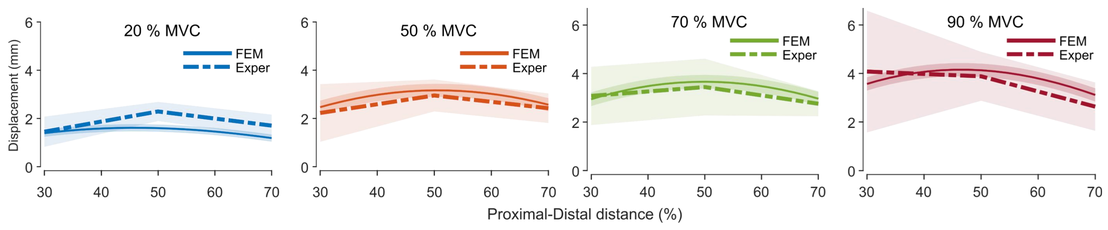
- Larger increase in pennation angle proximally.
- The developed force ranged from 89.5 to 96.4 N.

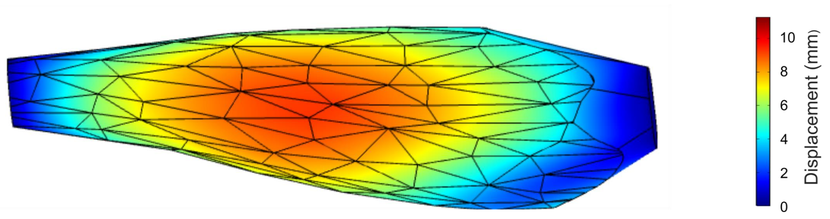
Validation

- Performed to assess the generalization ability of the FE model across different geometries and output variables.
- Conducted on the Flexor Carpi Radialis (FCR) muscle by comparing **displacement** and **force** values during isometric contractions with in vivo measurements.

Results

- Maximum longitudinal displacement occurred at the highest contraction intensity and at 50% of the muscle length.
- The **discrepancy** between experimental and simulated data remained consistently **below 0.7 mm.**



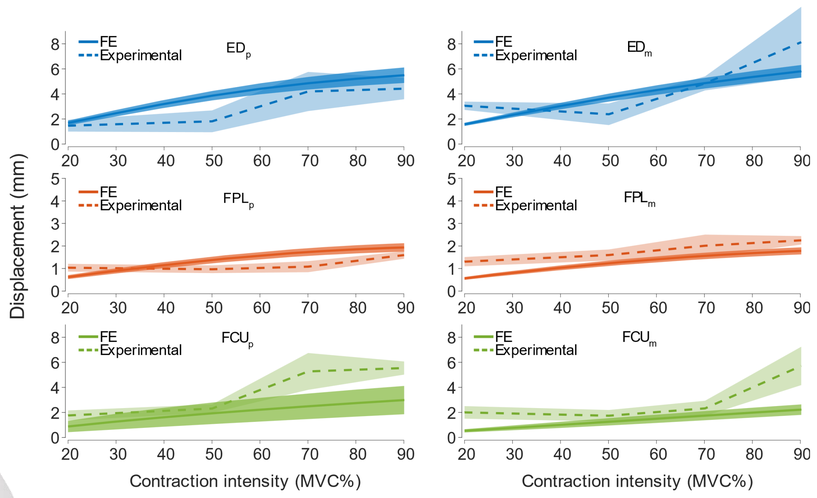




Amputation level

Transected muscle

- Comparison of predicted displacement for three transected muscles with in vivo data from a participant with **transradial amputation.**
- Measurements taken at proximal and distal recording sites, across **various contraction intensities**.
- Average displacement **error** was **below 1 mm** for ED and FPL, and **below 1.7 mm** for FCU.
- Overall, the simulated displacement slightly underestimated the experimental one.



Future directions

These results demonstrate the **feasibility** of accurately **predicting the behavior** of both intact and transected **muscles** using fast in vivo measurements.

Future studies should extend these findings by considering:

- A larger population.
- A larger number of muscles.
- Incorporating subject-specific geometries to refine model parameters and enhance the overall accuracy.

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