Department of Otolaryngology - Head and Neck Surgery

Finite Element Analysis of the Gracilis Muscle for Facial Reanimation Surgery

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Introduction

- **Facial Nerve Paralysis:** Complete or incomplete loss of facial nerve function leading to facial asymmetry, functional deficits, and psychosocial morbidity[1]
- **Gracilis Free Flap**
  - Gold standard for dynamic facial reanimation. Microneurovascular transfer that restores oral commissure function with movement and smile[2]



Fig. 1 Preoperative (A) and postoperative (B) facial appearance following single-stage gracilis free flap transfer

- **Gaps:**
  - Modifying anchoring strategies can improve the smile display zone[3]
  - Mechanical properties of the gracilis free flap remain uncharacterized
  - Quantifying mechanical properties and modeling the gracilis free flap would allow for advanced preoperative planning and provide data for the development of artificial muscle constructs
  - Gracilis muscle contains a mix of slow-twitch Type 1 and fast-twitch Type 2 fibers. Ideal muscle harvest would contain fast-twitch muscle fibers for smile reanimation[4]
  - Intraoperative tensile testing faces challenges of maintaining sterility and minimizing ischemia time

Methods

Case-series observational study with Institutional Review Board approval.

Tensile Testing and Contraction of the Gracilis Muscle Flap (n = 3)

a) b)

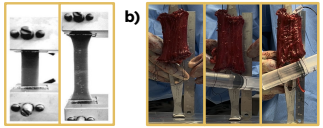


Fig. 2 a) Standard tensile testing setup used to generate stress–strain curves[5]
b) Intraoperative experimental setup for free flap testing with initial length, length under tension, and length with active stimulation

Recreate Gracilis Muscle Flap Geometry in Ansys and Perform FEA

a) b)

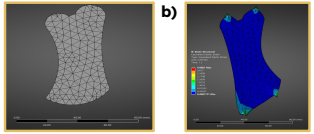


Fig. 3 a) Nonlinear FEA mesh of a patient-specific gracilis free flap **b)** Equivalent elastic strain results under an applied force of 0.346 N (15cc in 20cc syringe)

Results & Analysis

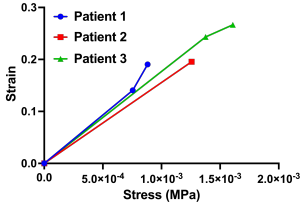


Fig. 4 Stress–strain curves of three patient-specific gracilis free flaps. The slope of each curve represents the tissue's Young's modulus (n = 5 loading conditions).

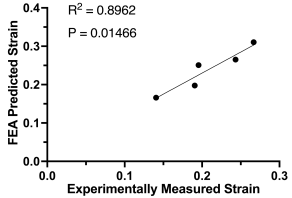


Fig. 5 Linear regression of FEA-predicted versus experimentally measured axial strain (R^2 = 0.896, slope significantly non-zero: $F_{1,3}$ = 25.91, P = 0.015, n = 5 loading conditions).

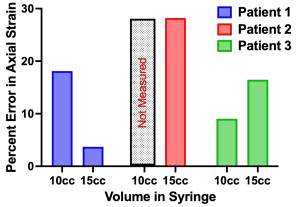


Fig. 6 Percent error of axial strain between FEA and experimental measurements for each patient under 10 cc and 15 cc syringe loads. Mean percent error was 15.09±9.35% (n = 5 loading conditions).

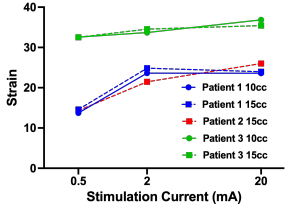


Fig. 7 Active contractile strain of gracilis free flap under different stimulation currents (n = 3 patients, 5 loading conditions).

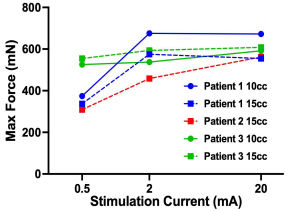


Fig. 8 Max force generated by the gracilis free flap under different stimulation currents (n = 3 patients, 5 loading conditions).

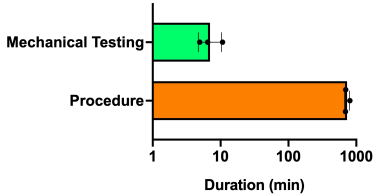


Fig. 9 Time to complete the Gracilis Free Flap Surgery compared to time to complete mechanical testing. X-axis is in log scale (n = 3).

Conclusions

- Characterization of mechanical properties of the gracilis free flap is possible using intraoperative, sterile techniques under ischemic conditions.
- There is a strong correlation between FEA predicted axial strain and experimentally measured axial strain (R^2 = 0.896, P = 0.015), demonstrating that the FEA model is a valid predictor of muscle strain under applied loads.
- FEA predicted axial strain with an average percent error of 15.09±9.35%, showing reasonable accuracy.
- Intraoperative contractile characterization yielded peak forces of 300-700 mN.
- The total time to mechanically test the gracilis is on average 6.98±2.99 minutes.

Limitations & Future Directions

- Muscle assumed to be isotropic elastic, nearly incompressible (Poisson's ratio v=0.49) with geometry having constant depth
- FEA used Young's modulus obtained from 15 cc measurements only, which may not fully capture load-dependent behavior.
- Muscle could not be tested to failure, limiting the full stress–strain characterization.
- Contractile characterization uses single twitch conditions with a handheld nerve stimulator rather than isometric tetanic stimulation.
- Future studies will expand intraoperative characterization across a larger patient cohort
- Twitch contraction kinetics will be quantified and correlated with muscle fiber type characterization.

Acknowledgements & References

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Acknowledgements: This work was supported by UC San Diego School of Medicine.