Towards the Development of a System to Measure Thumb-Tip Movement Produced by Muscles

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Introduction

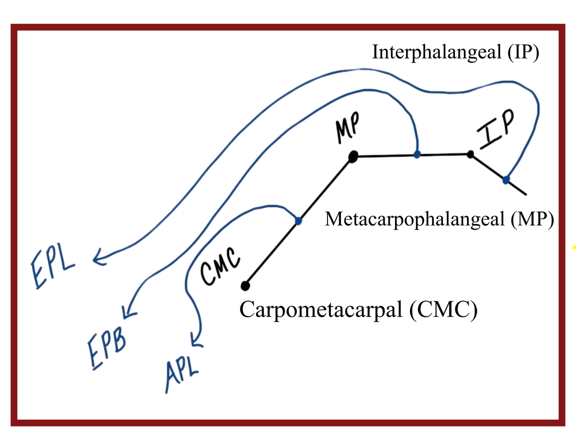
Grasp functions essential for daily tasks like self-feeding and writing are frequently impaired in tetraplegia. Tendon transfer surgeries offer a restorative solution. While the endpoint forces that thumb muscles produce have been studied in the context of improving outcomes after tendon transfer surgery for people with neurological injuries [1, 2], the endpoint velocities that thumb muscles generate, also important for improving such tendon transfer surgeries, remain unclear. The long-term goal of this study is to quantify the thumb-tip trajectories generated by both intrinsic and extrinsic thumb muscles.

Goal of Study

Quantify the thumb tip trajectories generated by extrinsic thumb muscles: EPL, EPB, APL, and FPL.

- Extensor Pollicis Longus (EPL)
- Extensor Pollicis Brevis (EPB)
- Abductor Pollicis Longus (APL)
- Flexor Pollicis Longus (FPL)

Figure 1 (right): Extrinsic muscles responsible for thumb tip movement: FPL, EPL, EPB and APL.



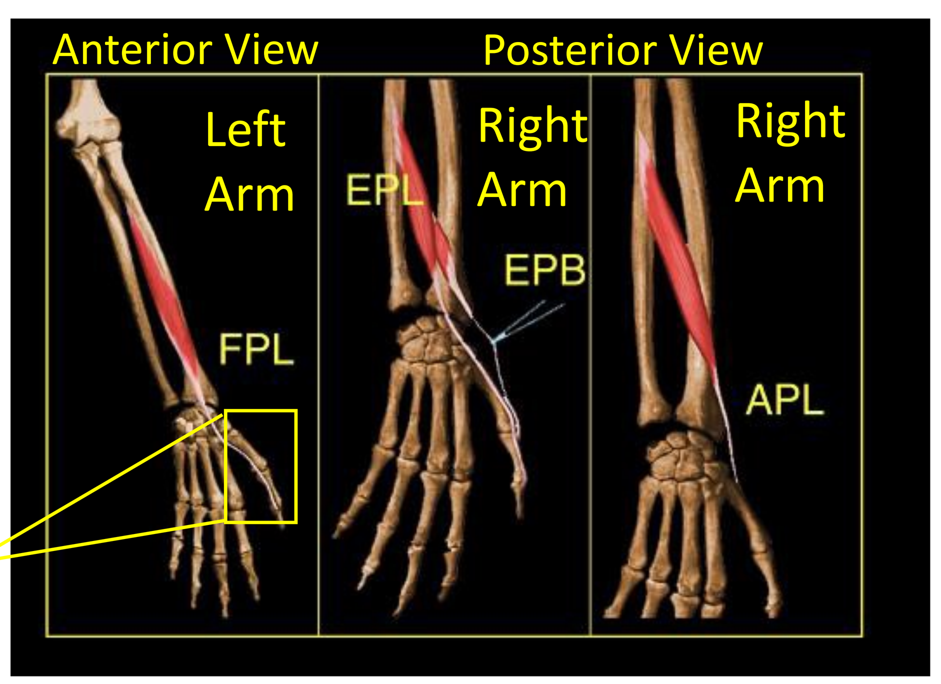


Figure 2 (left): CMC, MP, and IP joints located in thumb.

Discussion

1. EPB and FPL exhibit the greatest path length values.
   a) EPB plays a key role in extending the thumb-tip and is responsible for the longest path length.
   b) EPB tends to facilitate more three-dimensional thumb movements, whereas EPL predominantly enables movements in a two-dimensional plane.
      - Only muscle that produced a thumb-tip trajectory consistent with its nomenclature; upward/dorsally-directed thumb-tip movement.
2. FPL is responsible for the shortest path length and the highest intra-trial variability.
3. Muscles produce different amounts of endpoint change than the tendon input, which suggests that the thumb behaves like a variable transfer function.
4. Muscles produced thumb-tip movements inconsistent with how they are named, which points to the complexity of musculoskeletal biomechanics.

Methods

Phase 1: *Cadaver Preparation.* Dissected cadaveric specimens (n=2) to expose four muscles of interest.

Phase 2: *Arm Fixation Device*. Design of an arm fixation device to securely position cadaveric specimens during testing.

Phase 3: *Motion Tracking System*. Developed and validated custom thumb-tip motion tracking system to measure thumb joint and thumb-tip movement. [3]

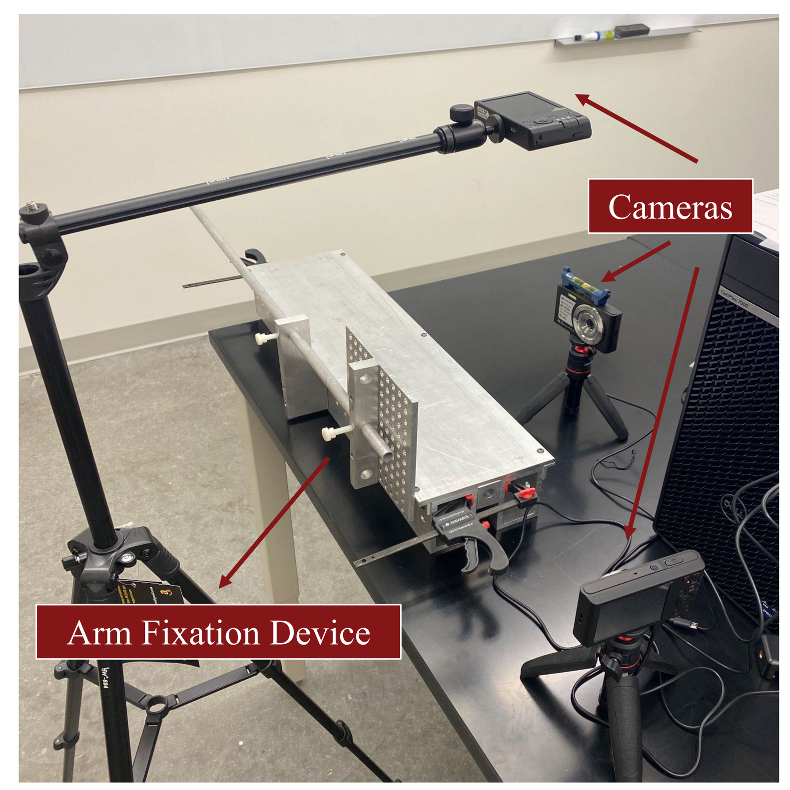


Figure 3: Camera system developed to capture 3D data as well as the arm fixation device used to secure specimen during testing.

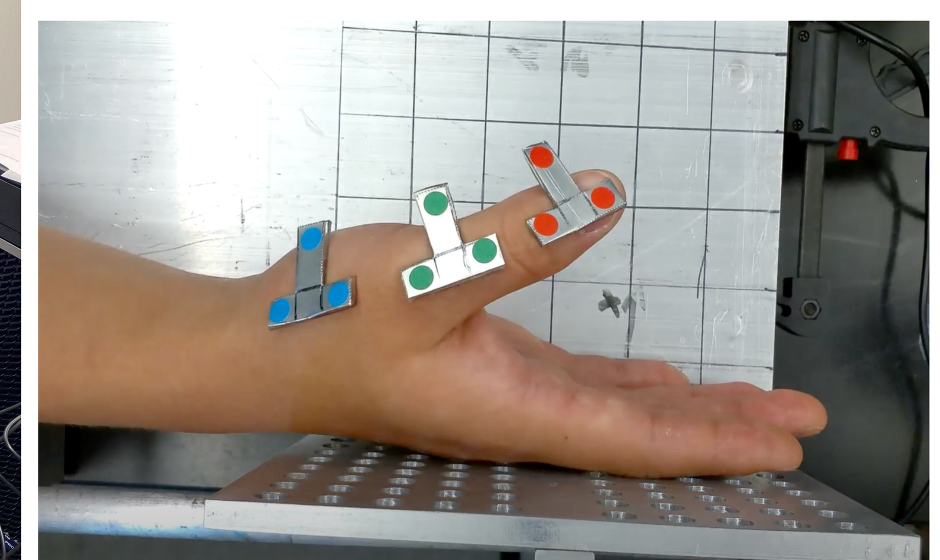


Figure 4: T-shaped markers and marker system used for motion capture.

Phase 4: *Actuation System*. Pulled tendon of interest to generate thumb movement.

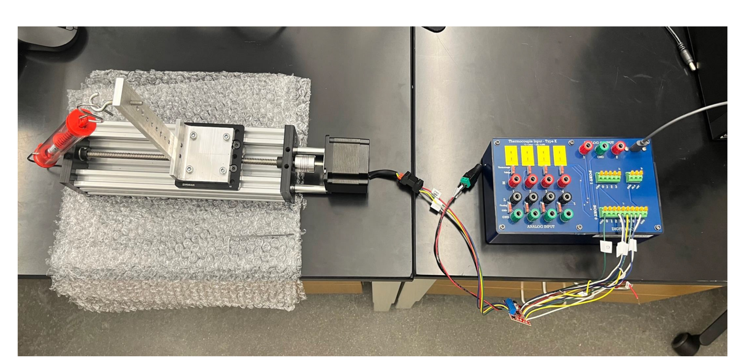


Figure 5: Motorized actuation system.

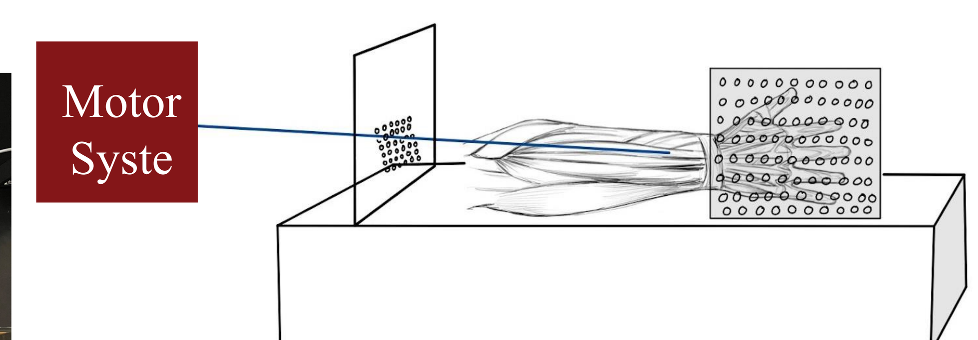


Figure 6: Schematic illustration of the motor system incorporating an arm fixation device.

Phase 5: *Data Extraction*. Computed 3D thumb-tip movement to understand muscle endpoint trajectories.

Future Work

1. Increase the specimen sample size and conduct statistical analyses to generalize our findings.
2. Compare measured data with current models of the hand to test the accuracy of current hand modes.
3. Implement multiple motor systems to pull on extrinsic muscles simultaneously and in a coordinated fashion to explore whether the relationship between muscle contraction velocity and endpoint trajectory is linear.
4. To measure endpoint trajectories that intrinsic muscle generates.

Results

Extensor Pollicis Brevis (EPB)

- Maximum path length of 48.5 mm
- Movement in the x, y, and z directions

Flexor Pollicis Longus (FPL)

- Maximum path length: 15 mm
- Primary movement: downward in the x-z plane
- Greatest degree of intra-trial variability in path smoothness, indicating a less predictable movement pattern

Extensor Pollicis Longus (EPL)

- Primary movement: positive z-direction within the x-z plane
- Additional activity in the x-y plane
- Path length: 46.2 mm

Abductor Pollicis Longus (APL)

- Primary movement: movements in the x-y plane
- Path length: 15.92 mm

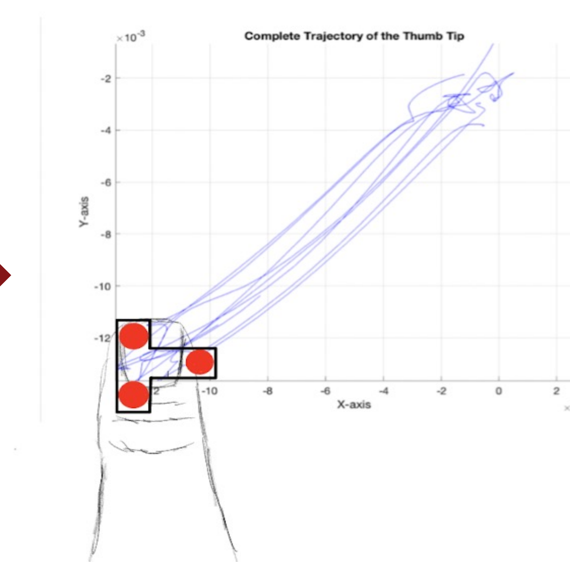


Figure 7: Trajectory of the thumb tip in x-y plane by pulling the EPL.

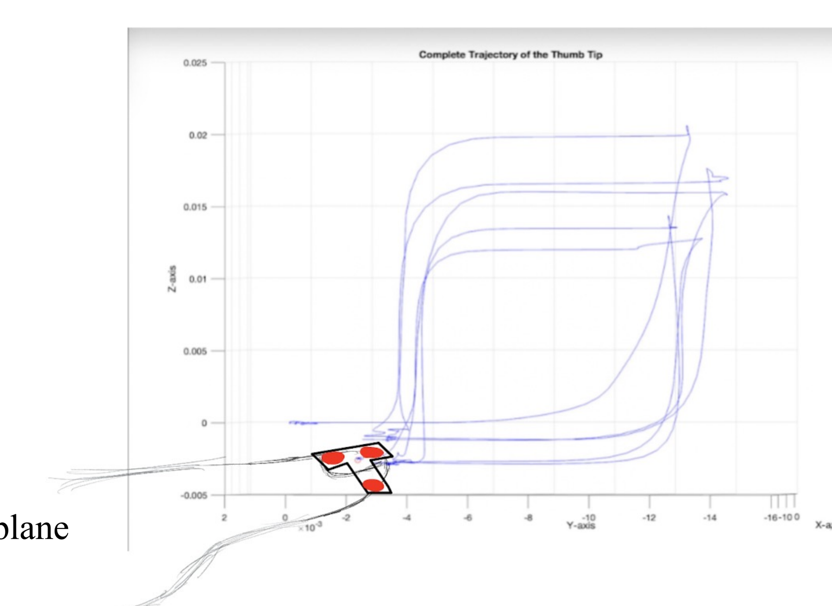


Figure 8: Trajectory of the thumb tip in y-z plane by pulling the EPL.

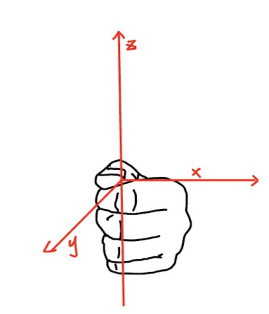


Figure 9: Schematic diagram showing x,y,z planes in relation to the thumb.

References

[1] Towles (2023). Measurement of the Three Dimensional Muscle Endpoint Forces in the Extended Thumb and Its Application to Determining Muscle Combinations that Enable Lateral Pinch Force Production Throughout the Plane of Flexion-Extension. Ann Int Conf IEEE Eng Med Biol Soc. pp 1-5.

[2] Towles et al. (2008). Use of Intrinsic Thumb Muscles May Help to Improve Lateral Pinch Function Restored by Tendon Transfer. Clin Biomech 23(4): 387-94.

[3] Li et al. (2008). Title. J Orthop Res 26(9): 1289-95.

Acknowledgments

We would like to thank Professor Joseph Towles for his mentorship on this project. Additionally, we would like to thank J. Johnson for assisting with the construction of the arm fixation device and Edmond Jaoudi for his contributions to the actuation system. Thank you to Justin Gonzalez '25 and Paolo Bosques-Paulet '27 for their contributions to the success of this project.