

EXTENSOR STRENGTH, SURGICAL TENSIONING, AND PINCH FORCE FOLLOWING BRACHIORADIALIS TO FPL TENDON TRANSFER: A SIMULATION STUDY

¹Jeremy P.M. Mogk, ²M. Elise Johanson, ²Vincent R. Hentz,
³Katherine R.S. Holzbaur, and ^{1,4,5}Wendy M. Murray

¹SMPP, Rehabilitation Institute of Chicago, ²VA Palo Alto Health Care System, ³Dept of Biomedical Engineering, Wake Forest University Health Sciences, ⁴Depts of Biomedical Engineering and Physical Medicine & Rehabilitation, Northwestern University, ⁵Edward Hines, Jr. VA Hospital
email: j-mogk@northwestern.edu, <http://www.smpp.northwestern.edu/Murray/index.shtml>

INTRODUCTION

Following cervical spinal cord injury (SCI), loss of hand function presents a challenge for autonomy. Functional independence can be greatly improved with surgical restoration of lateral pinch function, which involves transfer of the non-paralyzed brachioradialis muscle (BR) to the flexor pollicis longus (FPL) tendon. Computer simulations suggest that the surgeon's intraoperative "tensioning" of the BR-FPL transfer can have a marked effect on post-operative outcome, since the surgeon chooses the muscle attachment length, and force production varies with length [1]. These simulations assumed both non-impaired muscle strength and maximal activation of the transferred BR post-operatively. However, experimental data show that activation of the transferred BR is significantly lower during maximum lateral pinch efforts than resisted elbow flexion, with a more pronounced deficit in patients with weak elbow extension [2].

We used a biomechanical simulation approach to examine the effects of (i) muscle strength, and (ii) surgical attachment length on predictions of post-operative pinch force, based on recorded activation patterns.

METHODS

We integrated biomechanical simulations with MRI, EMG, dynamometric, and goniometric data. We augmented a model of the upper limb [3] to incorporate the BR-FPL transfer [1], and derived a Jacobian to enable pinch force calculation [4]. We included eight additional muscles that often remain under voluntary control after cervical SCI: two wrist extensors (ECRB and ECRL), three elbow extensors (all three heads of the triceps, TRI), and

three elbow flexors (brachialis, BRA, and both heads of the biceps, BIC). The remaining muscles were "paralyzed" by setting their active force-generating capacity to zero.

All simulations utilized EMG and joint posture data recorded from four individuals with tetraplegia and BR-FPL transfers during maximal lateral pinch force exertions. EMG recorded from the BIC, TRI and ECRB defined the activation levels of the modeled elbow flexors, as well as elbow and wrist extensors. The simulations computed the highest BR-FPL activation (act^{BR}), and the resultant lateral pinch force, for which (i) the elbow flexor moment was not larger than the extensor moment (i.e. $BR-FPL + BRA + BIC \leq TRI$), and (ii) the wrist flexor moment was not larger than the extensor moment (i.e. $BR-FPL \leq ECRB + ECRL$). Wrist and elbow moments were balanced about the flexion-extension axes only, and included posture-dependent inertial moments as well as passive moments produced by both active and paralyzed muscles. In this context, act^{BR} represents the proportion of posture-specific active BR muscle force that could be exerted without generating a net flexion moment at either joint. Test postures were defined by goniometric data. In these simulations, the shoulder was abducted (90°) and transversely flexed (30°) [2], and the elbow and wrist were extended.

Simulations were repeated at different strength levels and attachment lengths. "Non-impaired strength" assumed healthy muscle volumes [5] (and thus, force- and moment-generating capacity) in the tetraplegic limb. "Scaled strength" adjusted muscle volumes based on a combination of patient-specific wrist and elbow torque measurements and BR volume data (measured via MRI). Three surgical attachment lengths were also examined [1].

RESULTS AND DISCUSSION

Given the levels of elbow and wrist muscle co-activation recorded during maximum effort lateral pinch, our simulations suggest that strength influences both act^{BR} and pinch force. Simulations based on the BIC, TRI, and ECRB activations observed in two subjects illustrate limitations imposed by muscle weakness (Fig. 1). When we assumed non-impaired strength, calculated activations levels (1.0) and pinch forces (35.9 N) were maximized (and the same) for both patients because non-impaired extensor strength was sufficient to balance the flexor moments produced by BR-FPL and the elbow flexors. When strength was scaled, both act^{BR} and pinch force decreased substantially, yet uniquely, to accommodate for patient-specific elbow and wrist extensor weakness.

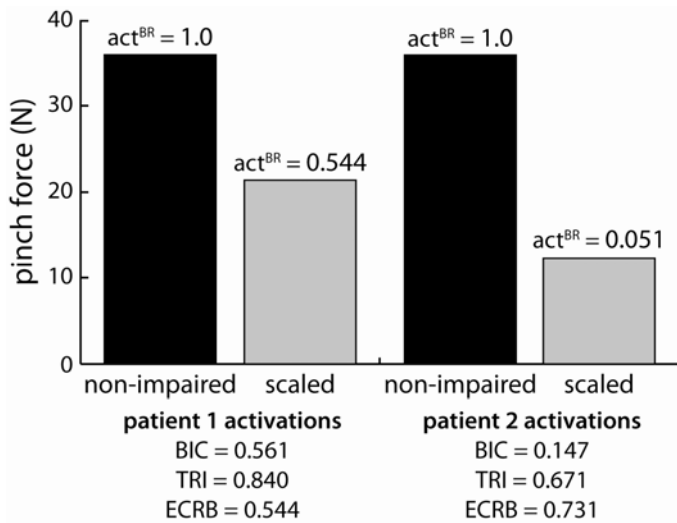


Figure 1. Pinch force and act^{BR} , calculated assuming non-impaired and scaled strength levels, given co-activation of elbow and wrist muscles from two patients.

Because act^{BR} was limited by weak elbow and wrist extensors in the simulations using patient-specific scaled strength levels, resultant pinch forces were less sensitive to surgical tensioning compared with those calculated using non-impaired strength (Fig. 2). For example, we calculated comparable pinch forces under “loose” (i.e. transferred length = 80% of original length) and “resting” (original length) tensioning conditions when we simulated patient strength levels, despite the fact that loose tensioning optimizes transferred BR force-length properties for extended elbow and wrist postures [1]. This occurred because calculated act^{BR} was less than 1.0 and varied with tensioning condition. In contrast, non-impaired extensor strength was sufficient for

$act^{BR} = 1.0$ for both tensioning conditions. The significantly different ($p < 0.005$) forces calculated in the non-impaired strength simulations reflect muscle force-length properties. For scaled strength, the pinch force predicted for each tension differed primarily in the relative contributions of active and passive force (i.e. looser tension = more active force), rather than force magnitude.

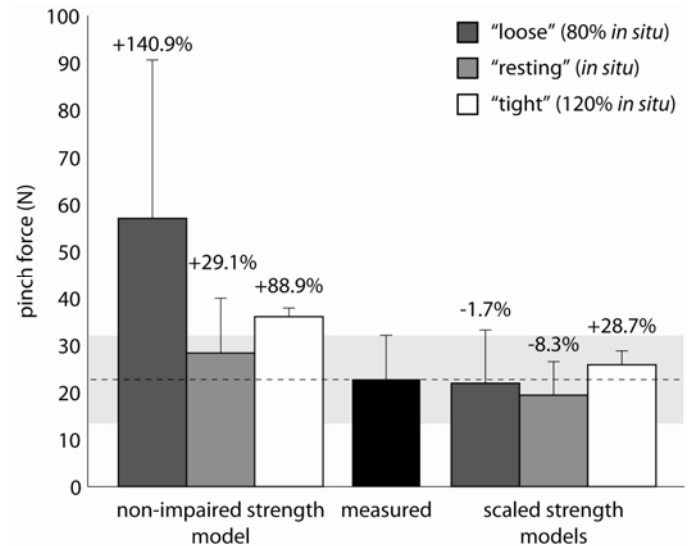


Figure 2. Comparison of measured and predicted pinch force (average of 11 trials; $n = 4$), with the mean % error shown above each bar.

Importantly, incorporation of patient-specific data led to results that were comparable to measured data (Fig. 2, black bar). Simulation results for the passive component of BR-FPL pinch force were larger than typically measured, and will be evaluated further.

CONCLUSIONS

Rehabilitation strategies that focus on strength training of the elbow and wrist extensors would benefit post-operative function of the surgically reconstructed tetraplegic limb.

REFERENCES

- Murray WM, et al. *J Bone Joint Surg* **88A**, 2009-2016, 2006.
- Johanson ME, et al. *J Hand Surg* **31A**, 747-753, 2006.
- Holzbaur KR, et al. *Ann Biomed Eng* **33**, 829-840, 2005.
- Goehler CM and Murray WM. *Proc ASME SBC*, Lake Tahoe, United States, 2009.
- Holzbaur KR, et al. *J Biomech* **40**, 742-749, 2007.

ACKNOWLEDGEMENTS

NIH 5 R01 HD 46774 and VA A3741R.