7-1-2019

The Effect of Wrist Position on Finger Tendon Loads Following Pulley Sectioning and Operative Reconstruction

Mohammad M. Haddara
Western University

B. Byers
St. Joseph's Health Care London

Shrikant Chinchalkar
St. Joseph's Health Care London

Louis M. Ferreira
Western University

Nina Suh
St. Joseph's Health Care London

Citation of this paper:
Haddara, Mohammad M.; Byers, B.; Chinchalkar, Shrikant; Ferreira, Louis M.; and Suh, Nina, "The Effect of Wrist Position on Finger Tendon Loads Following Pulley Sectioning and Operative Reconstruction" (2019). *Bone and Joint Institute*. 452.
https://ir.lib.uwo.ca/boneandjointpub/452

Journal of Hand Surgery Global Online 1 (2019) 154–160

Contents lists available at ScienceDirect

Journal of Hand Surgery Global Online

journal homepage: www.JHSGO.org

Original Research

The Effect of Wrist Position on Finger Tendon Loads Following Pulley Sectioning and Operative Reconstruction

Mohammad M. Haddara, MESc, [*] Brett Byers, MD, [†] Shrikant Chinchalkar, MThO, BScOT, [†]
Louis M. Ferreira, PhD, PEng, [*, †, ‡] Nina Suh, MD [†, ‡]

[*] *Department of Biomedical Engineering, Western University, London, Ontario, Canada*
[†] *Roth—McFarlane Hand and Upper Limb Centre, St Joseph's Health Care London, Ontario, Canada*
[‡] *Department of Surgery, Schulich School of Medicine & Dentistry, Western University, London, Ontario, Canada*

ARTICLE INFO

Article history:
Received for publication April 9, 2018
Accepted in revised form April 14, 2019
Available online June 22, 2019

Key words:
A2
A4
load
pulley reconstruction
wrist position

Purpose: Postoperative rehabilitation is important for maximizing patient outcomes after surgical pulley reconstruction. The purpose of this study was to identify the optimal wrist position in which rehabilitation should be undertaken to decrease the load on surgically reconstructed pulleys.
Methods: We tested 14 digits composed of the index, middle, and ring fingers from 5 cadaveric specimens in a novel *in vitro* finger motion simulator designed to achieve full finger flexion and extension actively. Servo-motors were used to generate motion through tendons under load or position control while measuring tendon forces, joint range of motion, and tendon excursion. Flexor digitorum profundus (FDP) and flexor digitorum superficialis loads were measured sequentially with native intact pulleys and A2 and A4 pulleys sectioned, and with reconstructed A2 and A4 pulleys. Each condition was tested with the wrist neutral and with 30° wrist flexion or extension. The effect of wrist position on FDP and flexor digitorum superficialis loads under each condition was analyzed using repeated-measures analysis of variance.
Results: With pulleys reconstructed, the wrist position had a significant effect on tendon load. The flexed wrist position resulted in a 31% reduction of FDP load compared with the neutral wrist position. Wrist extension also produced an apparent reduction of 14%, although not statistically significant.
Conclusions: After pulley repair, placing the wrist in 30° flexion decreased tension in the FDP tendon compared with a neutral wrist.
Clinical relevance: This study suggests that rehabilitation should be carried out with the wrist flexed to reduce the load on pulley reconstructions.

The finger flexor pulleys function to maintain and stabilize tendons close to bone.[1–3] The anatomical arrangement and function of the pulleys allow for any tensile force or excursion experienced by the flexor tendons to be translated efficiently into torque at the finger joints.[4] The A2 and A4 pulleys are known to be the most clinically important in maintaining independent interphalangeal joint function by preventing tendon bowstringing.[5–8]

The central tenet of current surgical reconstruction of flexor pulleys is to restore proper finger motion by repairing the biomechanical disadvantage caused by tendon bowstringing. Flexor pulley reconstructions are uncommon compared with other hand-related injuries such as tendon repairs; however, the reconstruction procedure itself is straightforward. Surgical reconstructions are often performed using the Bunnell technique, which involves the use of a free tendon graft, generally the palmaris longus or a slip of the flexor digitorum superficialis (FDS), and is looped at least twice or 3 times around the flexor tendon and the adjacent bone.[9–11]

Isolated pulley ruptures happen[12] frequently in the rock climbing community, for instance,[13–15] or may happen with proximal phalanx fractures. Although extensive research on the anatomy and the different surgical reconstruction techniques has been

---

Declaration of interests: No benefits in any form have been received or will be received by the authors related directly or indirectly to the subject of this article.

Corresponding author: Nina Suh, MD, FRCSC, Roth—McFarlane Hand and Upper Limb, Centre, St Joseph's Health Care London, 268 Grosvenor Street, Room D0-215, London, Ontario, Canada, N6A 4V2.

E-mail address: Nina.Suh@sjhc.london.on.ca (N. Suh).

https://doi.org/10.1016/j.jhsg.2019.04.002

widely reviewed and evaluated,[12,16–20] proper therapy after surgery remains inadequately explored. It is estimated that 6% of patients who undergo surgical reconstruction experience complications such as bowstringing, stiffness, and pain in the midst of rehabilitation.[14,15,21] One of many reasons stiffness in the finger occurs after reconstruction is believed to be inadequate gliding of flexor tendons. The cause and risk for such impediments, however, are neither well-described nor well-understood within the current clinical literature.

When undergoing therapy after pulley reconstruction, clinicians typically fix the wrist in a neutral position.[22–26] Frequently, this action is taken with insufficient justification for the impact of the wrist position. Further to any technical difficulties encountered during surgery, complications during healing remain challenging because the integrity of a pulley repair is directly influenced by loads exerted along the flexor tendons. The relation between load experienced by a pulley and that along a flexor tendon was first defined in a biomechanical model reported by Hume et al,[27] which was later improved by Roloff et al[4] and experientially tested by Schoffl et al.[13] Thus, measurement of the tendon load can be used as a surrogate for the pulley load. Consequently, the purpose of this study was to evaluate the effects of varying wrist positions (neutral, flexed, and extended) on the load experienced by the pulleys. The objective was to identify an optimal wrist position in which rehabilitation should be undertaken to decrease the load on pulleys after reconstruction surgery.

Materials and Methods

We tested 14 digits, composed of the index, middle, and ring fingers, from 5 freshly frozen cadaveric specimens amputated 10 cm proximal to the wrist (aged 71.8 ± 9.9 years; 2 men and 3 women). Specimens were thawed overnight (16 hours) at room temperature before testing. All computed tomography scans of specimens were screened before testing for the presence of osteoarthritis at the metacarpophalangeal (MCP), proximal interphalangeal, and distal interphalangeal (DIP) joints.

The arm was transversely sectioned at the mid-forearm and the distal radius and ulna were secured in the motion simulator using 2 screws in each bone, with attention to maintaining neutral forearm rotation. A hand fellowship-trained plastic surgeon carefully dissected the wrists to isolate the flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS), and extensor tendon of each finger. Once located, each tendon was subsequently sutured to individual load cells (Model 34; Honeywell, Charlotte, NC) using 0-braided Vicryl (Ethicon, Somerville, NJ) in a locked Krakow fashion and attached in series to linear servo-actuators for testing[28] (Fig. 1). Actuators were positioned to maintain the tendon physiological lines of action with sutures guided through low-friction eyelet guides. Two K-wires were inserted transversely through the metacarpals to ensure stability during finger motion. Tendon excursions were closed-loop controlled using the servo-actuator's internal encoder, and tendon loads were closed-loop controlled using the load cells, which were mounted to each actuator's end-effector (Fig. 1). Servo-actuator control and tendon load measurements were made with custom code (LabVIEW, National Instruments, Austin, TX). Joint kinematics and range of motion were measured using a trakSTAR (NDI, Waterloo, Ontario, Canada) electromagnetic tracking system. Each 2-mm-diameter electromagnetic tracker (Model M180) was press-fit into a drill hole made transversely at the mid-phalanx of each finger segment (Fig. 2).

Rigid foam wedges were used to adjust the wrist at varying positions (wrist neutral, 30° wrist flexion, and 30° wrist extension) (Fig. 3). The hand was stabilized using 2-mm Dacron braided cable (Melton International Tackle, Anaheim, CA) to tie down the metacarpal K-wires, to prevent movement of the wrist during finger motion. All remaining tissues within the specimen were left intact and saline solution was used to maintain hydration of the tissues throughout testing to prevent tissue desiccation.

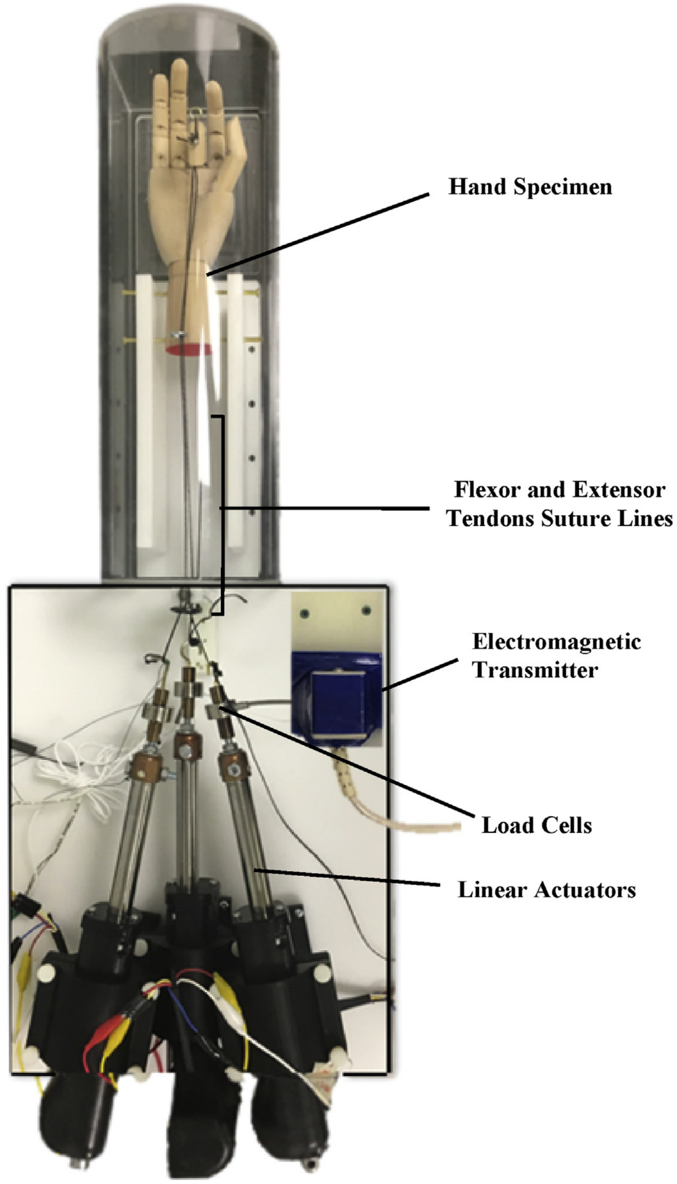

Figure 1. Active finger motion simulator. Full assembly of the simulator including linear tendon actuators and load cells for closed-loop control of tendon loads as well as tendon load measurement. Shown is a hand phantom used for motion control prototyping. An electromagnetic transmitter is used to measure joint ranges of motion.

To determine the amount of tendon excursion for each finger, a flexion trial was initially performed by moving FDP and FDS in position control against a 10-N extensor load until full flexion range of motion was achieved and visually confirmed by a fellowship-trained surgeon in all joints (MCP, 85° ± 16°; proximal interphalangeal, 112° ± 10°; and DIP, 55° ± 21°). This was repeated for finger extension, with the extensor in position control against a 5-N load on each flexor tendon. Those loads were used to ensure that the closed-loop load feedback controller did not allow slack within the tendons during motion.[29,30] This flexion-extension test was repeated for each finger (index, middle, and ring) in each wrist position (neutral, 30° flexed, and 30° extended).

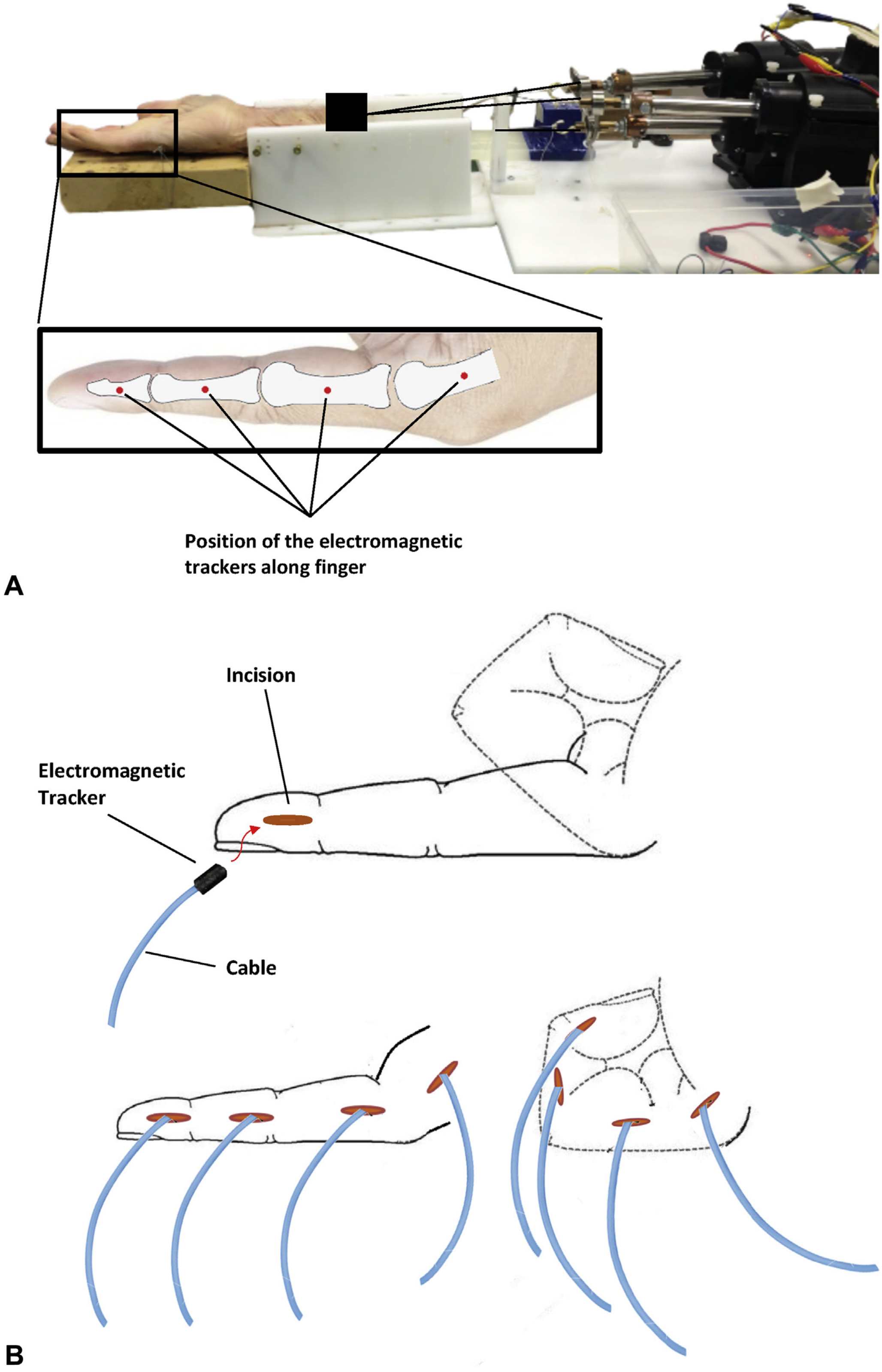

Figure 2. Kinematics tracking. **A** Six degrees of freedom electromagnetic trackers were mounted in each midphalanx and metacarpal as denoted by red dots **B** to measure range of motion.

After all intact active finger motion simulations, a longitudinal incision was made along the length of the volar surface of the digit 1 cm proximal to the MCP joint and 1 cm distal to the DIP joint to identify the pulleys. Lengths of the pulleys were recorded using a Vernier caliper (A2, 17.7 ± 2.1 mm; and A4, 6.4 ± 1.0 mm).

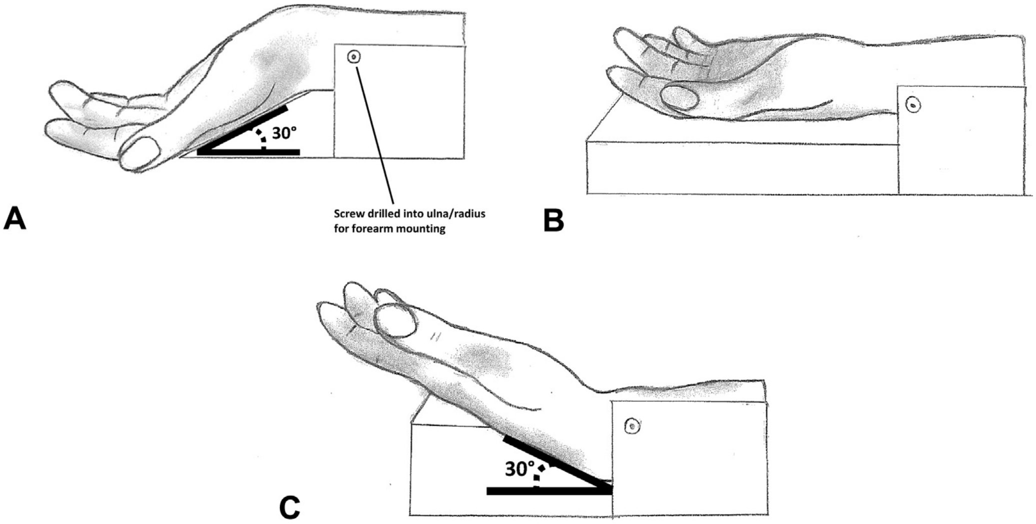

Figure 3. Wrist positioning. Foam wedge blocks provided wrist stability in 3 positions: **A** extended 30°, **B** neutral, and **C** flexed 30°.

All flexor loads were collected under 3 conditions: (1) with pulleys intact, (2) with A2 and A4 fully cut, and (3) full pulley reconstructions. For the fully cut condition, flexion runs were performed by actuating the FDP and FDS tendons to the excursions determined in the intact condition to observe possible changes in joint kinematics or tendon load as a response to the simulated injury. In the pulley reconstructed condition, the target flexion end point was the MCP joint angle achieved in the intact condition, which provided a direct comparison between intact and reconstructed conditions. Each flexion motion was repeated 3 times and the data used were recorded from the last (third) motion. Load values were recorded at the end of each flexion run, because maximum loads always occurred at full finger flexion.

Pulley reconstructions were performed in the wrist neutral position and were made using a circumferential tendon graft technique, looped twice for a double tendon thickness reconstruction around the proximal phalanx for A2 (Fig. 4) and around both the middle phalanx and extensor mechanism for A4. The palmaris longus was used as the primary graft donor, followed by split FDS tendon (from previously amputated digits) when additional graft material was required. To adjust the tension of the reconstruction, a snap was placed between the tendon and the reconstructed pulley while it was sutured. The tension was tested by flexing and extending the digits under direct visual observation for free gliding of the tendon; it was adjusted if required. The skin was sutured together after each cut or reconstruction to avoid desiccation.

A minimum sample size of 12 was determined with a repeated-measures analysis of variance model set to achieve statistical significance with 80% power for an effect size of 0.26. The effect size was determined from pilot tests in 4 specimens. Repeated-measures analysis of variance with Bonferroni correction were performed to analyze the effect of pulley condition with 3 levels (intact, A2 and A4 cut, and full reconstruction), as well as the effect of wrist position with 3 levels (neutral, 30° flexed, and 30° extended), during finger flexion-extension. Within-subject effects and pairwise comparisons were also examined, with significance set at $P < .05$.

Results

With A2 and A4 pulleys sectioned, finger flexion revealed a significant decrease in FDP and FDS tendon loads in every wrist

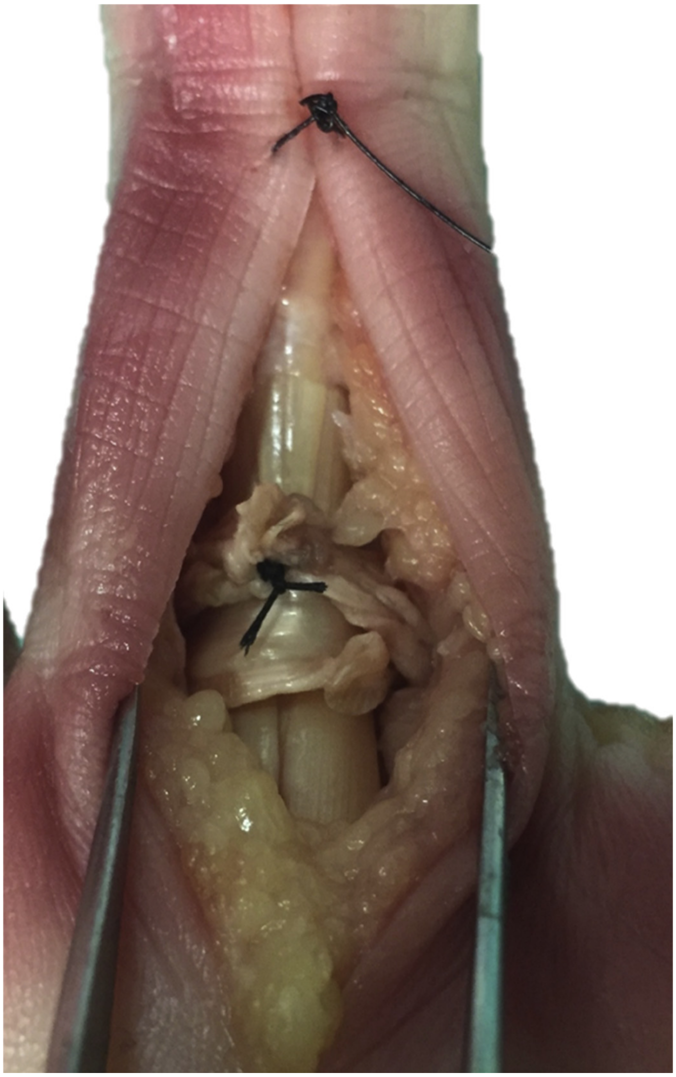

Figure 4. Bunnell's technique for pulley reconstruction. Reconstruction of the A2 pulley was performed by looping a tendon graft twice around the tendon and adjacent bone. The skin was sutured closed during finger motion trials to prevent desiccation.

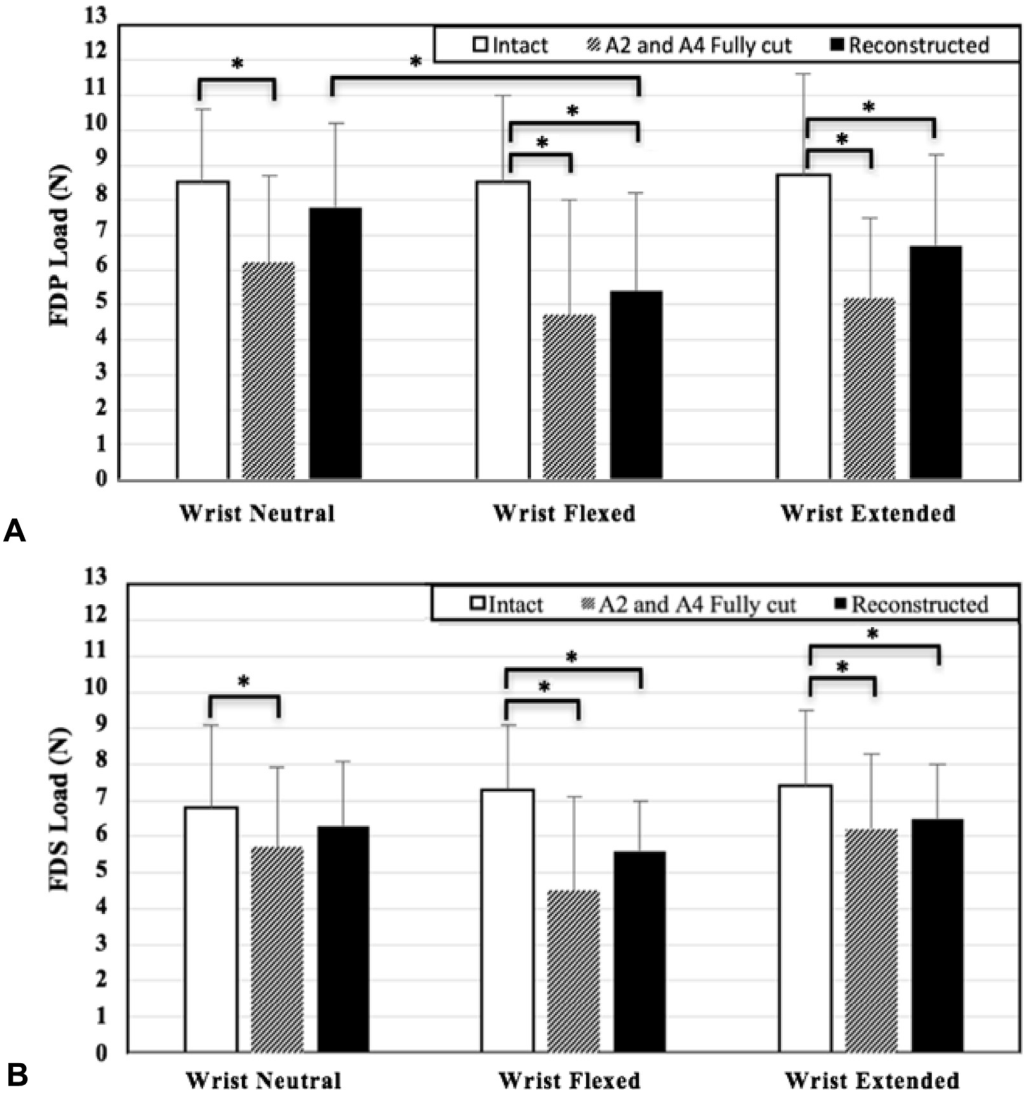

Figure 5. Flexor tendon peak loads during finger motion. Maximum **A** FDP and **B** FDS loads as a function of wrist position and pulley condition (*$P < .05$) in which whiskers denote 1 SD of 14 specimens. For the reconstructed A2 and A4 pulleys, the wrist flexed position produced less FDP load compared with the wrist neutral position ($P < .05$).

position compared with the intact state ($P < .05$). With both pulleys reconstructed, wrist position had an overall effect on FDP loads ($P < .05$) but not on FDS loads ($P = .28$) (Fig. 5). The flexed wrist position resulted in a reduction of 2.4 ± 3.9 N in FDP loads compared with the neutral wrist position ($P < .05$). The wrist extended position did not significantly reduce FDP tendon loads, which were 1.0 ± 3.5 N less than in neutral wrist position ($P = .29$). All trials were successfully measured, with no missing data points.

Wrist neutral

With the wrist in neutral, sectioning the A2 and A4 pulleys caused the FDP load to decrease by 2.3 ± 1.9 N ($P < .05$) and the FDS load to decrease by 2.3 ± 1.5 N ($P < .05$) compared with the intact pulley condition. Subsequent pulley reconstruction restored the FDP load within 0.7 ± 2.1 N ($P = .25$) and FDS loads within 0.5 ± 1.0 N ($P = .07$) of the intact pulley condition.

Wrist flexed

With the wrist fixed in the 30° flexed position, excision of both pulleys reduced FDP tendon load by 3.8 ± 3.5 N ($P < .05$), which then increased to within 3.2 ± 3.2 N of the intact condition ($P < .05$) by subsequent reconstruction. Similarly, pulley excision caused the FDS load to decrease by 2.9 ± 1.9 N ($P < .05$) and reconstruction increased the FDS load to within 1.7 ± 1.9 N of the intact condition ($P < .05$) with subsequent repair.

Wrist extended

With the wrist extended, excision of both pulleys reduced the FDP load by 3.5 ± 1.7 N ($P < .05$) and the FDS load by 1.3 ± 1.4 N ($P < .05$). Pulley repair increased both tendon loads, FDP and FDS, to within 1.9 ± 3.4 N ($P < .05$) and 1.0 ± 1.3 N ($P < .05$), respectively, of the intact condition.

Discussion

Surgical reconstruction of the A2 and A4 pulleys after an injury is important for restoring proper kinematics of the finger by preventing tendon bowstringing and resultant joint contracture.[31] To the authors' knowledge, this is the first study that directly examined rehabilitation after pulley repairs, as opposed to flexor tendon repairs. The relation between flexor tendon load and load experienced by the pulley was first defined by Hume et al,[27] later refined by Roloff et al,[4] and then tested by Schoffl et al.[13] Using tendon load as a surrogate for pulley load, the current study found that wrist position had a significant effect on tendon load after pulley reconstruction, with the flexed wrist position resulting in a 31% reduction of FDP load compared with the neutral wrist position. Wrist extension also produced an apparent reduction of 14% in the FDP load compared with the neutral wrist position, although this did not reach statistical significance. In addition, FDP loads in the wrist flexed and extended positions were restored to within 3 N (+7%) and 1.8 N (+19%), respectively compared with the intact condition. The wrist flexed position produced the lowest tendon loads with pulleys cut and repaired.

According to the literature, varying the wrist position is known to have an effect on flexor tendon loads; however, flexor tendon loads were similar, within 0.2 N, among different wrist positions (Fig. 5), although the cut and reconstructed pulley conditions demonstrated different tendon loads among wrist neutral, flexed, and extended positions. The reason for this is unclear, but it could be caused by a difference in the stiffness of the intact versus the reconstructed pulley, although this study was not designed to elucidate such an effect.

The FDP and FDS tendons experienced reduced loads after pulley excision in every wrist position. However, the restoration of tendon loads after reconstruction reached intact levels only in the wrist neutral position. In the wrist flexed and extended positions, reconstructed pulleys still showed a significant reduction of FDP and FDS loads. This suggests that the reconstructed pulleys experienced less load in the wrist flexed and extended positions after reconstruction. Decreasing the load on pulley reconstructions may facilitate early tendon mobilization without compromising the surgical repair. These results suggest that rehabilitation of surgically reconstructed flexor tendon pulleys should be carried out with the wrist flexed, as opposed to the wrist in neutral, as is conducted by clinicians in current practice.

This study had 3 main limitations. First, the cadaveric specimens were previously frozen and of advanced age. Second, all specimens were amputated proximal to the wrist. Consequently, this would have altered the loads within tendons compared with *in vivo*. However, we employed a repeated-measures experimental design; thus, any changes in tension resulting from amputation were applied to all tested conditions. Although the tension magnitude *in vivo* will likely be different, the statistically significant relation likely will remain. Finally, the protocol required amputation of each finger after it was tested, to accommodate the cords for electromagnetic trackers for the subsequent finger. This may have altered the biomechanics of the subsequently tested finger, because the decrease in friction and resistance caused by removing the adjacent finger simply by untethering the skin and connective tissues might have resulted in the tested finger being more responsive to tendon loads. Despite these limitations, an important strength of this study was the use of servo-motors with closed-loop control of the tendon load, which represents an advance from previously reported *in vitro* finger motion simulators. In addition, we performed a sample size analysis to predict sufficient statistical power for the hypothesis test, which is an improvement compared with standard practice in upper-extremity *in vitro* motion testing.

Our ability to place these findings in the context of the existing literature is limited by the lack of published case reports on rehabilitation protocols after pulley reconstruction. Although the effects of wrist position on internal tendon loads after flexor pulley surgical reconstruction "has not been fully explored," research on its effects after tendon repair continues to develop.[32,33] Elliot[34] concluded that placing the wrist in 20° to 30° flexion resulted in positive outcomes during rehabilitation after a tendon tear. Hazelton et al[35] also established an order regarding which wrist position produced the greatest to least finger flexion force: ulnar deviation, neutral, radial deviation, extension, and finally, flexion. In addition, Bhardwaj et al[36] reported that grip strength decreased by approximately 50% with the wrist in a 30° flexed position compared to neutral. These findings complement the current observations, further supporting the hypothesis that rehabilitation should be carried out with the wrist flexed. However, there have been multiple contradictory studies as to the optimal wrist position for the postoperative rehabilitation of flexor tendons. Becker et al,[22] Savage and Risitano,[23] Silfverskiöld and May,[26] Osada et al,[24] Saini et al,[37] and Moriya et al[25] placed the wrist in neutral or extension whereas Bernstein and Taras[38] and the protocol of Kleinert et al[39] placed the wrist in flexion. Therefore, although the concept of wrist flexion decreasing tension in the FDP tendon is intuitive, disagreement remains regarding the optimal wrist position after flexor tendon repair, let alone pulley reconstruction. Thus, the current study strengthens the theory that the wrist should be placed in the flexed position for postoperative finger rehabilitation.

References

1. Heithoff SJ, Millender LH, Helman J. Bowstringing as a complication of trigger finger release. *J Hand Surg Am*. 1988;13(4):567–570.
2. Zafonte B, Rendulic D, Szabo RM, Inanami H, Kuroshima N, Pechlaner S. Flexor pulley system: anatomy, injury, and management. *J Hand Surg Am*. 2014;39(12):2525–2532; quiz 2533.
3. Schöffl I, Oppelt K, Jüngert J, et al. The influence of concentric and eccentric loading on the finger pulley system. *J Biomech*. 2009;42(13):2124–2128.
4. Roloff I, Schöffl VR, Vigouroux L, Quaine F. Biomechanical model for the determination of the forces acting on the finger pulley system. *J Biomech*. 2006;39(5):915–923.
5. Doyle JR. Anatomy of the finger flexor tendon sheath and pulley system. *J Hand Surg Am*. 1988;13(4):473–484.
6. Chow JC, Sensinger J, McNeal D, Chow B, Amirouche F, Gonzalez M. Importance of proximal A2 and A4 pulleys to maintaining kinematics in the hand: a biomechanical study. *Hand (N Y)*. 2014;9(1):105–111.
7. Amadio PC, Lin GT, An K-N. Anatomy and pathomechanics of the flexor pulley system. *J Hand Ther*. 1989;2(2):138–141.
8. Dunlap J, McCarthy JA, Joyce ME, Manske PR. Biomechanical and histologic evaluations of pulley reconstructions in nonhuman primates. *J Hand Surg Am*. 1990;15(1):57–63.
9. Lin GT, Amadio PC, An KN, Cooney WP, Chao EY. Biomechanical analysis of finger flexor pulley reconstruction. *J Hand Surg Br*. 1989;14(3):278–282.
10. Boyes J. *Bunnell's Surgery of the Hand*. 4th ed. Philadelphia, PA: JB Lippincot; 1965.
11. Nishida J, Amadio PC, Bettinger PC, An KN. Flexor tendon-pulley interaction after pulley reconstruction: a biomechanical study in a human model in vitro. *J Hand Surg Am*. 1998;23(4):665–672.
12. Lister GD. Reconstruction of pulleys employing extensor retinaculum. *J Hand Surg Am*. 1979;4(5):461–464.
13. Schoffl I, Oppelt K, Schweizer A, et al. A new measuring technique for determining the forces acting on the pulley system of the finger. *J Biomech*. 2009;42(13):2183–2187.
14. Gabl M, Rangger C, Lutz M, Fink C, Rudisch A, Pechlaner S. Disruption of the finger flexor pulley system in elite rock climbers. *Sports Med*. 1998;26(5): 651–655.
15. Voulliaume D, Forli A, Parzy O, Moutet F. Surgical repair of flexor tendon pulley rupture in high level rock climbing 2004;. 2004;23(5):243–248.
16. Doyle J. Palmar and digital flexor tendon pulleys. *Clin Orthop Surg*. 2001;383: 84–96.
17. Clark T, Skeete K, Amadio P. Flexor tendon pulley reconstruction. *J Hand Surg Am*. 2010;35(10):1685–1689.
18. Mehta V, Phillips C. Flexor tendon pulley reconstruction. *Hand Clin*. 2005;21(2): 245–251.
19. Karev A, Stahl S, Taran A. The mechanical efficiency of the pulley system in normal digits compared with a reconstructed system using the "belt loop" technique. *J Hand Surg Am*. 1987;12(4):596–601.
20. Klinert HE, Bennett JB. Digital pulley reconstruction employing the always present rim of the previous pulley. *J Hand Surg Am*. 1978;3(3):297–298.
21. Dy CJ, Lyman S, Schreiber JJ, Do HT, Daluiski A. The epidemiology of reoperation after flexor pulley reconstruction. *J Hand Surg Am*. 2013;38(9):1705–1711.
22. Becker H, Orak F, Duponselle E. Early active motion following a beveled technique of flexor tendon repair: report on fifty cases. *J Hand Surg Am*. 1979;4(5):454–460.
23. Savage R, Risitano G. Flexor tendon repair using a "six strand" method of repair and early active mobilisation. *J Hand Surg Br*. 1989;14(4):396–399.

24. Osada D, Fujita S, Tamai K, Yamaguchi T, Iwamoto A, Saotome K. Flexor tendon repair in zone II with 6-strand techniques and early active mobilization. *J Hand Surg Am*. 2006;31(6):987–992.
25. Moriya K, Yoshizu T, Maki Y, Tsubokawa N, Narisawa H, Endo N. Clinical outcomes of early active mobilization following flexor tendon repair using the six-strand technique: short- and long-term evaluations. *J Hand Surg Eur Vol*. 2015;40(3):250–258.
26. Silfverskiöld KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. *J Hand Surg Am*. 1994;19(1):53–60.
27. Hume EL, Hutchinson DT, Jaeger SA, Hunter JM. Biomechanics of pulley reconstruction. *J Hand Surg Am*. 1991;16(4):722–730.
28. Haddara M. Development of an Active Finger Motion Simulator: With In-Vitro Assessments of Tendon Loads and Joint Kinematics [thesis]. London, Ontario, Canada: University of Western Ontario; 2017.
29. Ferreira LM, Johnson JA, King GJW. Development of an active elbow flexion simulator to evaluate joint kinematics with the humerus in the horizontal position. *J Biomech*. 2010;43(11):2114–2119.
30. Ferreira LM, King GJW, Johnson JA. Motion-derived coordinate systems reduce inter-subject variability of elbow flexion kinematics. *J Orthop Res*. 2011;29(4): 596–601.
31. Langer M, Oeckenpöhler S, Hartensuer R, Herrmann K, Wieskötter B. Pulley reconstruction in the hand [in German]. *Orthopade*. 2015;44(10):757–766.
32. Vucekovich K, Gallardo G, Fiala K. Rehabilitation after flexor tendon repair, reconstruction, and tenolysis. *Hand Clin*. 2005;21(2):257–265.
33. Rrecaj S, Martinaj M, Murtezani A, Ibrahimi-Kaçuri D, Haxhiu B, Zatriqi V. Physical therapy and splinting after flexor tendon repair in zone II. *Med Arch*. 2014;68(2):128–131.
34. Elliot D. Primary flexor tendon repair—operative repair, pulley management and rehabilitation. *J Hand Surg Am*. 2002;27(6):507–513.
35. Hazelton FT, Smidt GL, Flatt AE, Stephens RI. The influence of wrist position on the force produced by the finger flexors. *J Biomech*. 1975;11(8):301–306.
36. Bhardwaj P, Nayak SS, Kiswar AM, Sabapathy SR. Effect of static wrist position on grip strength. *Indian J Plast Surg*. 2011;44(1):55–58.
37. Saini N, Kundnani V, Patni P, Gupta S. Outcome of early active mobilization after flexor tendons repair in zones II-V in hand. *Indian J Orthop*. 2010;44(3):314–321.
38. Bernstein MA, Taras JS. Flexor tendon suture: a description of two core suture techniques and the Silfverskiöld epitendinous suture. *Tech Hand Up Extrem Surg*. 2003;7(3):119–129.
39. Kleinert H, Kutz J, Cohen M. Primary repair of zone 2 flexor tendon lacerations. In: Hunter J, Schneider L, eds. AAOS Symposium on Tendon Surgery in the Hand. St Louis, MO: CV Mosby; 1975:91–114.