SCIENTIFIC ARTICLE

Functional Consequence of Distal Brachioradialis Tendon Release: A Biomechanical Study

Timothy F. Tirrell, BS, Orrin I. Franko, MD, Siddharth Bhola, MD, Eric R. Hentzen, MD, PhD,
Reid A. Abrams, MD, Richard L. Lieber, PhD

Purpose Open reduction and internal fixation of distal radius fractures often necessitates release of the brachioradialis from the radial styloid. However, this common procedure has the potential to decrease elbow flexion strength. To determine the potential morbidity associated with brachioradialis release, we measured the change in elbow torque as a function of incremental release of the brachioradialis insertion footprint.

Methods In 5 upper extremity cadaveric specimens, we systematically released the brachioradialis tendon from the radius and measured the resultant effect on brachioradialis elbow flexion torque. We defined release distance as the distance between the release point and the tip of the radial styloid.

Results Brachioradialis elbow flexion torque dropped to 95%, 90%, and 86% of its original value at release distances of 27, 46, and 52 mm, respectively. Importantly, brachioradialis torque remained above 80% of its original value at release distances up to 7 cm.

Conclusions Our data demonstrate that release of the brachioradialis tendon from its insertion has minor effects on its ability to transmit force to the distal radius.

Clinical relevance These data imply that release of the distal brachioradialis tendon during distal radius open reduction internal fixation can be performed without meaningful functional consequences to elbow flexion torque. Even at large release distances, overall elbow flexion torque loss after brachioradialis release would be expected to be less than 5% because of the much larger contributions of the biceps and brachialis. Use of the brachioradialis as a tendon transfer donor should not be limited by concerns of elbow flexion loss, and the tendon could be considered as an autograft donor. *(J Hand Surg 2013;xx:. Copyright © 2013 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Brachioradialis, distal radius fracture, elbow torque.

THE BRACHIORADIALIS (BR) muscle is an elbow flexor that originates on the lateral supracondylar ridge and inserts just proximal to the radial styloid. It is most effective when the elbow is in a flexed position, because both biceps and brachialis generally have decreasing moment arms at flexion angles greater than 90°.[1] As a result of the placement of its insertion on the radius, it also participates in pronation and supi-

From the Departments of Orthopaedic Surgery and Bioengineering, and the Biomedical Sciences Graduate Program, University of California San Diego; and the Research Service, VA San Diego Healthcare System, San Diego, CA.

Received for publication March 31, 2012; accepted in revised form January 17, 2013.

The authors thank Shannon Bremner for technical assistance with device development. They also thank the individuals who donated their bodies and tissues for the advancement of education and research. The authors also thank Dr. Wendy Murray (Northwestern University) for providing valuable BR modeling data.

Funded by a grant from the American Foundation for Surgery of the Hand, the Department of Veterans Affairs, and National Institutes of Health grant R24HD050837.

Corresponding author: Richard L. Lieber, PhD, Departments of Orthopaedic Surgery and Bioengineering (0863), University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093; e-mail: rlieber@ucsd.edu.

0363-5023/13/xx0x-0001$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2013.01.029

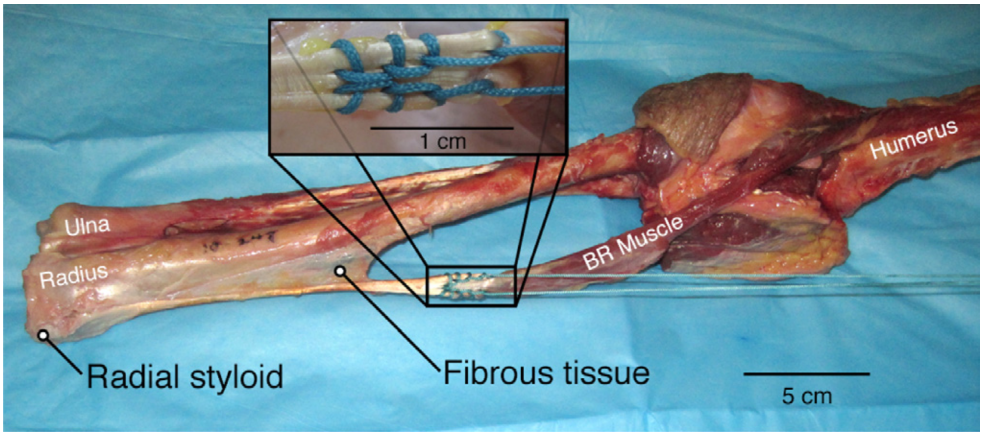

FIGURE 1: Limb dissection with all muscles except BR removed. Note the fibrous connections between the BR and the radius that can transmit force to the radius at release distances proximal to the tendinous insertion. Inset: Close-up view of the Krackow stitch used to secure the BR tendon.

nation, depending on forearm rotation. Its insertion forms the floor of the first dorsal compartment and takes the shape of a teardrop or a heart, with its point oriented proximally. The insertion is 15 mm long and 11 mm wide, and extends distally to a point that is 17 mm proximal to the tip of the radial styloid.[2]

Previous work suggested that the BR could be responsible for a commonly seen pattern of dorsal, proximal, and radial displacement of distal radius fracture fragments,[3] and Henry's approach may be modified to include release of the insertion of the BR to facilitate exposure during open reduction of these injuries.[4,5] As such, multiple authors recommended releasing the BR insertion during open reduction and internal fixation of distal radius fractures.[2,6–8] However, this common procedure potentially compromises elbow flexion torque, and these recommendations appear to be made without reference to any work quantifying the functional effect of BR release. Although the BR is the smallest of the 3 major elbow flexors, its moment arm over most of the elbow range of motion is greater than that of biceps or brachialis.[1] Thus, the purposes of this study were to measure the change in elbow torque as a function of BR release and to report the results and implications.

MATERIALS AND METHODS

Sample preparation

This experiment used 5 fresh-frozen upper limbs amputated through the midhumerus. We identified the BR muscle–tendon unit from origin to insertion and prepared specimens by removing all other muscles of the arm and forearm. We preserved muscular origins and elbow insertions so as to not disrupt the stability provided by the joint capsule. The hands were removed at the level of the wrist joint, with care taken to preserve all distal radial ligaments to allow direct visualization of the distal end of the radius (Fig. 1).

We drilled 2 self-tapping, 5-mm Schanz screws (Synthes, West Chester, PA) transversely through the distal humerus. We inserted 1 self-tapping, 4-mm Schanz screw into the distal articular surface of the radius and advanced it proximally in line with the shaft. With the forearm in neutral rotation, we placed a 1.6-mm Kirschner wire through the midshaft radius and ulna to prevent pronation and supination during testing. Care was taken to place wires dorsal or volar to the BR path, and screws were cut short to avoid interference with the muscle or tendon during testing (Fig. 2). We used the 5-mm Schanz screws to fix the humerus to a frame constructed from carbon fiber rods (11 mm in diameter) using self-holding clamps. Screws, carbon fiber rods, and clamps were obtained from a Synthes external fixation system. We affixed the 4-mm Schanz screw at the distal articular surface to a load cell with 6 degrees of freedom (Model MC3A-6-500; Advanced Mechanical Technology, Inc, Watertown, MA) with the forearm in neutral rotation and with the elbow in 90° flexion.

We secured suture (Size number 5 Ethibond Excel; Ethicon, San Angelo, TX) to the proximal BR tendon, just distal to the muscle–tendon junction, using a Krackow stitch with at least 6 locking loops (Fig. 2). The free end of the suture was clamped to a dual-mode servomotor (Model 310; Aurora Scientific, Inc, Aurora, Ontario, Canada). We oriented the limb so that the suture followed the natural path of the BR tendon and muscle, crossing the humerus at a point 5 to 6 cm proximal to the lateral epicondyle, consistent

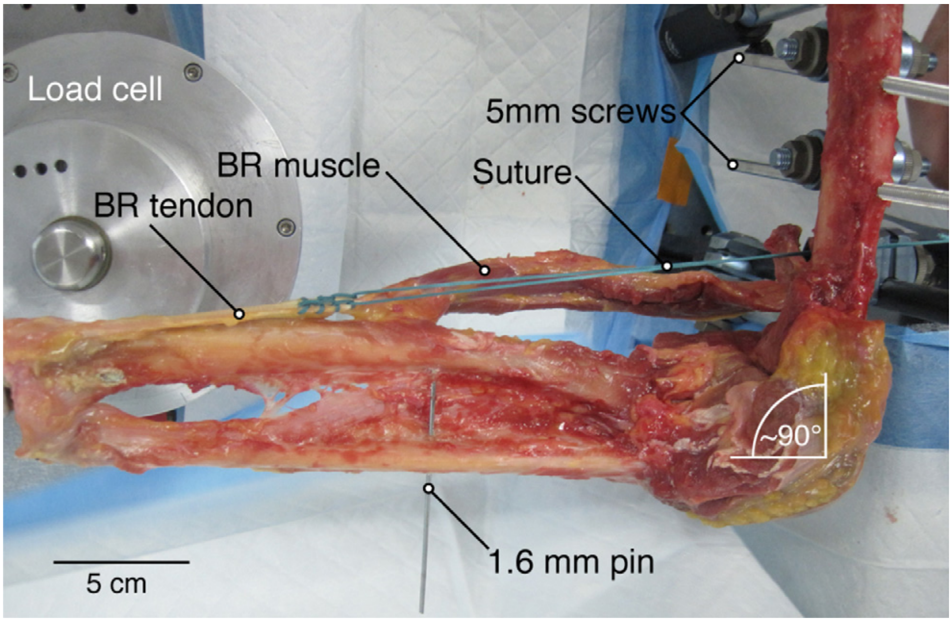

FIGURE 2: Experimental setup for biomechanical testing of BR torque production. The elbow was placed at 90° flexion and the forearm was placed in neutral rotation. This orientation was fixed with Schanz screws and a Kirschner wire to prevent elbow rotation and forearm pronation-supination.

with previously measured BR moment arm values at 90° flexion.[1,9]

Biomechanical testing

We performed testing by loading the suture via the servomotor with a 20-N force for 1,000 ms while simultaneously recording all 3 force and torque components (using the 6-axis load cell) at the distal radius with a sampling rate of 1,000 Hz. We chose the 20-N force based on the fact that the maximum predicted tension generated in the BR, as determined by physiologic cross sectional area (1.9 cm^2)[10] and specific tension (22 N/cm^2),[11] is 44 N. Thus, we chose 20 N to represent a reasonable physiologic force exerted by the BR while performing daily activities (about 50% maximal force). After we completed measurements with the BR insertion intact, we released the BR tendon from the radius in 2- to 5-mm increments by transecting the tendon and soft tissues down through the periosteum (Fig. 3). We defined release distances as the distance between the point of each transection and the tip of the radial styloid. After each release, we pulled the tendon as described above. This release method differs from surgical release of the BR, in which a knife blade is passed under the tendon from proximal to distal, releasing the tendon from its insertion on the fracture fragment. We chose the method of release used in this study because it allowed sequential testing of the same specimen at different release distances; transections were long enough (volar to dorsal) to ensure that tendon distal to the incision was completely released. Because of the progression from firm tendinous insertion to soft fibrous attachments, placement of releases at exact 2-mm intervals was not always possible; the variability in release increments reflects the difference in material properties at different locations. We performed this successive incremental release and force testing until the fibrous attachments of BR tendon tore away from the bone or until we reached the suture at the proximal end of the tendon.

Data analysis

Raw data collected include motor excursion distance, motor force applied, and force transmitted to the distal radius. All were collected at 1,000 Hz. From these data, we calculated stiffness and predicted torque loss. Acquired data were smoothed using a moving average function with a 21-ms interval. We took maximum force measured after smoothing as the force (applied or transmitted) at a given release distance. We calculated stiffness as the quotient of the force applied and the excursion of the motor arm necessary to produce such force. Release distance values were normalized to an average arm based on the distance from the lateral epicondyle to the radial styloid. Distances reported here are for an average arm with a distance of 259 mm from epicondyle to styloid. Because the release distances varied among experiments, we binned data into groups

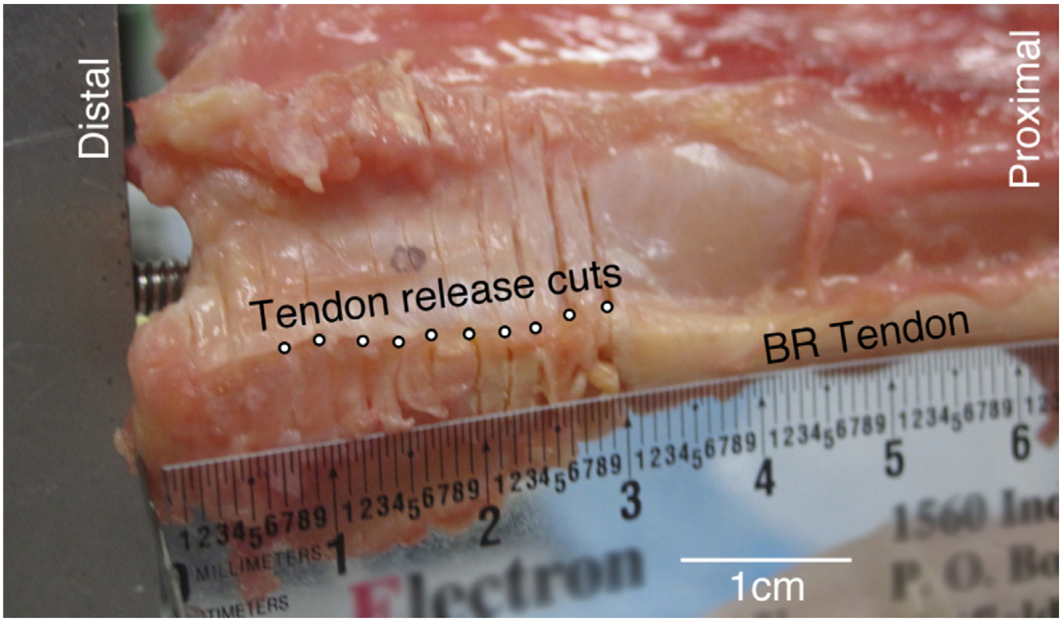

FIGURE 3: Close-up view of BR insertion. Successive BR releases progressing proximally from the radial styloid can be seen as individual incisions. Releases were performed as shown by transecting the tendon and soft tissue through the periosteum.

of 5 sequential data points and averaged them to allow comparison among all arms. Data are reported as means ± standard error unless otherwise noted.

RESULTS

The 5 specimens (4 females and 1 male) had a mean age of 78 years (range, 59–88 y) and a mean radial styloid to lateral epicondyle distance of 259 ± 5 mm. We recorded the mean percentage of total torque generated by the 20-N simulated BR force as a function of release distance (Fig. 4). As expected, as the BR was released, resultant elbow flexion torque decreased. However, the magnitude of this decrease was modest. Torque dropped to 95% ± 2%, 90% ± 2%, and 86% ± 3% of its original value at release distances of 27 ± 4, 46 ± 6, and 52 ± 10 mm, respectively. Even at the greatest release distance (72 cm), the resultant torque did not drop below 80% of its native value.

To gain insights into the biomechanical consequences of the release, we calculated mean tendon stiffness by measuring the excursion of the motor arm necessary to generate the 20 N of force (Fig. 5). Mean stiffness rose until a release distance of 18 mm, after which it monotonically decreased with larger release distances.

DISCUSSION

Our findings demonstrated that distal BR tendon insertion release of up to 7 cm results in less than a 20% decrease in BR-induced elbow flexion torque. Relative contributions of the 3 major elbow flexors (biceps brachii, brachialis, and BR) can be estimated by the relative products of physiologic cross-sectional area and moment arm. The physiologic cross-sectional area for biceps brachii, brachialis, and BR are 5.1, 5.4, and 1.9 cm^2, respectively.[10,11] At 90° flexion, moment arms are 3.8, 2.9, and 5.2 cm for males; values are 3.9, 2.4, and 4.6 cm for females.[1] Using these values, we calculate that BR is responsible for 21% to 22% of elbow torque at 90° flexion for both males and females. Therefore, a 20% loss in BR-induced elbow flexion torque would correspond to about 4% to 5% loss of overall elbow flexion torque. Thus, we believe that BR release can be performed without noteworthy functional consequences. Release distances that nearly reached the musculotendinous junction resulted in torque losses of less than 20%, which suggests that more than 80% of BR elbow flexion torque is retained through intermuscular fascial connections along the muscle belly.

Extensive properties: stiffness

Measurement of tendon stiffness provided insights into the biomechanical consequences of BR release (Fig. 5). Mean stiffness increased for short release distances (up to 19 mm), a result that would be expected in shortening the length of a homogeneously stiff material such as the distal footprint of the BR tendon. However, the tendinous insertion of the BR is more complicated than a

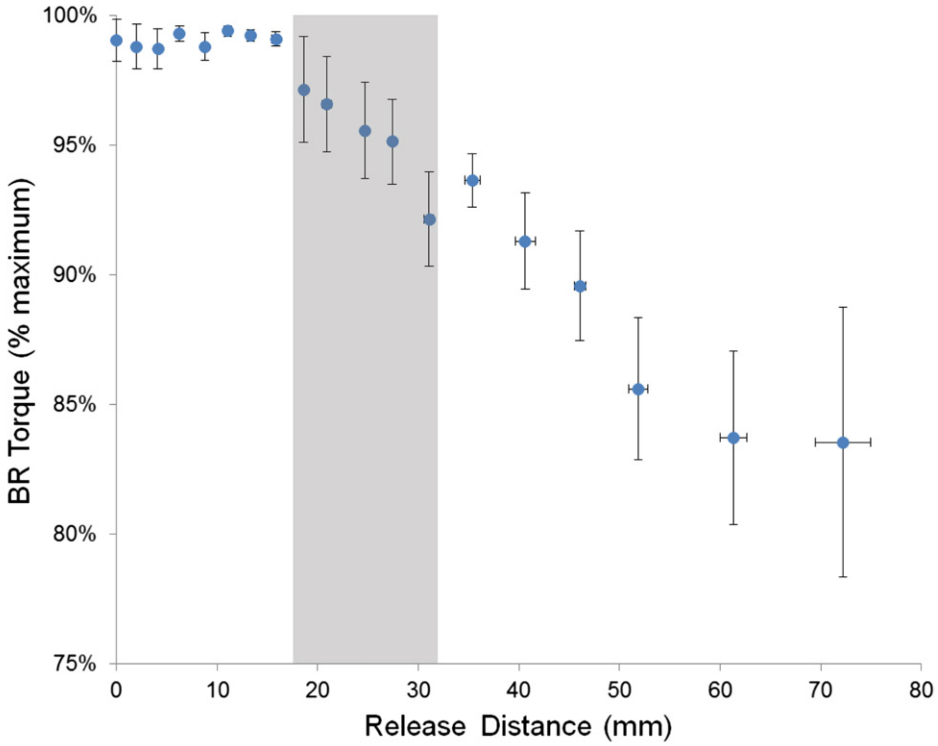

FIGURE 4: Graphical representation of mean torque as a function of release distance (n = 5 specimens). Torque is expressed relative to the maximum torque generated by placing a 20-N load on the BR tendon. Release distances up to 15 mm resulted in virtually no loss of torque production. Even at large release distances, BR force production would be expected to decrease by less than 20%. The shaded region corresponds to the BR tendon insertion footprint, as previously described.[2] The vertical axis origin extends to 75% maximum.

single isolated insertion site: Fibrous connections between the BR tendon and the radius have previously been identified.[2] The decrease in tendon stiffness beyond 18 mm represented releasing the tendon beyond the proximal limit of the BR insertion footprint, because force transmission to the radius occurs primarily through these more compliant fibrous connections. These fibers were thin and easily pierced by blunt dissection (Fig. 1), but were surprisingly effective at force transmission to the distal radius.

Clinical implications

The results of our mechanical data are relevant to clinical scenarios when tempered by a sensible consideration of the limitations inherent in our experimental approach. Release of the BR insertion, as routinely performed during distal radius open reduction internal fixation, can likely be performed without adversely affecting elbow flexion torque. A previous radiographic study of distal radius fractures found that the average distance from the radial styloid to the radial limit of the fracture line was 28 mm (SD, 6 mm).[2] Based on our results, the mean functional loss of BR-induced torque at this level should be less than 10% (Fig. 4). Our results also demonstrated that the insertion may be released from distal to proximal for 7 cm with less than a 20% decrease in BR-induced torque production. Prior studies demonstrate that at 90° elbow flexion, the BR is predicted to contribute 18% to 19% of elbow torque, as calculated from magnetic resonance imaging data[9] or physiologic cross-sectional area[10,11] and moment arm data.[1] Therefore, even at long release distances, total loss of elbow flexion torque after BR release is expected to be less than 5%.

In addition, in its normal anatomic configuration, there are connections between the BR and surrounding muscles. Our experimental approach considered the BR muscle–tendon unit in isolation, ignored these connections, and assumed that all force was transmitted to the radius via the tendinous insertion. Surrounding connections likely transmit force independent of the actual insertion point, so torque loss from tendon release would likely be mitigated because of the presence of these alternative paths of force transmission. In addition, postsurgical healing and scarring of the transected tendon may recapitulate part of its ability to transmit

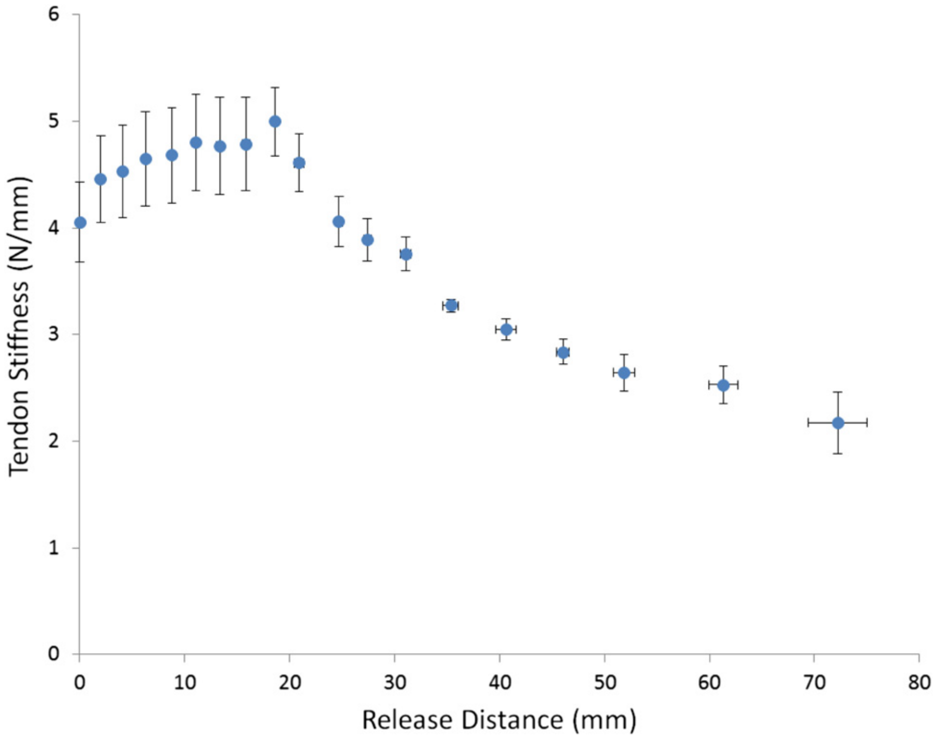

FIGURE 5: Mean BR tendon stiffness as a function of release distance (n = 5 specimens). This graph summarizes the overall stiffness change of the BR tendon at different release distances. Stiffness increased at small release distances, reflecting a decrease in tendon length without loss in force production capacity.

force distally. Our experiment therefore represents a worst-case scenario of BR release effects.

Brachioradialis-to-flexor pollicis longus transfer is commonly performed in tetraplegia surgery[12–14] to restore lateral key pinch. When performing this procedure, it is implicit that restoration of pinch is more important than the potential concomitant decrease in elbow flexion strength that might occur as a result of changes to the BR's native anatomic configuration. This work supports and strengthens this assumption. However, a prior study demonstrated that large release distances are necessary to obtain sufficient fiber excursion for a BR-to-flexor pollicis longus transfer to be successful.[10] The distances suggested (as much as 9 cm proximal to the insertion to obtain minimal additional excursion) are larger than those measured in the current study. Because we have concluded that most BR elbow flexion torque is retained through intermuscular fascial connections along the muscle belly, the limited decrease in elbow flexion torque observed with tendon release may actually be greater in BR-to-flexor pollicis longus transfers.

Another implication of this study is the potential use of the BR tendon as autograft donor in the distal forearm. To date, the most common graft choices are palmaris longus or flexor carpi radialis, and are used for procedures such as interposition arthroplasty,[15] tendon grafts, or pulley reconstruction.[16,17] However, the small size (3.1 mm^2)[18] and inconsistent presence[19] of the palmaris longus tendon diminishes its utility,[20] and flexor carpi radialis harvest may result in uneven and altered wrist function.[21] Nevertheless, the distal BR tendon is larger than the palmaris longus and is always present, and we have shown that it has several centimeters of length available for harvest without adversely affecting elbow flexion torque.

It is important to note that this study is purely mechanical and represents an isolated system; thus, the conclusions drawn must be interpreted in this context. Our experiment did not consider changes in moment arm resulting from pronation-supination or flexion-extension, and reflected only the consequence of BR release at a single joint configuration. Greater flexion angles result in larger moment arms,[8] and loss of BR function could be enhanced at these angles. However, the BR's relative contribution to flexion at these angles is approximately 24% to 26% (for males and females, respectively); elbow torque loss would still be less than 5%, which suggests that our findings are broadly applicable.

Our approach does not account for differential activation of the BR. It is traditionally considered a weak elbow flexor and also has a much smaller physiologic cross-sectional area than biceps or brachialis. However, it is possible that its relative recruitment and activation may change with forearm position. Our experimental approach was not designed to detect differences in torque loss resulting from changing levels of muscle activation.

Another limitation is that the values reported here represent release distances based on average anatomy. The BR tendon dimensions observed during dissection were sufficiently variable to warrant further investigation. We caution that tendons should be not removed or released with impunity. Rather, the results of this study can form the basis of an informed decision when considering release of the BR tendon.

REFERENCES

1. Murray WM, Delp SL, Buchanan TS. Variation of muscle moment arms with elbow and forearm position. *J Biomech.* 1995;28(5):513–525.
2. Koh S, Andersen CR, Buford WL, Patterson RM, Viegas SF. Anatomy of the distal brachioradialis and its potential relationship to distal radius fracture. *J Hand Surg Am.* 2006;31(1):2–8.
3. Sarmiento A. The brachioradialis as a deforming force in Colles' fractures. *Clin Orthop Relat Res.* 1965;(38):86–92.
4. Orbay JL, Badia A, Indriago IR, et al. The extended flexor carpi radialis approach: a new perspective for the distal radius fracture. *Tech Hand Up Extrem Surg.* 2001;5(4):204–211.
5. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. *J Hand Surg Am.* 2002;27(2):205–215.
6. Badia A, Khanchandani P. Volar plate fixation. In: Slutsky DJ, Osterman AL, eds. *Fractures and Injuries of the Distal Radius and Carpus*. Philadelphia: Elsevier; 2009:149–156.
7. Protopsaltis TS, Ruch DS. Volar approach to distal radius fractures. *J Hand Surg Am.* 2008;33(6):958–965.
8. Wulf CA, Ackerman DB, Rizzo M. Contemporary evaluation and treatment of distal radius fractures. *Hand Clin.* 2007;23(2):209–226, vi.
9. Kawakami Y, Nakazawa K, Fujimoto T, Nozaki D, Miyashita M, Fukunaga T. Specific tension of elbow flexor and extensor muscles based on magnetic resonance imaging. *Eur J Appl Physiol Occup Physiol.* 1994;68(2):139–147.
10. Fridén J, Albrecht D, Lieber RL. Biomechanical analysis of the brachioradialis as a donor in tendon transfer. *Clin Orthop Relat Res.* 2001;(383):152–161.
11. Lieber RL. *Skeletal Muscle Structure, Function, and Plasticity*. 3rd ed. Baltimore: Lippincott Willims & Wilkins; 2010.
12. Fridén J, Reinholdt C, Gohritz A, Peace WJ, Ward SR, Lieber RL. Simultaneous powering of forearm pronation and key pinch in tetraplegia using a single muscle-tendon unit. *J Hand Surg Eur Vol.* 2012;37(4):323–328.
13. Mogk JPM, Johanson ME, Hentz VR, Saul KR, Murray WM. A simulation analysis of the combined effects of muscle strength and surgical tensioning on lateral pinch force following brachioradialis to flexor pollicis longus transfer. *J Biomech.* 2011;44(4):669–675.
14. Murray WM, Hentz VR, Fridén J, Lieber RL. Variability in surgical technique for brachioradialis tendon transfer: evidence and implications. *J Bone Joint Surg Am.* 2006;88(9):2009–2016.
15. Burton RI, Pellegrini VD. Surgical management of basal joint arthritis of the thumb, part II: ligament reconstruction with tendon interposition arthroplasty. *J Hand Surg Am.* 1986;11(3):324–332.
16. Clark TA, Skeete K, Amadio PC. Flexor tendon pulley reconstruction. *J Hand Surg Am.* 2010;35(10):1685–1689.
17. Kaufmann RA, Pacek CA. Pulley reconstruction using palmaris longus autograft after repeat trigger release. *J Hand Surg Br.* 2006;31(3):285–287.
18. Carlson GD, Botte MJ, Josephs MS, Newton PO, Davis JL, Woo SL. Morphologic and biomechanical comparison of tendons used as free grafts. *J Hand Surg Am.* 1993;18(1):76–82.
19. Seiler JG. Flexor tendon injury. In: Wolfe SW, Hotchkiss RN, Pederson WC, Kozin SH, eds. *Green's Operative Hand Surgery*. Philadelphia: Elsevier; 2011:189–238.
20. Jakubietz MG, Jakubietz DF, Gruenert JG, Zahn R, Meffert RH, Jakubietz RG. Adequacy of palmaris longus and plantaris tendons for tendon grafting. *J Hand Surg Am.* 2011;36(4):695–698.
21. Naidu SH, Poole J, Horne A. Entire flexor carpi radialis tendon harvest for thumb carpometacarpal arthroplasty alters wrist kinetics. *J Hand Surg Am.* 2006;31(7):1171–1175.