

Dorsal Transfer of the Brachioradialis to the Flexor Pollicis Longus Enables Simultaneous Powering of Key Pinch and Forearm Pronation

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Purpose: To show biomechanically that the brachioradialis (BR) muscle can be transferred to restore key pinch and forearm pronation simultaneously.

Methods: Nine fresh-frozen forearms were thawed and instrumented with a custom muscle-tendon excursion jig. Maximum BR muscle-tendon excursion was measured with the wrist and thumb mobile. Muscle-tendon excursion then was measured from 60° of supination to 60° of pronation in 15° increments with the wrist and thumb fixed. Measurements were performed in 3 configurations: the native BR, the BR transferred volarly to the flexor pollicis longus (FPL) tendon, and the BR transferred dorsally (posterior to the radius) through the interosseous membrane to the FPL tendon. Muscle excursion-joint angle data were differentiated to compute pronation/supination moment arms. Two-way analyses of variance and *post hoc* Tukey tests were used to compare transfer conditions.

Results: Maximum muscle excursion was nearly identical when volar and dorsal transfer conditions were compared. When pronation/supination motions were isolated, however, the volar transfer was associated with muscle shortening and small pronation moment arms through 30° ± 9° of supination. Importantly, the dorsal transfer was associated with muscle shortening and larger pronation moment arms through 28° ± 10° of pronation, a significant difference of 58.0° ± 16.0° compared to the traditional volar transfer.

Conclusions: These data suggest that dorsal BR-to-FPL transfers can power key pinch and forearm pronation simultaneously even in the absence of other functional pronators. This transfer can be accomplished without changes to total muscle excursion compared with the traditional volar BR-to-FPL transfer. This result may enable the use of the BR-to-FPL transfer in patients who need key pinch but who lack functional pronation muscle groups (eg, ocular cutaneous 3). As result a larger patient population may benefit from the BR-to-FPL reconstructive procedure. (*J Hand Surg* 2006;31A:993–997. Copyright © 2006 by the American Society for Surgery of the Hand.)

Key words: Brachioradialis, flexor pollicis longus, forearm and hand biomechanics, tendon transfer surgery, tetraplegia.



Individuals with tetraplegia lack fully functional upper extremities. Some individuals with complete tetraplegia lack key pinch, which dramatically limits their ability to perform such tasks as personal grooming, feeding, and grasping.¹ One solution to restore thumb function is to transfer the

brachioradialis (BR) to the flexor pollicis longus (FPL). Traditionally this transfer is performed by moving the distal BR tendon volarly and securing it to the FPL tendon, thus restoring key pinch.^{2,3} Although this transfer is reported to restore function successfully for a number of patients with tetraple-

gia,² anecdotally it has been associated with a loss of pronation torque. In patients who lack other pronators the resulting functional deficit can be problematic. It is estimated that most of the ocular cutaneous 3 (OCu3) patients (ie, those with only BR, extensor carpi radialis longus, and extensor carpi radialis brevis muscles of sufficient strength distal to the elbow) could benefit if some method were developed to restore key pinch while at the same time enhancing—or at least not compromising—forearm pronation.

Historically skeletal muscle architecture and joint biomechanics have been used to define the appropriate tendon transfer donors and the mechanical factors that influence postoperative function.⁴ These studies have provided surgeons with the baseline muscle force and excursion data that allow donor and host muscle pairs to be identified and indicate how donor muscles might function in their new configuration. For example, the pronator teres has been identified as a suitable donor for the extensor carpi radialis brevis and extensor pollicis longus to power wrist or thumb extension based on physiologic cross-sectional area and fiber-length measures.⁵ Another example is the suitability of the posterior deltoid as an elbow extensor based on matching posterior deltoid fiber lengths with the functional range of the elbow joint itself.⁶ With these studies as background we are interested in the use of the BR muscle for tendon transfers in tetraplegia.^{7–9} This muscle is one of the most widely studied in the upper extremity. Previous reports have documented the architectural properties,^{7,8} sarcomere length–elbow joint angle relationship, muscle length–passive tension relationship,^{10,11} and muscle length–elbow joint angle relationship.¹⁰ It is accepted clinically that the BR muscle pronates and supinates the forearm from supination and pronation to neutral; our aim was to document the pronation/supination moment arms of this muscle, especially when an alternate muscle path is chosen explicitly. Thus the purpose of this study was to define the supination/pronation moment arm of the BR in its native, dorsally transferred, and volarly transferred paths to create a potential surgical solution for powering simultaneous key pinch and pronation. These data may serve as the mechanical benchmark for a transfer in a previously unsupported patient population and provide scientists and surgeons with baseline native BR muscle–tendon excursion and moment arm data.

Materials and Methods

Nine fresh-frozen cadaver forearms (6 male, 3 female; mean age, 80 ± 8 y; mean ulnar length, 26.3 ± 1.9 cm) were used for this experiment. Surgical incisions were made over the lateral aspect of the forearm, exposing the BR muscle to its most proximal origin. The ulna and distal humerus were secured to a custom-made jig at 90° of elbow flexion with bicortical screws. The distal tendon of the BR muscle was secured with a running 2-0 nylon suture and passed through a custom-made eyelet attached to the midpoint of the humeral origin of the BR muscle fibers to re-create the line of action of the muscle. The proximal end of the suture was attached to a dual-mode servomotor (Model 310B-LR; Aurora Scientific, Aurora, Ontario, Canada) that allowed excursion to be measured (accuracy, 0.05 mm) while a constant 500-g load was placed on the suture and muscle–tendon unit. An inclinometer (accuracy, 5°) was attached to the dorsal aspect of the distal radius to measure forearm pronation and supination. Loren et al¹² documented and diagrammed a similar experimental setup.

Maximum BR muscle–tendon excursion was measured by defining BR tendon movement from maximum forearm supination with the wrist and thumb maximally extended to maximum forearm pronation with the wrist and thumb maximally flexed. Muscle–tendon excursions then were measured from 60° of supination to 60° of pronation in 15° increments in 3 configurations: the native BR, the BR transferred volarly to the radius and secured to the FPL tendon, and the BR transferred dorsally (posterior to the radius) through the interosseous membrane (average distance from the lateral epicondyle, 9.7 ± 0.7 cm) and secured to the FPL tendon. For the volar and dorsal transfer conditions the distal interphalangeal joint was fixed at 30° of flexion. The proximal interphalangeal, carpometacarpal, and scaphoradial joints were fixed in neutral with Steinmann pins and the wrist was fixed in 20° of extension. All procedures in this investigation conformed with the policies on the use of human cadaveric tissue of the University of California San Diego Human Research Protection Program and Anatomical Services Department.

Three tendon excursion trials were averaged for each configuration before data were fit with quadratic polynomials ($r^2 = 0.97–0.99$) using software (MatLab version 7.0 [R14]; The Mathworks Inc., Natick, MA). Curves then were differentiated to compute pronation/supination moment arms under each condition as previously described.¹⁰ Briefly, if a muscle–

tendon excursion joint angle function is known, that function can be differentiated mathematically to generate a moment arm–joint angle curve. Comparisons of maximum excursion, excursion–joint angle, and moment arm–joint angle between trials were performed with 2-way repeated-measures analyses of variance. When significant main effects or interactions were observed *post hoc* Tukey tests were performed at each joint position to determine where differences existed. The results are presented as mean \pm standard error and the significance level (α) was set at 0.05.

Results

The maximum muscle excursion was nearly identical between transfer conditions (volar, 9.0 ± 1.1 mm vs dorsal, 8.9 ± 0.9 mm), showing that either transfer route results in the same overall muscle excursion. The angular ranges over which muscle length changed, however, differed significantly among the native BR configuration and the 2 transfer conditions ($p < .001$) (Fig. 1). In the native BR configuration, when the forearm was rotated from 60° of supination to neutral or from pronation to neutral the muscle shortened (Fig. 1, squares). For the volar transfer configuration, however, the muscle shortened only slightly 60° of supination to 30° of supination and

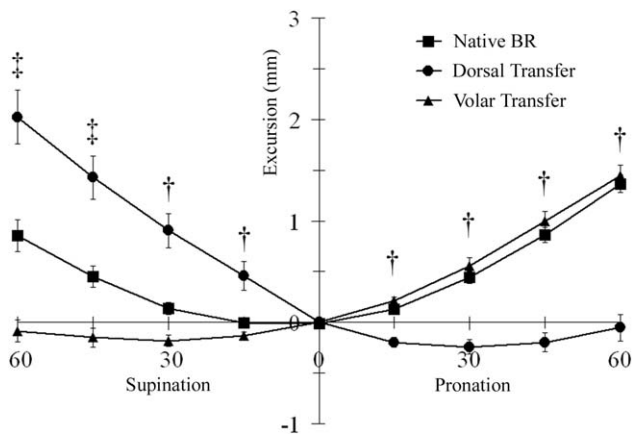


Figure 1. Muscle excursion (mm) as a function of pronation/supination forearm angle (degrees). Positive muscle excursion indicates muscle lengthening; thus in the native BR condition, as the forearm is moved from 0° toward pronation or supination the BR muscle lengthens. §Significant difference among all 3 testing conditions ($p < .05$); †significant difference between the dorsal transfer and the other 2 groups ($p < .05$). Positive muscle excursion indicates muscle lengthening; thus in the dorsal transfer condition, as the forearm moves from 60° of supination toward pronation the muscle is shortening to a greater extent compared with the volar transfer condition. Each data point represents the mean \pm standard error for 9 specimens.

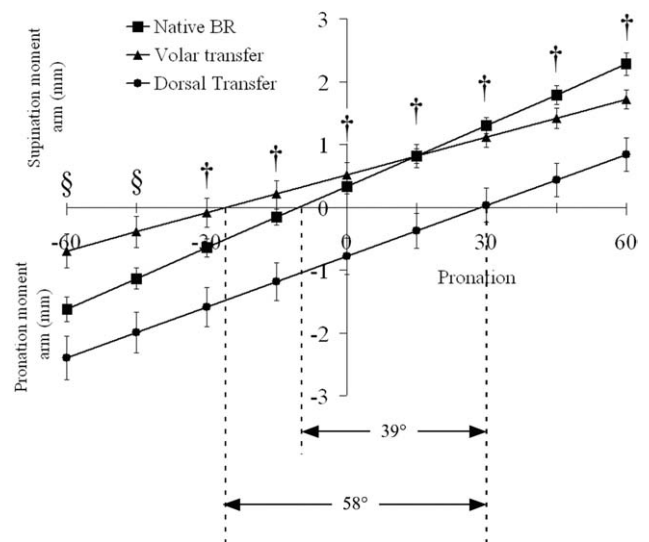


Figure 2. Pronation–supination moment arm (mm) as a function of forearm position (degrees). §Significant difference between the dorsal and volar transfer conditions ($p < .05$); †significant difference between the dorsal transfer and the other 2 groups ($p < .05$). The dorsal transfer condition shows greater pronation moment-arm magnitudes, which occur $\sim 45^\circ$ more supinated compared to the volar transfer condition. Each data point represents the mean \pm standard error for 9 specimens.

then lengthened from this point to 60° of pronation (Fig. 1, triangles). Finally, a very different relationship was observed for the dorsal transfer configuration in which the muscle shortened from 60° of supination to 30° of pronation and then lengthened slightly to 60° of pronation (Fig. 1, circles).

Based on the difference in the angular dependence of excursion (Fig. 1) the pronation/supination moment arms calculated by differentiation of the excursion data differed significantly among the native BR and the 2 transfer conditions ($p < .001$) (Fig. 2). The magnitudes of pronation moment arms generally were larger for the dorsal transfer compared with either the volar transfer or the native BR, suggesting that the dorsal transfer would generate larger pronation moments. The dorsal transfer was the only one in which large pronation moment arms were produced in supination and carried into pronation. The dorsal transfer condition yielded a pronation moment arm further into pronation ($28^\circ \pm 10^\circ$) than either the native configuration ($11^\circ \pm 4^\circ$ of supination, $p < .05$) or the volar transfer configuration ($30^\circ \pm 9^\circ$ of supination, $p < .05$). This result shows that not only is the dorsal transfer the only configuration in which the BR could rotate the forearm from supination into pronation, but the magnitude of this rotational difference is 60° . The dorsal transfer can pronate the

forearm significantly farther into pronation compared with either the native configuration ($40^\circ \pm 9^\circ$, $p < .005$) (Fig. 2, dotted lines) or the traditional volar transfer ($58^\circ \pm 16.0^\circ$, $p < .05$) (Fig. 2, dotted lines).

Discussion

The purpose of this investigation was to determine whether routing the BR-to-FPL tendon transfer dorsal to the radius would allow patients to pronate more effectively compared with the traditional volar transfer method. These data show that biomechanically routing the tendon dorsal to the radius yields larger pronation moment arms and that the pronation moment arms are significant even with the forearm pronated, which is not the case with the traditional volar transfer (Fig. 2). The magnitude of the difference between the 2 transfers is 60° , suggesting a tremendous potential gain in function over traditional methods. These novel pronation moments were created without changing absolute muscle excursion, suggesting that the muscle would operate over the same range of muscle and sarcomere lengths while simultaneously powering key pinch.

There are several limitations to this study. First, the skin envelope surrounding the forearm was open during the entire experiment and it is possible that this may alter our excursion measurement and therefore our moment arm magnitudes compared with the condition in which the skin is intact. We would expect, however, that this effect would be systematic across testing conditions and would not change the intertransfer configuration comparisons. Second, it is difficult to define an absolute neutral forearm pronation/supination configuration. We chose a position where a plane across the dorsal aspect of the radius and ulna was vertical. A slightly different definition of “neutral,” however, would shift excursion and moment arm curves toward pronation or supination. Again, this effect would be systematic across testing configurations, and would not affect comparisons between transfer methods. Third, the elbow joint was fixed at 90° of flexion during the experiment and therefore the effect of elbow extension was not documented. We would expect that elbow motion would produce a systematic change in muscle excursion across all transfer conditions because the BR origin was identical among transfer conditions. It is possible, however, that elbow extension would be associated with pronation in the dorsal transfer condition. These important aspects of posttransfer function likely will be elucidated in future clinical trials. These data, however, provide the preliminary data

needed to justify attempting the surgery. Preliminary qualitative results (video can be viewed at the *Journal's* web site, www.jhandsurg.org) show the efficacy of the transfer in producing pronation and key pinch with a single muscle. In this supplemental video a patient can be seen pronating from a position of 45° of supination to 60° of pronation while generating key pinch at the thumb and second digit. Similarly postoperative ultrasound of the transferred BR in the patient from the supplemental video shows unobstructed movement through the interosseous membrane (Fridén et al, unpublished data).

A secondary purpose of this study was to generate primary data for BR pronation/supination moment arms. Maximum pronation moment arm values observed in the native BR condition in this study were 1.6 ± 0.2 mm and maximum supination moment arms were 2.2 ± 0.2 mm at 60° of pronation. Similar maximums were documented in 2 cadaveric specimens by Murray et al¹⁰ and were thought to be too small, perhaps because of experimental error. Our data reinforce these relatively small values and were reproducible across 9 specimens (coefficient of variation, $<10\%$). Given that the peak moment arms are relatively small compared with other pronators (eg, pronator teres = ~ 2 cm¹⁰) the pattern of moment arms likely is important. Our data indicate that the BR muscle is a pronator in positions of supination and a supinator in positions of pronation, which agrees with the existing literature.¹⁰

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