Journal of Hand Surgery (European Volume)

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What is This?

Simultaneous powering of forearm pronation and key pinch in tetraplegia using a single muscle-tendon unit

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Abstract

This study clinically assessed the concept that both thumb flexion and forearm pronation can be restored by brachioradialis (BR)-to-flexor pollicis longus (FPL) tendon transfer if the BR is passed dorsal to the radius. Six patients [two women and four men, mean age 32.3 years (SD 4.9, range 23–56)] underwent BR-to-FPL transfer dorsal to the radius and through the interosseous membrane (IOM). Lateral key pinch strength and pronation range of motion (ROM) were measured 1 year after surgery. A group of six patients [two women and four men, mean age 31.2 years (SD 5.0, range 19–52)] who underwent traditional palmar BR-to-FPL was included for comparison. Postoperative active pronation was significantly greater in the dorsal transfer group compared to the palmar group [149 (SD 6) and 75 (SD 3), respectively] and pinch strength was similar in the two groups [1.28 (SD 0.16) kg and 1.20 (SD0.21) kg, respectively]. We conclude that it is feasible to reconstruct lateral key pinch and forearm pronation simultaneously using only the BR motor.

Introduction

Tendon transfers are commonly used to restore lost function after spinal cord injury (Fridén and Lieber, 2002). Choosing donor muscles for tendon transfers requires the surgeon to balance the function gained by the transfer against any morbidity created by harvesting and re-routing a donor muscle. This choice is particularly difficult when only a few potential donors are available. For example, in restoring key pinch for the C5/6 spinal cord-injured patient, the most common donor muscle is the brachioradialis (BR) because of its large excursion (Fridén et al., 2001). Based on a knowledge of the physiological cross-sectional area (PCSA) of the elbow flexors and their moment arms (Murray et al., 2000), it can be calculated that harvesting BR would result in an approximately 20% loss of elbow flexion strength. Although this is considered

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Table 1. Patient characteristics

Patient number	Sex	Age at injury	Age at surgery	Level of injury	Cause of injury	Int. class.	BR-to-FPL transfer route	Follow-up (years)	Forearm pronation MRC pre-op.	Forearm pronation MRC post-op.	Pinch strength (kg) post-op.
1	M	18	30	C5–C6	Dive	OCu3	Dorsal	2.5	2	2	2.0
2	M	20	25	C6	Sports	OCu2	Dorsal	1.0	0	1	1.2
3	M	22	32	C5–C6	Car	OCu3	Dorsal	1.5	2	2	0.8
4	F	15	23	C5–C6	Dive	OCu3	Dorsal	1.5	0	2	1.5
5	M	26	28	C5–C6	Dive	OCu3	Dorsal	1.0	0	2	1.2
6	F	53	56	C5–C6	Car	O1	Dorsal	1.0	0	1	0.5
7	F	30	37	C5–C6	Sports	OCu2	Palmar	1.0	1	1	1.1
8	M	17	20	C5–C6	Sports	O1	Palmar	1.0	0	0	1.0
9	F	20	52	C5–C6	Fall	O2	Palmar	1.0	0	0	1.0
10	M	17	19	C5–C6	Fall	O1	Palmar	1.0	0	0	1.4
11	M	15	29	C5–C6	Motorcycle	OCu2	Palmar	1.5	2	1	2.0
12	M	23	30	C6	Gunshot	OCu3	Palmar	1.0	3	2	1.2

acceptable (Fridén and Lieber, 2002), less attention has been paid to the loss of pronation strength that accompanies the BR-to flexor pollicis longus (FPL) transfer when transferred by the traditional palmar route (Freehafer et al., 1988). This is not a problem in a patient who has sufficient function in pronator teres (PT) to pronate the forearm after removal of BR, but many patients with this level of injury can only pronate using the BR itself. As a result, after BR-to-FPL transfer, they are left in the less desirable condition of requiring gravity-powered pronation or key pinch in a supinated forearm position.

Recently, in an effort to solve the problem of loss of pronation resulting from BR harvest in this group of patients with no other pronators, we proposed re-routing the BR dorsally around the radius and through the interosseous membrane (IOM) to create simultaneous key pinch and forearm pronation (Ward et al., 2006). Although this modification was shown in a cadaver model to create a 2–3 mm pronation moment arm and was predicted to create an increase in pronation of around 60° compared to the traditional palmar transfer, it was not clear whether such a re-routing procedure would produce clinically acceptable results. Dorsal routing of the BR could result in functional failure (i.e. loss of pinch strength and pronation) due to restriction of BR amplitude secondary to friction or fibrosis; inability of an individual to activate the BR performing two functions; morbidity resulting from IOM resection; or harming vital structures (e.g. median nerve, interosseous vessels) that could occur during passage through the distal IOM. The purpose of this study was to assess the results of the dorsal BR-to-FPL transfer in a group of patients in which it had been used to increase the range of forearm pronation without losing key pinch strength.

Patients and methods

Patients

Six patients [two women, four men, with a mean age of 32.3 years (SD 4.9, range 23–56)] with tetraplegia were selected for the dorsal BR transfer procedure. All were undergoing surgical reconstruction of key pinch by transfer of the BR-to-FPL. The patients lacked PT function and were classified as O1 to OCu3 according to the International Classification (McDowell et al., 1986). The mechanism of spinal cord injury was traumatic (Table 1). The mean time between the onset of paralysis and operation was 8.8 years (SD 8.3, range 2–32). A comparison group of six patients [two women, four men with a mean age of 31.2 years (SD 5.0, range 19–52) in whom the traditional palmar BR-to-FPL route (Freehafer, 1991)was used during the same time period (3 years) was included in order to compare pinch strength and pronation ability between the two different routes of tendon transfer. Two out of six and three out of six patients in the dorsal and palmar groups, respectively, demonstrated active pronation preoperatively, powered by BR (MRC grade 1–3) (Medical Research Council, 1976). Pronation strength was assessed at the initiation of pronation from the most supinated position of the forearm to avoid the difficulties with the gradual loss of pronation strength as pronation progresses towards and beyond neutral forearm rotation.

Operative technique

The distal BR tendon was exposed and released via a curved incision over the palmar aspect of the radial styloid. Through a separate incision on the dorsal aspect of the myotendinous junction of BR, the
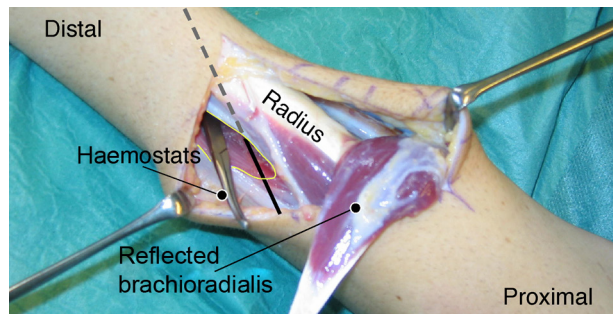
Figure 1. Intraoperative view of reflected brachioradialis before entry into the tunnel formed by resection of a portion of the interosseous membrane. Haemostats are shown traversing the tunnel from distal to proximal, ready to accept the brachioradialis tendon. The black line and grey dotted line show the anticipated path of transferred brachioradialis.

Figure 2. Intraoperative view of brachioradialis tendon after traversing the tunnel and before tenorrhaphy to the flexor pollicis longus tendon. The proximal belly of the brachioradialis can be seen in the upper portion of the picture. Inset shows the brachioradialis tendon secured to the flexor pollicis longus tendon using side-to-side running sutures back and forth and along both of its sides. This ensures stability and permits early rehabilitation. FCR, flexor carpi radialis tendon.

muscle was extensively released until a minimum 5 cm amplitude was obtained (Fridén et al., 2001). For the dorsal transfer group, the IOM was exposed 5 cm proximal to the proximal border of the pronator quadratus muscle. An incision was made in the IOM, a 1 × 1 cm area removed and the hole widened using blunt dissection. Special care was paid to protect the anterior and posterior interosseous vessels and nerves. Using haemostats, the BR was routed dorsally, passed through the IOM (Figure 1) and secured to the FPL tendon using side-to-side running 2-0 Ti-Cron® sutures (Sherwood, Davis & Geck, St. Louis, MO, USA) back and forth and along both sides of the donor tendon (Figure 2). In order to ensure stability and permit immediate mobilisation, which is critical after transfers through the IOM, the overlap between the donor and recipient tendon was 5 cm (Figure 2, inset) (Brown et al., 2010). For the traditional group (palmar transfer), all procedures were the same with the exception that BR was passed palmar to the radius and secured to FPL. For both techniques, the carpometacarpal joint of the thumb was always fused to direct the resulting power of the BR-FPL transfer into the radial aspect of the index finger at the level of the middle phalanx. The metacarpophalangeal joint of the thumb was left free and the interphalangeal joint was stabilised with an FPL–EPL tenodesis to prevent hyperflexion of the joint after BR–FPL transfer.

The passive tension in BR was set identically in both groups so that a substantial touch was achieved between the thumb pulp and the proximal interphalangeal joint of the index finger when the elbow was flexed at 90°, the wrist was maintained in 20° of extension and the forearm was fully pronated. After surgery, the reconstruction was protected in a well-moulded plaster splint until training was started on the following day.
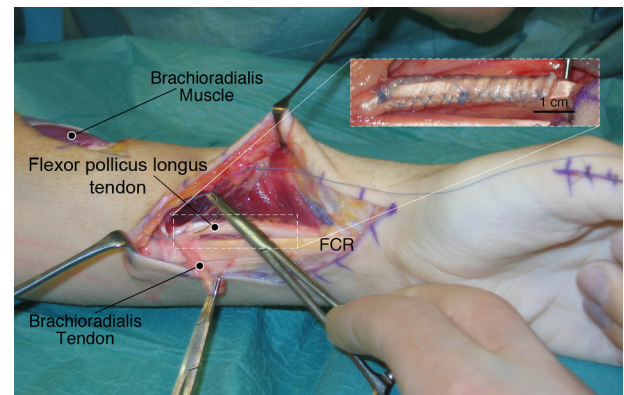
Postoperative rehabilitation and evaluation

Patients undergoing dorsal BR transfer underwent the same postoperative regimen as those undergoing traditional palmar BR transfer. The rehabilitation was divided into two training periods. The first period started on the first postoperative day and focused on early mobilisation of the BR-driven forearm pronation/thumb flexion action. Task-oriented training was introduced after 4 weeks and the permitted motion was restricted by an orthosis in order to parallel the functional training.

All patients were assessed 4 weeks, 3 months, 6 months and 1 year after the operation. In addition to the routine clinical assessment, a goniometer was used to measure active supination and pronation. Pronation was measured as the total active range of motion from the position of maximum supination (start point) to the position of maximal pronation (end point). Lateral key pinch was measured as the average of three voluntary contractions using a Preston pinch gauge (European Bissell Healthcare Ltd, Winchester, England). In two cases, the amplitude of the BR tendon motion through the IOM was visualised by ultrasound during forearm pronation from a fully supinated to maximally pronated position.

Statistical methods

Pre- and postoperative comparison of range of motion for the dorsal transfer patients was made using the paired Student's *t*-test. Postoperative comparison of
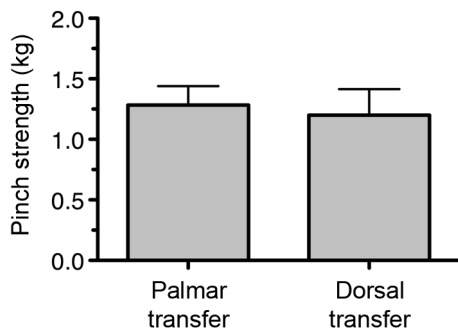
Figure 3. Pinch strength measured in patients who received either traditional palmar transfer or the dorsal transfer of the brachioradialis. There was no significant difference in pinch strength between the two groups. Data expressed as means, with the whiskers indicating SEM.
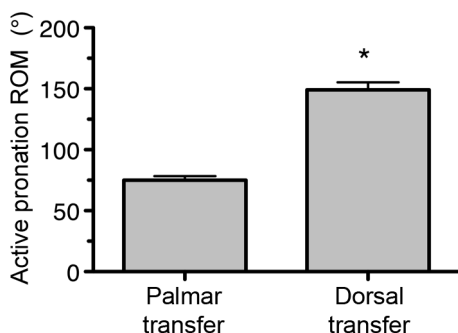

Figure 4. Active pronation range of motion (ROM) measured in patients receiving either traditional palmar tendon transfer or the dorsal transfer of the brachioradialis. The active pronation ROM in the dorsal transfer group was twice that of the palmar transfer group ($p < 0.0001$). Data expressed as means, with the whiskers indicating SEM.

Figure 5. Graphic representation of average active pronation after dorsal (upper diagram) or palmar BR-to-FPL tendon transfer. Note that although pronation can be initiated from approximately the same degree of forearm supination, the palmar technique cannot provide sufficient moment to enable active pronation beyond neutral forearm rotation.

the pinch strength between the two patient populations was made using the unpaired Student's *t*-test. Significance level (α) was set at 0.05. Statistical power for non-significant differences was calculated after the data were acquired using the 'G*Power' program (Erdfelder et al., 1996). Data are expressed as mean and standard error of the mean unless otherwise noted.

Results

No significant difference was observed between dorsal transfer patients compared to those having the traditional palmar tendon transfer in terms of pinch strength (Figure 3). Thus, in spite of the fact that the entire length of the BR was in significant contact with the radius and IOM, the dorsal transfer group pinch strength was only about 10% lower than the traditional transfer group, which was not significant ($p > 0.5$).
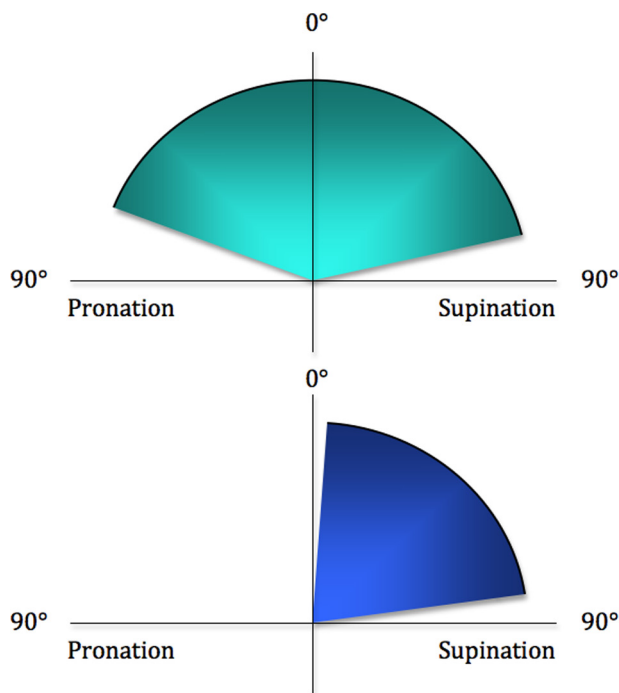
The range of active pronation (149°) was significantly greater in the dorsal transfer group postoperatively, essentially twice that of the palmar group (75°) (Figure 4; $p < 0.0001$). Patients were also able to achieve more pronation from the neutral forearm rotation after the dorsal transfer [73 (5)°] compared to the palmar transfer [–5 (5)°] (Figure 5).Patients who underwent palmar transfer could only complete forearm pronation past neutral by using gravity assistance.

In the dorsal transfer group, the thumb could not be actively flexed without simultaneous pronation of the forearm but the forearm could always be independently pronated providing the FPL tendon was slackened, i.e. when the wrist was passively flexed.

Discussion

This study demonstrated that, in those patients for whom it is indicated, it is both feasible and effective to reconstruct lateral key pinch and forearm pronation simultaneously using only the BR muscle. Biomechanical measurements have previously demonstrated the nearly 60° increase in pronation range of motion using the dorsal transfer route (Ward

et al., 2006). However, we were still concerned that, in practice, such a result might not be possible. Potential confounding factors included adhesion of BR to the IOM, inability of the patient to retrain the BR for simultaneous pronation and key pinch, or obstruction of the novel transfer route by critical neurovascular structures. However, none of these factors limited the application of this biomechanical concept to clinical practice and the dorsally transferred muscle was seen by ultrasound to be mobile in the forearm. This transfer now permits surgical reconstruction in patients who have only a single pronator (BR), without concern for any morbidity associated with loss of elbow flexion strength or complications due to BR dysfunction when passed through the IOM.

A review of 318 tetraplegia patients in the Swedish National Registry for Reconstructive Hand Surgery in Tetraplegia revealed that 151 (47%) of the patients belong to the groups OCu 1,2 and 3 without active pronator teres muscle function and therefore this development appears to be relevant to a relatively large number of patients.

The dorsal BR transfer requires several surgical steps that differ from the traditional palmar routing. First, an extensive BR release is particularly important to ensure a proper line of action through the IOM (Figure 1, dotted line). We previously argued that an extensive BR release enhances the intrinsic functional properties of this muscle (Fridén et al., 2001) and we view this release step as an essential step in the operation. Although a separate incision is not necessary to resect a distal portion of the IOM, the proximal skin incision must extend sufficiently ulnarward to enable 'threading' of the BR through the IOM. Lastly, sufficient resection of the IOM is necessary, not only to permit the distal passage of the BR tendon but also to permit the muscle belly of BR to extend through the IOM opening, which occurs if the elbow or wrist is extended. Therefore we removed a 1 × 1 cm portion of the IOM and then extended the opening by blunt dissection to prevent any tethering.

Of course, the primary purpose of this reconstructive procedure is to create lateral key pinch. Should it compromise key pinch strength, the use of the dorsal BR transfer route would be unacceptable. Theoretically, such a loss in strength would occur if the muscle-tendon unit became tethered to surrounding tissues, stretched to an unfavourable length of sarcomere, or subject to high force loss due to friction. Direct measurement of key pinch strength (Figure 3) showed no difference in strength between patients who had either the dorsal or traditional palmar transfer. We were willing to accept a loss in

strength of about 10% (effect size, δ) believing that the gain in pronation would justify a small decrease in strength. This corresponds to a pinch strength difference of 0.13 kg (Figure 3). Given the experimental variability (σ) of 0.15 kg and our sample size of 12 (Table 1), our experiment has a 81% chance of showing this magnitude of a 10% effect (Erdfelder et al., 1996). In other words, this experiment has a statistical power of 81% to prove that a 0.13 kg pinch strength decrease did not occur. A statistical power of 80% is considered excellent (Freiman et al., 1978).

Surgeons must be aware that rehabilitation after this operation requires the active participation of the patient and the knowledgeable guidance of a skilled hand therapist. In our unit the patient, surgeon and therapist discuss the necessity of early mobilisation of the transferred tendon, not only to prevent adhesions but to facilitate the development of motor control patterns that are necessary for simultaneous key pinch and forearm pronation. Of course, early mobilisation requires meticulous attention to the tenorrhaphy between the BR and FPL tendons, as described in the operative technique. An interesting implication of this study is that it challenges current dogma in tendon transfer, namely the 'one muscle-one function' assertion (Brand and Hollister, 1993). In the procedure described here, the BR acts as both a thumb flexor and forearm rotator. The biomechanical reason that a single motor can simultaneously accomplish these two functions is that they are kinematically independent. Specifically, forearm rotation is completely independent of key pinch since the change in length associated with forearm rotation (moment arm = 1–3 mm) is an almost negligible fraction of the long fibres of the BR (121 mm) (Fridén et al., 2001). Such mismatches of fibre length and moment arm are rare in the upper extremity, but the fact that even one example can be recognised should make surgeons cautious about making broad general statements about the functionality of muscles in tendon transfer.

Note

This investigation conforms to the University of Gothenburg and University of California Human Research Protection Program guidelines.

Conflict of interests

None declared.

Funding

References

Brand PW, Hollister A. *Clinical mechanics of the hand*, 2nd Edn. St Louis, Mosby, 1993.

Brown SH, Hentzen ER, Kwan A, Ward SR, Fridén J, Lieber RL. Mechanical strength of the side-to-side versus Pulvertaft weave tendon repair. J Hand Surg Am. 2010, 35: 540–5.

Erdfelder E, Faul F, Buchner A. GPOWER: A general power analysis program. Behav Res Meth Instrum Comput. 1996, 28: 1–11.

Freehafer A. Tendon transfers in patients with cervical spinal cord injury. J Hand Surg Am. 1991, 16: 804–9.

Freehafer AA, Peckham PH, Keith MW, Mendelson LS. The brachioradialis: anatomy, properties, and value for tendon transfer in the tetraplegic. J Hand Surg Am. 1988, 13: 99–104.

Freiman JA, Chalmers TC, Smith HJ, Kuebler RR. The importance of beta, the Type II error and sample size in the design and interpretation of the randomized controlled trial: survey of 71 'negative' trials. N Engl J Med. 1978, 299: 690–4.

Fridén J, Albrecht D, Lieber RL. Biomechanical analysis of the brachioradialis as a donor in tendon transfer. Clin Orthop Relat Res. 2001, 383: 152–61.

Fridén J, Lieber RL. Tendon transfer surgery: clinical implications of experimental studies. Clin Orthop Relat Res. 2002, 403(Suppl.): S163–70.

McDowell C, Moberg E, House J. The Second International Conference on Surgical Rehabilitation of the Upper Limb in Tetraplegia (Quadriplegia). J Hand Surg Am. 1986; 11: 604–8.

Medical Research Council. *Aids to the investigation of peripheral nerve injuries. War memorandum No. 7*, 2nd Edn. London, Her Majesty's Stationery Office: 1976.

Murray WM, Buchanan TS, Delp SL. The isometric functional capacity of muscles that cross the elbow. J Biomech. 2000, 33: 943–52.

Ward SR, Peace WJ, Fridén J, Lieber RL. Dorsal transfer of the brachioradialis to the flexor pollicis longus enables simultaneous powering of key pinch and forearm pronation. J Hand Surg Am. 2006, 31: 993–7.