Transfer of the Distal Terminal Motor Branch of the Extensor Carpi Radialis Brevis to the Nerve of the Flexor Pollicis Longus: An Anatomic Study and Clinical Application in a Tetraplegic Patient

BACKGROUND: In tetraplegics, thumb and finger motion traditionally has been reconstructed via orthopedic procedures. Although rarely used, nerve transfers are a viable method for reconstruction in tetraplegia.

OBJECTIVE: To investigate the anatomic feasibility of transferring the distal branch of the extensor carpi radialis brevis (ECRB) to the flexor pollicis longus (FPL) nerve and to report our first clinical case.

METHODS: We studied the motor branch of the ECRB and FPL in 14 cadaveric upper limbs. Subsequently, a 24-year-old tetraplegic man with preserved motion in his shoulder, elbow, wrist, and finger extension, but paralysis of thumb and finger flexion underwent surgery. Seven months after trauma, we transferred the brachial muscle with a tendon graft to the flexor digitorum profundus. The distal nerve of the ECRB was transferred to the FPL nerve.

RESULTS: The branch to the ECRB entered the muscle in its anterior and proximal third. After sending out a first collateral, the nerve runs for 2.4 cm alongside the muscle and bifurcates intramuscularly. A main branch from the anterior interosseous nerve, which entered the muscle 3 cm from its origin on the radius, innervated the FPL. The ECRB and FPL nerves had similar diameters (~1 mm) and numbers of myelinated fibers (~180). In our patient, 14 months after surgery, pinching and grasping were restored and measured 2 and 8 kg strength, respectively.

CONCLUSION: Transfer of the ECRB distal branch to the FPL is a viable option to reconstruct thumb flexion.

KEY WORDS: Nerve transfer, Neurorotation, Spinal cord injury, Tetraplegia, Tetraplegic hand

In the United States, more than 100 000 people live with tetraplegia. A primary goal in the tetraplegic hand is to reconstruct a pinch between the thumb and the lateral side of the index finger (ie, lateral pinch). However, no consensus exists as to how to achieve this by orthopedic procedures. An interesting approach is to transfer an accessory wrist extensor to the flexor pollicis longus (FPL). However, accessory wrist extensor muscles are very rare. In this group of tetraplegic patients with preserved wrist extension, the brachioradialis tendon has been sutured to the FPL. Results of this technique are no better than just anchoring the FPL directly onto the radius and relying on thumb flexion produced by wrist extension.
Another possibility to regain thumb flexion is to suture the tendon of the FPL side by side to the extensor carpi radialis brevis (ECRB). Thumb flexion is achieved after wrist extension. This is a natural and synergic motion. However, despite good initial results, ruptures of the ECRB have been reported. If the extensor carpi radialis longus has been transferred concomitantly for finger flexion reconstruction, rupture of the ECRB leads to the inability to extend the wrist. This is the most serious complication that can occur in a tetraplegic patient. Because surgical reconstruction of the ruptured ECRB is unreliable, the patient is condemned to lose the capacity to grasp and pinch.

Over the past decade, nerve transfers have largely ameliorated the results of brachial plexus reconstruction. Based on our experience treating brachial plexus lesions, we have started to apply the concept of distal nerve transfers in tetraplegic patients. Following anatomic studies, we have successfully transferred branches of the axillary nerve for triceps reinnervation, as well as the supinator nerve to the posterior interosseous nerve to regain thumb and finger extension.

In this study, we investigated the innervation of the ECRB and the FPL, with the aim of transferring a motor branch of the ECRB for reconstruction of thumb flexion. We also report our first clinical case in which such a nerve transfer was used, together with transfer of the brachialis muscle to the tendons of the flexor digitorum profundus.

**MATERIALS AND METHODS**

**Anatomic Study**

Fourteen upper limbs from 5 formalin-fixed and 2 fresh cadavers were used for this anatomic study. We dissected the radial nerve at the elbow and identified the branch that innervated the ECRB. The nerve to the ECRB was dissected along its entire length, and the number of collaterals was determined. We measured the distance from the emergence of the nerve to the ECRB and the lateral epicondyly, together with the distance of the collaterals stemming from the main nerve and the lateral epicondyly. The diameter of the terminal branch was measured using a caliper. We dissected the FPL muscle and observed its innervation. The course, distribution, and size of the main branch were investigated. The nerve diameter was measured using a caliper. Nerve specimens from the FPL and ECRB were removed, embedded in paraffin, sectioned transversally, and stained with hematoxylin and eosin for myelinated fiber counting. Nerve counts were performed manually. Means were compared by the Student’s t test using InStat 3.0 software. The threshold for statistical significance was set at \( P < .05 \).

As a second step, in 1 fresh cadaver, the surgical procedure was simulated in vitro. Through an oblique incision along the proximal forearm, the branch of the ECRB was identified and sectioned distally to the first collateral. The nerve of the ECRB was sectioned as distally as possible. The median nerve was dissected, the anterior interosseous nerve (AIN) was located, and the main motor branch to the FPL was identified and separated from the AIN up to its origin from the median nerve. The nerve to the FPL was sectioned proximally and connected to the dissected terminal branch of the ECRB.

**Case Report**

In advance of any data collection, the protocol of this study was approved by the local ethics committee. The patient provided written informed consent before participation, in accordance with the Declaration of Helsinki guiding biomedical research involving human subjects (http://www.cirp.org/library/ethics/helsinki/).

A 24-year-old man was in a motorcycle accident that produced a spinal cord injury. Soon after his injury, he underwent surgery for spinal stabilization. Four months after his accident, the patient presented to our department seeking assistance to improve his left hand function. At the time of the initial examination, he was sitting in a wheelchair and exhibited no lower limb motion. He had full motion and strength of both shoulders. Elbow flexion on the right and left side scored M5, according to the British Medical Research Council scale. His biceps, brachialis, and brachioradialis muscles all were functional. Triceps function was strong and scored M4 on both sides. In the left and right forearms, pronation was possible, scoring M3+. Flexor carpi radialis scored M3 on the right and left. Wrist extension scored M4 on both sides. On the left side, 8 kg of wrist extension strength was recorded using a push-pull dynamometer (Baseline, White Plains, New York). Active thumb and finger extension were possible bilaterally. Finger and thumb flexion were present on the right side (M3+). On the left side, thumb flexion was totally paralyzed, and finger flexion scored M2. All the intrinsic muscles of his left hand were affected. Hand sensation was largely preserved. The patient was reviewed 3 months later, and the clinical scenario was unchanged. In particular, thumb flexion was paralyzed and finger flexion continued to score no higher than M2. Because no improvement had been observed since the previous clinical examination, reconstructive surgery was proposed.

Seven months after his accident, the patient underwent surgical repair of his left upper limb, transferring the brachialis muscle to the flexor digitorum profundus, aided by a graft harvested from the right anterior tibialis tendon (Video 1, Supplemental Digital Content 1, http://links.lww.com/NEU/A416, which demonstrates pre and post-operative motion of the left hand). The distal branch of the ECRB was harvested and transferred to the nerve of the FPL. The extensor index proprius was transferred to enhance thumb abduction.

**Surgical Technique for Brachialis Muscle and Distal ECRB Motor Nerve Transfer**

The patient was operated on while under general anesthesia without muscle relaxants and in the supine position with a tourniquet block. Via an oblique incision along the proximal forearm, the subcutaneous tissue was divided (Figure 1). The bicipital aponeurosis was identified and divided, and the brachial artery and the median nerve were located. The median nerve was traced distally; the AIN was identified, together with its lateral branch to the FPL. Electrical stimulation confirmed the identity of the FPL nerve. On the lateral side of the incision, the superficial branch of the radial nerve (SBR) was identified. In a deeper and parallel plane to the SBR, the branch of the ECRB was recognized and electrically stimulated to confirm its identity (Figure 1).

The brachialis muscle was de-inserted from the ulna, the articular surface of the elbow, and the humerus by blunt dissection. The harvested tendon from the anterior tibialis muscle was sutured to the brachialis muscle, passed between the flexor digitorum profundus and superficialis, and retrieved distally in the wrist incision. The grafted tendon was then sutured to the flexor digitorum profundus under adequate tension (Figure 2). The tourniquet was released and hemostasis achieved with bipolar forceps.
Back at the proximal incision, the branch to the FPL was dissected and sectioned as proximally as possible, while the distal motor branch of the ECRB was sectioned as distally as possible. The motor branch of the ECRB was sutured to the branch of the FPL under the microscope using 9-0 sutures (Figure 3). The subcutaneous tissue was approximated and the skin closed.

Postoperative Care and Evaluation
After surgery, the patient’s left wrist was immobilized in neutral position and the elbow immobilized in 90 degrees of flexion for 10 days. The patient underwent regular sessions of physiotherapy. Nandrolone decanoate 50 mg was administered intramuscularly every 15 days for 3 months, followed by a 1-month rest period. This cycle was repeated 3 times. The patient was taught to flex his elbow while co-contracting the triceps to avoid motion at the elbow, thereby transferring brachialis power to finger flexion. He also was taught that wrist extension produced thumb flexion and increased the power of his grasp and pinch. The patient was followed at 3-month intervals for 14 months. At the time of final evaluation, thumb and finger motion was scored according to the British Medical Research Council scale, and pinch, grasp and wrist extension strength were measured using dynamometers (Baseline).

RESULTS

Anatomic Findings
The ECRB muscle was disposed vertically, with the anteroposterior axis parallel to the lateral side of the radius. The ECRB was innervated by a branch that arose either from the posterior interosseous nerve (PIN) \((n = 7)\) or from the SBR \((n = 7)\) at an average (± standard deviation [SD]) distance of 2.6 (± 0.5) cm from the lateral epicondyle. The motor branch and the vascular pedicle enter the ECRB via the anterior region in the proximal third of the muscle (Figure 4). The trajectory of the nerve to the ECRB was parallel to the SBR and to the anterior border of the muscle. At an average distance of 5 (± 1.6 ) cm from the lateral epicondyle, the nerve was observed to bifurcate: 1 branch entered the muscle, whereas the remaining nerve ran for a distance of 2.4 (± 0.8) cm before bifurcating \((n = 10)\) or trifurcating \((n = 4)\),
already almost inside the muscle. In 3 cases, 2 collaterals entered the muscle before final branching.

At the level of the flexor digitorum superficialis arcade, 7.7 (± 2.3) cm distal to the medial epicondyle, the nerve of the FPL emerged from the lateral side of the AIN. The motor branch to the FPL entered the muscle in its proximal third, at a point 3 (± 0.5) cm distal to the upper limit of the muscle (Figures 5 and 6). The origin of the FPL branch was cephalad to the pronator teres, but its motor entry point was caudal. The FPL main branch could be dissected from the AIN up to the origin of the latter from the median nerve. This allowed us to extend the stump of the FPL main branch for at least 3 cm. In 3 of the 14 specimens, a secondary main branch was identified just distal to the first main branch. In 10 of the 14 dissections, 2 or 3 very thin twigs to the FPL arose from the lateral side of the AIN within the middle third of the forearm (Figures 5 and 6).

During our in vitro surgery, the main branch of the FPL could be directly connected to the terminal branch of the ECRB. The average diameter of the ECRB was 0.9 (± 0.1) mm, whereas that of the FPL was 1.1 (± 0.1) mm. The number of myelinated fibers in the distal branch of the ECRB was 183 (± 58), whereas that of the FPL was 182 (± 68). There was no statistical difference in the mean diameter ($P = .2$) and number of myelinated fibers ($P = .93$) between the ECRB and FPL. Histological preparations are depicted in Figure 7.

**Clinical Case**

Fourteen months after surgery, the patient had regained finger and thumb flexion. Grasp strength scored M4 and measured 8 kg, and pinch strength scored M4 and exhibited 2 kg strength. Interphalangeal flexion of the thumb scored M4. The patient was now able to grasp and release objects with his previously paralyzed hand. There were no donor site deficits. Wrist extension was M4 and scored 9 kg (see Video 1).

**DISCUSSION**

The ECRB motor branch entered the muscle via its anterior surface, sent a first collateral, and then continued for 2.4 cm before bifurcating. It emerged in half of the dissections from the PIN and in half from the SBR. Abrams et al.\(^1\) found it to originate from the SBR in 25% of their cases. These variations in nerve origin can be explained because the ECRB nerve emerges around the bifurcation of the radial nerve.\(^1\) Hence, emergence from the SBR or PIN might be related to the fascicular arrangement or to nerve dissection.

The FPL was consistently innervated by a branch that originated from the lateral side of the AIN, in accordance with a previous report.\(^1\) This branch had a high origin in the forearm and entered the muscle at an average distance of 3 cm from its proximal insertion into the radius. After section, the distal branch of the ECRB could reach the FPL nerve directly. Direct connection without the use of nerve grafts is a prerequisite for a good functional recovery in distal nerve transfers.\(^1\) The numbers of myelinated fibers were similar within the ECRB and FPL. Because wrist extension is synergic with thumb and finger flexion, our patient did not have difficulty achieving motor control of thumb flexion. Should motor function be inadequate with our nerve transfer, transfer of the brachioradialis tendon to the FPL tendon or suturing the
FPL tendon to radius would be alternatives to reconstruct thumb interphalangeal flexion.3

Previously, Hsiao et al28 reported the transfer of the entire motor branch of ECRB for the reinnervation of the pronator teres in an isolated injury of the median nerve. In tetraplegics, wrist extension strength is not normal. Hence, complete denervation of the ECRB should be avoided. Our surgery was designed not to fully denervate the ECRB, by preserving its proximal motor branch. In fact, in our clinical case, we can attest to the preservation of wrist extension strength after harvesting the distal branch of the ECRB for transfer to the FPL. In our case, wrist extension strength could have been preserved either by hypertrophy of either the ECRL or the remaining innervated portion of the ECRB or by reinnervation of the distal portion of ECRB by nerve sprouting from innervated zones. This last scenario has been observed after partial motor branch sections for the treatment of spasticity.19 Brunelli and Brunelli19 refer to this phenomenon as adoption reinnervation.

We reconstructed finger flexion by transferring the brachialis muscle to the flexor digitorum profundus with the help of a tendon graft, in the same manner that we have done before for brachial plexus injuries.20 Finger flexion was produced by active contraction of the brachialis muscle, adjusted by the position of the elbow, and strengthened by wrist extension. An alternative to our muscle transfer would be the transfer of the brachialis nerve for finger flexion as first described by Vasconcellos,21 for brachial plexus reconstruction.

In tetraplegics with concomitant paralysis of thumb and finger extension, the supinator nerve might be transferred to the PIN nerve via the same incision. This is an important consideration because all hand function can be reconstructed in a single stage. This is in contrast to the current orthopedic approach, in which surgery for finger extension and finger flexion is carried out in different stages.4 This is a major drawback for tetraplegics, who invariably depend on others for medical and personal assistance. Dependence on caregivers and family, multiple-stage surgeries, and long immobilization periods are factors that dissuade patients from pursuing reconstructive surgery of the upper limb.3 Concerning nerve transfers, we believe that the entire limb can be reconstructed (ie, elbow extension, thumb and finger flexion/extension) during a single surgery, which is a significant advantage.
Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES


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COMMENT

In a survey of tetraplegic patients several years ago, they voted use of the hand as the lost function that they would most wish to regain. As the authors note, operations to restore finger grip or pinch, involving transfer of tendons for wrist extension to finger flexors, have been performed on persons with cervical spinal cord injury for many years. However, in the United States, less than 10% of patients with cervical spinal cord injury at the appropriate level undergo such surgery. Functional electrical stimulation to nerves mediating finger and thumb is another technique for this group of patients. Nerve transfers have become the mainstay of brachial plexus reconstruction in the past 2 decades and extrapolation of the knowledge that has been accumulated to the gaining of hand function after spinal cord injury is welcome, perhaps overdue. The authors are well-known for their detailed anatomic studies relevant to nerve transfer, for example, a widely referenced paper describing which branches of the radial nerve are good donors to reinnervate the circumflex axillary nerve without losing triceps strength. Nerve surgeons who decide to use the operation described in this article would find the anatomic information regarding the nerve to extensor carpi radialis brevis invaluable. One caveat is that in some persons with C5-6 injury, the C7 motoneurons are implicated through gray matter destruction: in such cases the anterior interosseous nerve would not be a reliable recipient for nerve transfer, although the corresponding tendon transfers would still be feasible. One looks forward to further clinical experience from this and other groups to determine the place of this and other nerve transfer procedures in improving finger function after tetraplegia at the C5-6 level.

Peter Richardson
London, United Kingdom