Tendon Transfer: Radial Nerve Injury Management

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Abstract

Radial nerve injury may be the consequence of a complex humerus fracture, direct nerve trauma, compressive neuropathies, neuritis, or (rarely) from malignant tumor, and considered one of the most debilitating injury affecting function in the hand because of impairment of grasp. These injuries are not uncommon in our society resulting in poor quality of living, dependency & loss of livelihood.More than 70% of RNP cases will recover conservatively. Conservative treatment consists of the patient wearing a brace and undergoing rehabilitation. The aim of rehabilitation is to maintain the passive motion of various joints and to limit the risk of adhesions. Tendon transfers are also an alternative method and it has been used for over a century to restore function after radial nerve injury or paralysis with good results. Innumerous tendon transfers have been described to treat radial nerve palsy, and all have their advocates who have shown commendable results.

Keywords:Radial Nerve Injury, Tendon transfer.

Radial Nerve Anatomy

The radial nerve arises from the posterior cord of the brachial plexus. As all three trunks contribute posterior divisions to the posterior cord, all roots of the plexus contribute to the various radially innervated muscles. For example, the brachialis and supinator are innervated by C5 and C6, whereas the extensor indicis proprius (EIP) and extensor pollicis longus (EPL) are innervated by the C7 and T1 roots. **[1]**

The radial nerve enters the upper posterior brachium and passes through a triangular space that is bordered superiorly by the teres major muscle, laterally by the humerus, and medially by the long head of the triceps muscle. Accompanied by the profunda brachii artery, the nerve enters the musculospiral groove between the medial and lateral heads of the triceps. **[1]**

The nerve crosses the humerus posteriorly from proximal medial to distal lateral. It is closely adherent to bone for a distance of approximately 6.5 cm. The nerve is coincident with the medial aspect of the humerus at approximately 18 cm proximal to the medial humeral epicondyle or at approximately the junction of the proximal and the next 25% of the length of the humerus.[7] It traverses the lateral aspect of the humerus at approximately midhumeral length, which is approximately 14 cm proximal to the lateral humeral epicondyle.**[1]**

Throughout its course posterior to the humerus, the nerve gives off branches to the lateral and medial heads of the triceps and to the lower lateral brachial cutaneous nerve. After passing around the lateral aspect of the humerus and piercing the lateral intermuscular septum, the radial nerve enters the interval between the brachialis and brachioradialis muscles.**[1]**

The brachialis muscle is usually dually innervated and receives motor supply from the musculocutaneous and radial nerves. Proximal to the lateral epicondyle, branches go to the brachioradialis and the extensor carpi radialis longus (ECRL). The origin of the branch to the extensor carpi radialis brevis (ECRB) is variable, arising from the main nerve trunk, the superficial branch of the radial nerve, or the posterior interosseous nerve (PIN). The incidence of each of the ECRB nerve branch morphologies is highly variable in the literature.**[2, 3]**

Near the level of the lateral epicondyle of the humerus, the nerve bifurcates into the superficial and deep branches . The superficial branch of the radial nerve continues distally beneath the brachioradialis muscle, until it passes between the tendons of the brachioradialis and the ECRL, approximately 9 cm proximal to the radial styloid Fig (1.1).**[2, 4]**

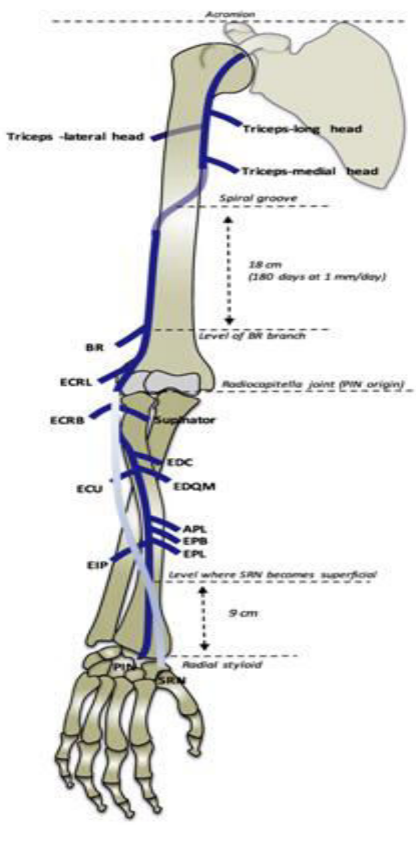

Fig 1.1 Branches of radial nerve in relation to bony land marks (4)

Distally, it arborizes to provide sensory innervation to the dorsoradial aspect of the hand, thumb, index finger, and, variably, the long and ring fingers .occasionally in some patients the superficial branch of the radial nerve is absent and its function is preempted by the lateral antebrachial cutaneous nerve.**[2]**

On the other hand, distal to the elbow joint, the deep radial nerve branch, or posterior interosseous nerve , passes beneath recurrent vessels from the radial artery and then, approximately 5 cm distal to the lateral humeral epicondyle, enters the supinator muscle underneath the arcade of Frohse. The arcade of Frohse is the proximal margin of the supinator. Its morphology can vary from a muscular to a tendinous quality This arcade is fibrous in about one-third of cases and may compress the nerve.**[5, 6]**

The nerve winds around the neck of the radius between the two heads of the supinator. In 25% of cases,

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it lies against the periosteum for about 3 cm (bare area) when the forearm is supinated; it is more vulnerable at this level. Multiple branches innervate the supinator as the nerve traverses beneath it.**[5, 6]**

As the posterior interosseous nerve emanates from the distal margin of the supinator, branches exit to supply the extensor digitorum communis (EDC), the extensor digiti quinti (EDQ), and the extensor carpi ulnaris (ECU). The remaining trunk of the posterior interosseous nerve continues distally in the interval between the extensor pollicis longus (EPL) and the abductor pollicis longus (APL).**[6]**

One branch exits the nerve to branch again to innervate the abductor pollicis longus (APL) and extensor pollicis brevis (EPB), another branch emanates from the nerve and subdivides to supply the extensor indicis proprius (EIP) andthe extensor pollicis longus (EPL), and the remainder of the nerve continues distally to the wrist joint (Fig. 1.2).**[6]**

Knowledge of proximal-to-distal muscle innervation order is practical information when observing for spontaneous radial nerve recovery or recovery after neurorrhaphy. In different cadaver specimens, this order is variable (2,3). Average innervation distances from a proximal landmark indicates the average innervation order from proximal to distal for the extensor forearm muscles (Fig. 1.2)(table 1.1).**[2, 7]**

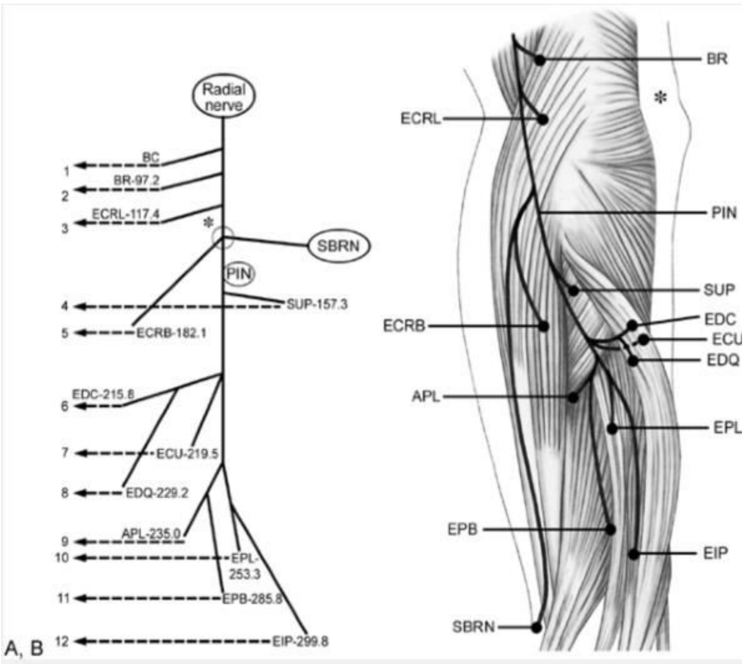

FIG 1.2 Branches of radial nerve**A**: Schematic of the typical branch pattern sequence (1,2,3,4,5,6,7,8,9,10,11 and 12). Numbers with decimals represent distances in millimeters along the nerve and branches from a landmark on the humerus that is 100 mm proximal to the lateral epicondyle (*asterisk*). The lateral epicondyle is near the branch point of the posterior interosseous nerve (PIN) and the superficial branch of the radial nerve (SBRN). **B:** Artist's drawing of the extensor forearm with an overlay showing PIN anatomy. APL, abductor pollicis longus; BC, brachialis; BR, brachioradialis; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; EDQ, extensor digiti quinti; EIP, extensor indicis proprius; EPB, extensor pollicis brevis; EPL, extensor pollicis longus; SUP, supinator.[8]

Measuring from a landmark 100 mm proximal to the lateral humeral epicondyle, the mean distance to the point at which the most proximal branch reaches the brachioradialis was 97.2 mm. The analogous distance to the EIP (usually the distal-most radial nerve–innervated muscle) was 299.8 mm.[8] Using the estimation by Seddon and Medawar **[8]**that nerve regeneration proceeds at a rate of approximately 1 mm per day, a theoretic prediction of time to recovery of muscles that are supplied by an injured radial nerve can be made. For example, if the nerve was injured 100 mm proximal to the lateral humeral epicondyle, recovery would begin with the brachioradialis at approximately 3 to 4 months and would be complete, ending with the EIP, by approximately 10 months.**[8]**

Radial Nerve Injury Treatment

Despite numerous studies, the management of radial nerve palsies associated with humeral shaft fractures remains a controversial topic. There are a few circumstances in which there is little controversy, and early exploration is the well-accepted standard of care. These circumstances include open fractures, fractures that cannot achieve an adequate closed reduction and require open reduction internal fixation, fractures with associated vascular injuries, and polytrauma patients. Palsies associated with gunshot fractures of the humerus are unique scenarios that, according to Bercik and colleagues, can be managed expectantly unless associated with concomitant vascular injury. Earlier reports included secondary palsies after closed reduction as an absolute indication; however, as cited earlier, there is growing evidence that these too can be managed expectantly. For the typical primary radial nerve palsy associated with a closed humeral shaft fracture, in general, the debate is split between 2 basic camps of thought: practitioners favoring early exploration versus those favoring expectant management with possible late exploration. **[9]**

- Nonoperative Treatment

By far the most important aspects of nonoperative management of the patient with radial nerve palsy are maintenance of full passive range of motion in all joints of the wrist and hand and prevention of contractures, including that of the thumb-index web. In most patients, the constant supervision of a therapist is not required, but the patient must be taught very soon after the original nerve injury how to carry out an appropriate exercise program to keep the joints supple. It is the patient's responsibility to do the exercises, and the role of the therapist at this point is to teach the patient and to monitor progress to be certain that the exercise program is carried out correctly.**[10]**

Many types of splints have been described for patients with radial nerve palsy. Most of these incorporate some type of dynamic outriggers to extend the fingers and thumb with elastic traction while allowing full mobility for active flexion**[10,11].**

For example, a person who does data entry and wishes to continue working might be able to do so with the dynamic finger and thumb extension splint shown in. However, an insurance salesman who is more concerned about appearance would probably be content with only a small, inconspicuous volar cock-up wrist splint, even though this does not provide nearly as much functional improvement as the dynamic splint. In some patients, merely stabilizing the wrist in extension imparts remarkably good temporary function.**[12]**

FIG 2 Types of RNI splints :Many types of splints have been designed for patients with radial nerve palsy, most of which offer some type of extension assist.
A, In one of the less cumbersome designs, passive MP extension is provided by simple elastic webbing beneath the proximal phalanges.
B, Active flexion of the PIP joints is not impeded. **(12)**

Burkhalter observed that grip strength may be increased three to five times by simply stabilizing the wrist with a splint. Brand recommended that if a wrist splint is only worn during the day, the patient should alternate this with a night splint that holds the wrist and fingers in extension. This is because the disturbed balance of the wrist in radial nerve palsy can result in loss of fiber length of the flexor muscles, making it more difficult to achieve normal balance after the final nerve recovery or operation.**[13, 14]**

- OPERATIVE TREATMENT

- Early Exploration

Proponents of early exploration in all cases with a radial nerve palsy with a humerus fracture argue that all radial nerve palsies following humeral shaft fractures should be treated with early exploration. They support this position by claiming the following advantages. Early exploration is indicated, as a sufficient number of radial nerve palsies do not recover spontaneously (approximately 30% of cases), thereby still warranting late exploration 3 months after injury prolonging rehabilitation, disability, and potentially compromising nerve recovery. Early exploration allows for early nerve injury characterization and classification (neuropraxia, incarceration, partial transection, and complete transection) and subsequent early treatment and recovery before the setting-in of soft tissue scarring, nerve retraction, motor end plate loss, and muscular atrophy. Early exploration and nerve repair (if incarcerated or transected) leads to superior outcomes, as nerve recovery outcomes are time dependent. Early exploration is technically easier and safer than late exploration, with the latter being more prone to soft tissue scarring and potential entrapment of the nerve in fracture callus. Early nerve exploration affords concomitant fracture stabilization with internal fixation, thereby facilitating quicker functional recovery and rehabilitation of patients. **[14]**

The next argument points to the fact that earlier nerve repair leads to superior outcomes. According to

Sunderland, a delay of more than 12 months does not worsen outcomes. However, Seddon states that a good prognosis is more likely if it is treated before 12 months. Lowe and colleagues supports this stand, affirming that the timing of nerve repair is paramount and that motor end plates must be reinnervated by 12 months for useful function to be restored; however, irrecoverable muscle atrophy can ensue sooner. There is further evidence in the literature to support that delays beyond even 5 months have shown inferior outcomes. Advocates of early exploration also claim it is technically easier, safer, and reduces the chance that the radial nerve remains enveloped in callus and scar tissue. A case report from Ikeda and Osamura shows how challenging a nerve repair can be when enveloped in fracture callus. In this specific case, the nerve could not be safely released from the fracture callus and was, therefore, sharply dissected at the bone and repaired end to end.**[15]** In short, delayed exploration and observation of patients with a lacerated or incarcerated radial nerve will result in a lack of early functional recovery, potential muscle atrophy and motor end plate loss, and substantial interim loss of patient function and livelihood. On the other hand, early exploration and repair can expedite quicker characterization of the nerve injury, quicker return of function, and, most importantly to some, peace of mind. Furthermore, on stabilization of the fracture with open reduction internal fixation, a repaired nerve will theoretically benefit from a better environment for healing with less traction, motion, or callus formation to impede nerve regeneration. **[15]**

1. **Nerve transfer**

The nerve transfer procedures have dramatically changed the treatment paradigm of brachial plexus injuries. The success achieved by repair of brachial plexus injuries has also been realized in the periphery, with multiple authors describing good clinical outcomes. Success with other nerve transfers led to consider the use of redundant median nerve branches as donor nerves to recover radial nerve function. Although both tendon transfer and nerve grafts are appropriate for management of radial nerve injuries, there is a group of patients with notable hand stiffness who are not candidates for tendon transfer or are older patients with medical comorbidities that make them poor candidates for sural nerve grafting. Authors first devised median and radial nerve transfer for that group of patients.**[16]**

Surgical exploration and reconstruction procedures were offered if no clinical or electrical evidence of target muscle reinnervation was observed by 3 months post injury. As they described, exploration and reconstruction were performed using a lazy-S–type incision over the volar forearm from the ante cubital fossa.Initially, step lengthening of the superficial head of the pronator teres was performed to allow easier exposure of the median nerve. At the proximal end of the incision and ulnar to the radial vessels, the branches of the median nerve were identified in a consistent branching pattern. Releasing the tendinous arch of the deep head of the pronator teres and flexor digitorum superficialis (FDS) allowed for further exposure of the median nerve branches. The nerve to the pronator teres branch was encountered in the proximal antecubitalfossa. Distal to the antecubital crease, the branch to theflexor carpi radialis (FCR) and palmaris longus (PL)was identified coming off medially.**[16]**

Distal to the FCR/PL branch, 2 branches to the FDS were encountered,followed shortly by the main sensory branch and the anterior interosseous nerve. Once the median nerve branches had been identified and mobilized, intraoperative nerve stimulation was used to verify the FDS andFCR donor fascicles. Moving to the lateral side of the radial vessels, identification of the extensor carpi radialisbrevis (ECRB) branch and posterior interosseousnerve (PIN) was carried out by following the radial sensory branch deep to the brachioradialis. After thePIN and ECRB branch were identified, the PIN wasfollowed distally and the tendinous edge of the supinatorwas released.

All procedures were performed in a completely tension free manner using a distal-based donor stump and proximallybased recipient stump to ensure good overlapand no tension**[16]**

Now the preferred technique evolved to consistently include coaptation of the FDS nerve to ECRB nerve and FCR nerve to PIN.Postoperative motor re-education and physical therapy are critical; nevertheless, their experience has been characterized by excellent return of radial nerve function with no appreciable loss of donor nerve function.**[16]**

The most interesting issue in this type of procedure is, when it is successful, median-to-radial nerve transfer allows independent finger and thumb extension, because the original radial muscles with their original muscle tension setting are being reinnervated.**[16]**

In most recent studies results is not as good as original tendon transfer yet ,as half of the nerve transfer patients underwent additional tendon transfer procedures later, with increasing the numbers of operations and weakening of donor muscle source after devoiding them from their nerve supply making the planning is so difficult.**[16]**

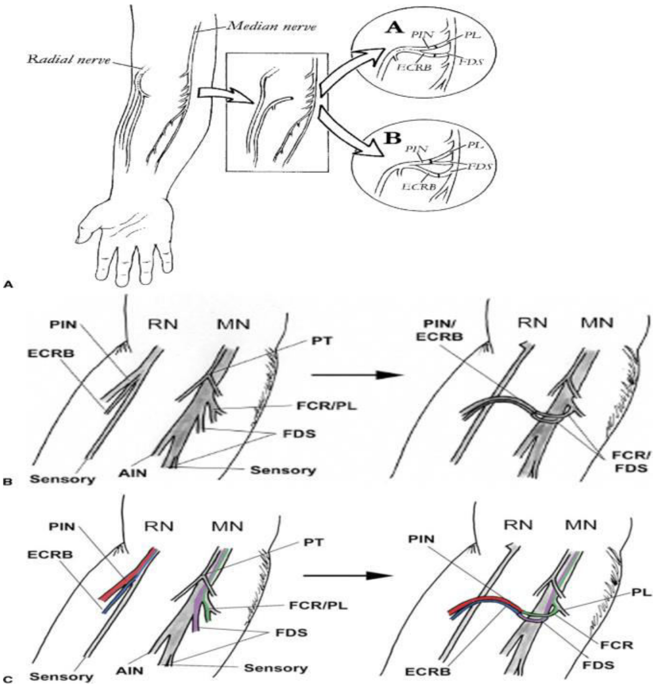

FIG 3: Median To radial nerve transfer**A :**Technique involved use of fascicles from the PL and FDS. **B** : Further evolution of the transfer technique with all fascicles of FDS nerve and FCR nerve coadapted to ECRB nerve and PIN without separation of individual donor and recipient branches.**[16]**

<u>2- Tendon Transfer</u>

Tendon transfers have been used for radial nerve palsy for more than one century, when hope of spontaneous or surgical recovery appears to be unlikely. Nerve grafting may restore sensation and motor function but, even when this procedure is possible, the result is not always good enough to give complete extension of the wrist and digits**[3]** Under such circumstances, tendon transfers are an alternative means of restoring good wrist and digital function.

Early Transfers ("Internal Splint")

Burkhalter believed that the greatest functional loss in the patient with radial nerve injury is weakness of power grip. Consequently, he was perhaps the strongest advocate of an early PT to ECRB transfer to eliminate the need for an external splint and, at the same time, to restore a significant amount of power grip to the patient's hand.**[14]**

In advocating early tendon transfer, Burkhalter was careful to emphasize what he called three indications and three important principles. The indications are that the transfer (1) works as a substitute during regeneration of the nerve to eliminate the need for splintage; (2) works as a helper after reinnervation by adding the power of a normal muscle to the reinnervated muscles; and (3) acts as a substitute in cases in which the results of nerve repair are statistically poor (e.g., elderly patients, chronic injuries, crush injuries). The important principles are that the transfer should (1) not significantly decrease the remaining function in the hand; (2) not create a deformity if significant return occurs following nerve repair; and (3) be a phasic transfer or one capable of phase conversion.**[14]**

Burkhalter believed that the PT to ECRB transfer fulfills all of these indications and principles, and he therefore suggested that the operation be done at the time of radial nerve repair or as soon as possible thereafter. The tendon juncture is done end-to-side, and the continuity of ECRB is not disrupted so that it may regain its own function if reinnervation should occur.**[14]**

Generally, a delay of 6 months is recommended before transfers are carried out when there is no possibility of spontaneous nerve recovery because tendon transfers will never achieve the same finger extension as that following nerve recovery and are always partially dependent on the wrist tenodesis effect. For patients older than 60 years, transfers can be carried out earlier because nerve grafting will not give as good a result as in younger patients and a prolongated wait can be detrimental to functional recovery after the transfer in this age group.**[17]**

A single transfer cannot act effectively on the tendon of five different muscles, as used by Jones. A transferred tendon can act on different tendons of the same muscle, such as the EDC, but its action is dispersed or even cancelled if it is fixed on the tendons of different muscles that each have a specific function.**[17]**

A tendon transfer used to extend the fingers will also extend the wrist if the latter is not stabilized. If the amplitude of movement has already been used to extend the wrist,the tendon will not have sufficient action left to extend the fingers. Therefore, the mainlines of treatment are established in the following manner:

• Re-establish, by separate transfers (1), wrist extension; (2) extension of the proximalphalanges of the fingers; and (3) extension, spreading, and retropositioning of thethumb.

• Conserve a muscle that will ensure stability of the wrist.

Tendon Transfer Options

Franke provided one of the earliest descriptions of tendon transfers for radial nerve palsy using the flexor carpi ulnaris (FCU) to extensor digitorum communis (EDC) transfer through the interosseous membrane.**[18]** The flexor carpi radialis (FCR) to extensor pollicis longus (EPL) transfer has also been described. The pronator teres (PT) to ECRL and extensor carpi radialis brevis (ECRB) transfer for wrist extension was first reported in 1906 by Sir Robert Jones. Zachary**[19]** emphasized the importance of retaining at least one wrist flexor, preferable the FCR to facilitate wrist control. Other authors have argued that FCU is not an expendable tendon and therefore prefer to use the FCR as the donor tendon to restore finger extension.

The advantage of using FCR is that it preserves the important moment of flexion and ulnar deviation of the wrist, which is so important for a power grip in working people. This factor is particularly important in patients with a posterior interosseous nerve (PIN) palsy in which ECRL function is preserved but extensor carpi ulnaris (ECU) function is lost. This condition results in radial deviation of the wrist with attempted wrist extension. Use of the FCU in this setting will only increase the radial deviation of the wrist because there would be no ulnar deviating motors of the wrist.**[18]**

More than 50 modifications of tendon transfers have been reported for radial nerve palsy, but 3 patterns of transfer have evolved. The use of PT to provide wrist extension has become universally accepted, the only remaining controversy being whether to insert PT into the ECRB alone or into both the ECRL and the ECRB. The 3 patterns of tendon transfer differ, therefore, only in the technique of restoring finger extension and thumb extension and radial abduction (Table 1).**[20]**

Table 3-1 : Tendon transfer options **[20]**

Tendon transfers for radial nerve palsy

	FCU Transfer	FCR Transfer	Boyes Superficialis Transfer
Wrist extension	PT to ECRB	PT to ECRB	PT to ECRB
Finger extension	FCU to EDC	FCR to EDC	FDS of ring finger to EDC long, ring, and small fingers
Thumb extension	PL to EPL	PL to EPL	FDS long finger to EIP and EPL

Abbreviations: EIP, extensor indicis proprius; FDS, flexor digitorum superficialis; PL, palmaris longus.

Standard FCU transfer

The FCU transfer is the authors' preferred technique for patients with a radial nerve palsy; the FCR transfer is preferred in patients with a PIN palsy. Through an inverted J-shaped incision over the ulnar-volar aspect of the distal forearm, the FCU tendon is transected at the wrist crease and released extensively from its fascial attachments up into the proximal third of the forearm, taking care not to damage the neurovascular pedicle, using a second incision in the proximal forearm if necessary. Through the same distal incision, the palmaris longus (PL) tendon is transected at the wrist crease and the muscle mobilized into the middle third of the forearm. An S-shaped incision is then made beginning over the volar-radial aspect of the middle third of the forearm and passing dorsally and ulnar over the radial border of the forearm, through which the tendon of the PT is elevated from the radius. The ECRB is transected at its musculotendinous junction if there is no chance of future reinnervation of the wrist extensors. The PT is then rerouted around the radial border of the forearm superficial to the brachioradialis and the ECRL tendons in a straight direction and sutured to the ECRB. The FCU tendon is passed through a subcutaneous tunnel made with a Kelly clamp from a dorsal incision around the ulnar border of the forearm into the Jshaped incision used to mobilize the FCU and sutured to the EDC tendons proximal to the extensor retinaculum. Alternatively, the FCU tendon may be passed from the palmar incision to the dorsal incision through a window in the interosseous membrane. If no return of the EDC function is to be expected, the EDC tendons are transected at their musculotendinous junctions so that a more direct line of pull can be achieved. Otherwise, an end-to-side juncture is performed. The EPL tendon is divided at its musculotendinous junction, removed from the third dorsal extensor tendon compartment, and passed through a subcutaneous tunnel from the base of the thumb metacarpal into the volar forearm incision and sutured to the PL. If the PL is absent, the EPL tendon is included with the EDC tendons so that the FCU provides both finger and thumb extension.

To prevent a collapse flexion deformity at the carpometacarpal joint of the thumb, a tenodesis of the abductor pollicis longus (APL) may be necessary. After transection of the APL tendon in the distal forearm, it is looped around the brachioradialis proximal to the radial styloid and sutured to itself with the thumb metacarpal held in extension with the wrist in 30° of extension. The proper tension in radial nerve tendon transfers should be tight enough to provide full extension of the wrist and digits but without restricting the flexion of the digits when the wrist is fully extended. The PT at resting tension is woven through the ECRB tendon with the wrist in 45° of extension. The distal ends of the 4 EDC tendons to the index, long, ring, and small fingers are sutured to the FCU tendon proximal to the extensor retinaculum. The extensor digiti minimi is not usually included unless there is still an extensor lag when proximal traction is applied to the EDC tendon to the small finger. With the wrist in neutral and the FCU under resting tension, each individual EDC tendon is sutured to provide full extension at the MCP joint, starting with the index finger and finishing with the small finger. Appropriate tension is then evaluated by checking that all 4 digits extend synchronously when the wrist is palmar flexed and, most importantly, that all 4 digits can be passively flexed into a fist when the wrist is extended. Finally, the PL and the EPL are interwoven over the radio-volar aspect of the wrist, with the PL at resting tension and the EPL at maximal tension with the wrist in neutral. The wrist is immobilized in 45° of extension in a volar splint, with the MCP joints positioned in slight flexion and the thumb in full extension and abduction. Active flexion and extension of the fingers and thumb are started at 3.5 to 4.0 weeks and active exercises of the wrist are started at 5 weeks. Protective splinting is continued until 6 to 8 weeks postoperatively.

Figure **(a)** A volar J-shape incision is made over the ulnar aspect of the distal third forearm. **(b)** The flexor carpi ulnaris (FCU) is transected just proximal to its pisiform insertion. The muscle is freed from its bed proximally to the junction of the proximal 1/3 and distal 2/3 of the forearm. **(c)** A dorsal curvilinear incision is made. **(d)** The extensor digitorum communis (EDC), extensor indicis proprius (EIP), and extensor pollicis longus (EPL) are exposed, just proximal to the extensor retinaculum. **(e)** The FCU is transferred to the dorsal wound around the ulnar border of the forearm through a subcutaneous tunnel. The FCU tendon is interweaved with the EDC, EIP, and EPL tendons in an oblique direction, as distally as feasible. **(f)** The FCU is sutured separately with these tendons midway between full tension and full relaxation. **(g)** An above-elbow plaster slab is applied with the wrist in 40° extension and the metacarpophalangeal (MCP) joints of the fingers and thumb in full extension. **(h)** Simultaneous extension of the MCP joints of the fingers and thumb extension at follow-up.

Fig 4: FCU single transfer steps

FCR transfer

The PT is transferred to the ECRB and the PL is transferred to the EPL exactly as described in the standard FCU transfer. The FCR is divided at the wrist crease and mobilized to the level of the midforearm and then rerouted around the radial border of the forearm or passed through a window in the interosseous membrane. The 4 EDC tendons, and if necessary, the EDM may be woven through the donor FCR tendon proximal to the extensor retinaculum, but more usually the extensor tendons need to be rerouted superficial to the extensor retinaculum to obtain a straighter line of pull. To prevent a bulky tendon juncture, the small finger EDC and EDM may be sutured side to side to the ring finger EDC and the index finger EDC sutured side to side to the long finger EDC under appropriate tension. Then only the 2 EDC tendons to the long and ring fingers require weaving through the FCR tendon. As with the standard FCU transfer, these tendon junctures are performed with the wrist in neutral and the MCP joints in full extension with the FCR tendon under resting tension. Postoperative management is similar to that for the FCU transfer.

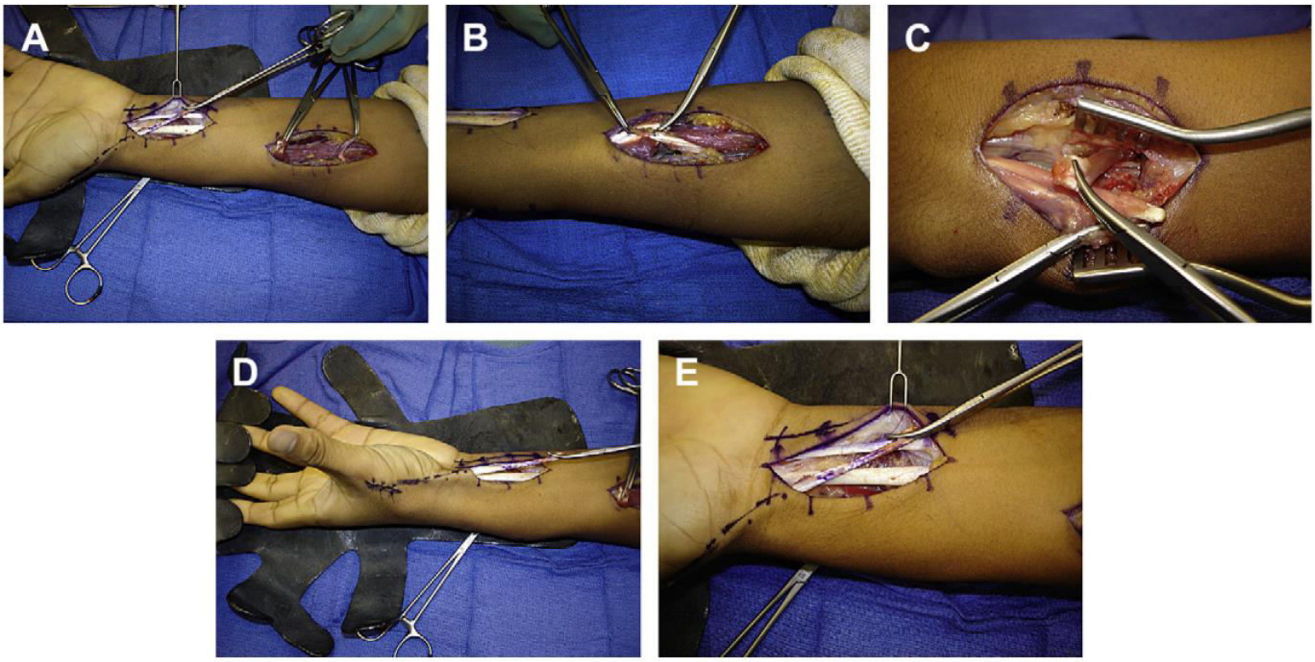

Fig. 5. (**A**) Through a volar incision in the distal third of the forearm, the palmaris longus and flexor carpi radialis are isolated and the transected extensor pollicis longus tendon rerouted into this incision. Through a separate incision over the radial aspect of the middle third of the forearm, the pronator teres is detached from the radius and the extensor carpi radialis brevis is transected at its musculotendinous junction. (**B**) The pronator teres is first sutured to the extensor carpi radialis brevis with the wrist in full extension and the pronator teres at its resting tension. (**C**) The flexor carpi radialis is passed to the radial aspect of the flexor tendons and median nerve through a window in the interosseous membrane and sutured at resting tension to the extensor digitorum communis tendons with the fingers in full extension at the MCP joints. (**D, E**) With the thumb in full radial abduction and extension, the rerouted extensor pollicis longus tendon is sutured to the palmaris longus tendon at its resting tension.

Boyes superficialis transfer

Boyes**[21]** was the first to argue that neither FCU nor FCR have sufficient amplitude (30 mm) to produce full excursion of the digital extensor tendons (50 mm) without incorporating the potential increase in amplitude obtained through the tenodesis effect of wrist flexion. He, therefore, advocated using the superficialis tendons to the long and ring fingers, which have an amplitude of 70 mm, to act as the donor tendons to restore finger extension.**[21, 22]** The advantages of the Boyes transfer are that this transfer will potentially allow simultaneous wrist and finger extension, it may allow independent thumb and index finger extension, and it does not weaken wrist flexion.

However, the long and ring fingers are deprived of superficialis function and this may result in weak grip. Harvesting of the superficialis tendons may also lead to the subsequent development of either a swan-neck deformity or a flexion contracture at the proximal interphalangeal (PIP) joint of the donor finger. In Boyes' original description, PT was sutured to both the ECRL and the ECRB,8 but to prevent excessive radial deviation, PT should only be woven end to end into the ECRB with the wrist in 30 degrees of extension. The long finger superficialis is then passed to the radial side of the profundus muscles and the ring finger superficialis to the ulnar side through an interosseous window into a dorsal incision. After transection of the EPL and EIP tendons, they are woven end to end into the long finger superficialis tendon. Similarly, the transected EDC tendons to the index, long, ring, and small fingers are woven end to end into the ring finger superficialis tendon, although this arrangement can be reversed. The tendon junctures are performed proximal to the extensor retinaculum with the donor superficialis tendons at resting tension and traction on the extensor tendons to produce full extension at the MCP joints.

Modified Jones Transfer Through a Single Incision

Various modifications in the classic Jones transfer for radial nerve palsy have been described. All use multiple incisions producing multiple surgical scars over the forearm, to avoid this problem a recent technique was introduced by Chandraprakasam et al, in which all the tendons needed for transfer are identified,trancected and sutured through a single incision running along the radial border of the distal third of the forearm curving obliquely at the lower end of radius to end at the Lister tubercle.

FIG (6). The vertical limb of the incision extends from the mid third-lower third junction on the radial aspect of the forearm and ends 1 cm proximal to the radial styloid. The oblique limb extends dorsally toward the Lister tubercle to enable access to the extensor pollicis longus.

By good retraction of the wound proximally, Pronator teres muscle is raised from its insertion with a sleeve of periosteum. The pronator teres tendon is passed subcutaneously around the radial border of the forearm, superficial to the brachioradialis and extensor carpi radialis longus to reach the musculotendinous junction of extensor carpi radialis brevis muscle. The palmaris longus and the flexor carpi radialis tendons are identified and transected at the level of the wrist. Both tendons are identified at a higher level through the same incision and pulled up proximally. The flexor carpi radialis tendon is passed around the radial border of the forearm to reach the extensor digitorum communis tendons at the lower third of the forearm. Extensor pollicis longus tendon is divided at the musculotendinous junction and rerouted to the radial side of Lister tubercle. Now the tendon anastamosis are carried out one by one under appropriate tension. Pronator teres is sutured to the extensor carpi radialis brevis tendon, followed by suturing of flexor carpi radialis tendon to extensor digitorum communis tendons, and finally, the palmaris longus tendon is sutured to the extensor pollicis longus tendon.**[23]**

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