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Clinical Outcomes following median to radial nerve transfers

Wilson Z. Ray, M.D.¹ and Susan E. Mackinnon, M.D.²

¹ Department of Neurological Surgery, Washington University, St. Louis

² Division of Plastic and Reconstructive Surgery, Washington University, St. Louis

Abstract

Purpose—In this study the authors evaluate the clinical outcomes in patients with radial nerve palsy who underwent nerve transfers utilizing redundant fascicles of median nerve (innervating the flexor digitorum superficialis and flexor carpi radialis muscles) to the posterior interosseous nerve and the nerve to the extensor carpi radialis brevis.

Methods—A retrospective review of the clinical records of 19 patients with radial nerve injuries who underwent nerve transfer procedures using the median nerve as a donor nerve were included. All patients were evaluated using the Medical Research Council (MRC) grading system.

Results—The mean age of patients was 41 years (range 17 – 78 years). All patients received at least 12 months of follow-up (20.3 ± 5.8 months). Surgery was performed at a mean of 5.7 ± 1.9 months post-injury. Post-operative functional evaluation was graded according to the following scale: grades MRC 0/5 - MRC 2/5 were considered poor outcomes, while MRC of 3/5 was a fair result, MRC grade 4/5 was a good result, and grade 4+/5 was considered an excellent outcome. Seventeen patients (89%) had a complete radial nerve palsy while two patients (11%) had intact wrist extension but no finger or thumb extension. Post-operatively all patients except one had good to excellent recovery of wrist extension. Twelve patients recovered good to excellent finger and thumb extension, two patients had fair recovery, five patients had a poor recovery.

Conclusions—The radial nerve is a commonly injured nerve, causing significant morbidity in affected patients. The median nerve provides a reliable source of donor nerve fascicles for radial nerve reinnervation. This transfer was first performed in 1999 and evolved over the subsequent decade. The important nuances of both surgical technique and motor re-education critical for the success of this transfer have been identified and are discussed.

Keywords

Nerve transfer; neurotization; brachial plexus; median nerve; radial nerve

Introduction

Proximal radial nerve injuries are a common orthopedic problem[1–5]. The radial nerve is the most commonly injured nerve following orthopedic trauma[6,7] and is highly correlated with open humeral shaft fractures[5]. Although radial nerve injuries can occur anywhere along the course of the nerve the clinical picture is similar. Involvement of the posterior

Corresponding Author: Susan E. Mackinnon, MD, Division of Plastic and Reconstructive Surgery, Washington University School of Medicine, 660 South Euclid Avenue, St. Louis, MO 63110, Tel: 314-362-4585, Fax: 314-362-4536, mackinnons@wudosis.wustl.edu.

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interosseous nerve (PIN) produces lack of finger and thumb extension and limited radial wrist extension, while more proximal injuries invariably produce a complete radial nerve palsy. The traditional treatment has been tendon transfers, and while these transfers can produce good results in both wrist and finger extension[8–11] there is no clear consensus on the most appropriate combination of transfers and some authors have cited unsatisfactory results following transfer[6,12–14]. The use of autologous nerve grafts to repair radial nerve defects is also a viable option and has produced mixed results based largely upon timely treatment of injuries[15–20]. If the radial nerve injury is proximally located and involves a long gap, then long sural nerve grafts are required. Nerve transfer procedures have dramatically changed the treatment paradigm of brachial plexus injuries[21–24] and the success enjoyed by the repair of brachial plexus injuries has also been realized in the periphery with multiple authors describing good clinical outcomes[25–29]. Success with other nerve transfers led us to consider the use of redundant median nerve branches as donor nerves to recover radial nerve function. While both tendon transfer and nerve grafts are appropriate for management of radial nerve injuries there is a group of patients with significant 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. It was for that group of patients that we first devised the median and radial nerve transfer[27,30].

Our experience has evolved over time and we have expanded our indication for median to radial nerve transfer as our experience with this transfer has increased. While post-operative motor re-education and physical therapy are critical, our experience has been characterized by excellent return of radial nerve function with no appreciable loss of donor nerve function. In this article we present our experience with median to radial nerve transfers following radial nerve injury. Over the last decade we have determined key points in technique that we believe are critical in the success of this transfer and discuss our “pearls and pitfalls” in this report.

Clinical Materials and Methods

After obtaining approval from the institution’s Human Studies Committee, a retrospective chart review of the office and hospital charts was performed on all patients evaluated for radial nerve injuries. Patients that had undergone a nerve transfer using redundant fascicles from the median nerve to the radial nerve with at least 12 months (mean follow-up of 20 months) follow-up were included.

Patient Population

The review included nineteen patients (11 men & 8 women), with a summary of all cases outlined in Table 1. All patients were initially evaluated at an outside hospital and subsequently referred for evaluation by the senior author. The mechanism of injury varied among patients with motor vehicle collision (MVC) representing the most common etiology. The mean patient age was 41 years (range 17–78 years), and the mean time from occurrence of injury to surgery was 5.7 ± 1.9 months (range 3–10 months). All patients were evaluated in a systematic standardized fashion including: pre-operative clinical and physical evaluation, muscle testing of involved extremity and contralateral extremity using the Medical Research Council Grading System (MRC), electromyography, and nerve conduction studies. All nerve conduction studies were performed at least 3 months after the initial injury, to assess for evidence of reinnervation any patients that had motor unit potentials were not offered surgery and continued expectant management was pursued.

Surgical Procedure

Surgical exploration and reconstruction procedures were offered if no clinical or electrical evidence of target muscle reinnervation was observed by three months post-injury. As we recently described exploration and reconstruction were performed using a lazy-S type incision over the volar forearm from the antecubital fossa[12]. 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 indentified in a consistent branching pattern. Releasing the tendinous arch of the deep head of the pronator teres and FDS allowed for further exposure of the median nerve branches. The nerve to the pronator teres was branch encountered in the proximal antecubital fossa. Distal to the antecubital crease the branch to the FCR and PL was identified coming off medially. Distal to the FCR/PL branch, two 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 utilized to verify the identification of the FDS and FCR donor fascicles. Moving to the lateral side of the radial vessels identification of the ECRB branch and PIN was carried out by following the radial sensory branch deep to the brachioradialis. After the PIN and ECRB branch were identified the PIN was followed distally and the tendinous edge of the supinator was released. All transfers were based on our mantra “donor distal and recipient proximal” to ensure a tension-free coaptation. If the donor nerve is not divided distally enough and the recipient nerve proximally enough, then there is not enough overlap to allow a tension-free repair. Having done nerve transfers since 1991, we still repeat that mantra donor distal recipient proximal on every nerve transfer. We always divided the donor nerve as distally as possible first and then move the donor nerve toward the recipient nerves. We then divide the recipient nerves as we can always dissect more proximally on the recipient nerves to ensure no tension. Over the treatment period, our preferred technique evolved to consistently include coaptation of the FDS nerve to ECRB nerve and FCR nerve to PIN. Other orientations of these transfers were done (Figure 1A–B), as described below and in Table 1, with less pleasing results and more difficult motor re-education.

As detailed in Table 1, in three patients redundant motor fascicles innervating the FDS were coadapted to the PIN and the PL to the ECRB (Figure 1A). In two patients with active wrist extension the FDS nerve was transferred to the PIN. In three patients the FDS nerve was transferred to both the ECRB and PIN. In one patient the FCR nerve was utilized as the sole donor to the ECRB and PIN. In one patient the FDS and FPL nerves were transferred to the ECRB nerve and PIN. In the remaining nine patients our transfer followed our currently preferred method of transferring of the FDS nerve to ECRB nerve and FCR nerve to PIN (Figure 1B). All procedures were performed in a completely tension free manner and utilizing a distal based donor stump and proximally based recipient stump to ensure good overlap and no tension. Nine patients underwent a pronator teres to ECRB tendon transfer procedures to augment the nerve transfer and provide wrist extension at the time of nerve transfer. We offer patients a pronator teres to extensor carpi radialis brevis tendon transfer to all patients. In some patients with reflex sympathetic dystrophy or extremely stiff hands this is not possible. Our goal is to obtain maximum and best function as soon as possible. The median-to-radial nerve transfer, when successful, will allow independent finger and thumb extension, as the original radial muscles with their original muscle tension setting are being reinnervated. However, the pronator teres to extensor carpi radialis tendon transfer is tried and true and will give prompt wrist extension. In fact if the patients do not have a stiff wrist we recommend extending the proximal volar forearm incision to facilitate the PT to ECRB tendon transfer at the time of the median nerve to radial nerve transfer.

Post-operative management

Post-operative management included immobilization for approximately four weeks if tendon transfers were performed and one week if just the nerve transfers were performed. Full range of motion exercises commenced approximately two weeks following surgery. Focused occupational and physical therapy, as well as dedicated hand therapy were continued for the first postoperative year. Focused motor re-education is integrated in to all physical therapy sessions, while all patients are given directed home exercises to promote recruitment of extensor muscles. Early motor reeducation is done in a position requiring the least effort from the “recipient” muscle allowing even the weakest muscle the chance to initiate movement. Since both transfers utilize synergistic movements the patient is taught to attempt co-contraction of donor and recipient muscles in attempt to initiate development of the new motor pathway for the recipient muscle. Patients were followed on a monthly basis to advance their donor strengthening and to monitor progress, compliance and accuracy of the motor reeducation exercises. All patients retained full strength of wrist and finger flexion and yet resistance training was continued with the intent of continuing to foster development of the new motor pathway for the recipient muscle. Strength training continues on a monthly basis.

Results

The mean follow-up for all patients was 20.3 ± 5.8 months (range 12–33 months). Postoperative functional evaluation was graded according to the following scale: grades MRC 0/5 - 2/5 were considered a poor outcome, MRC 3/5 was a fair result, MRC grade 4/5 was a good result, and grade 4+/5 represented an excellent outcome. As detailed in Table 1, Pre-operatively, seventeen patients (89%) had a complete radial nerve palsy while two patients (11%) had intact wrist extension with loss of finger and thumb extension. Post-operatively all patients except one had good recovery of wrist extension, while one patient failed to make any recovery. Twelve patients recovered good finger and thumb extension, two patients had fair recovery, while five patients made a poor functional recovery.

The small number of patients did not allow for any meaningful statistical analysis, but of the nineteen patients, fourteen patients underwent early reconstruction procedures (< 6 months denervation time). Eight of the fourteen patients that underwent early reconstruction regained good return of function. Interestingly, four of the five patients that underwent reconstruction > 6 months after their injury regained good (MRC 4/5) wrist and finger extension.

Patient ages varied widely in this series (17 – 78 years). Analysis of outcomes based on patient age did not demonstrate any significant trends based on age alone. Eight patients were less than 30 years of age, and of these patients four made a good functional recovery of both wrist and finger extension. Two patients recovered good wrist extension (MRC 4/5) and poor finger extension (MRC 2/5). One patient regained good wrist extension (MRC 4/5) with fair finger extension (MRC 3/5) while the final patient treated only for finger drop had a fair functional recovery (MRC 3/5).

Discussion

The use of nerve transfers for traumatic and obstetric brachial plexus injuries has gained significant momentum over the last decade. The results observed with nerve transfers for proximal injuries have also been realized with distal nerve transfers [12,28,31–33]. The proximity of regenerating axons to motor endplates in distal nerve transfers allows for more rapid motor reinnervation of distal target muscles by decreasing the distance between the nerve injury and the target motor end plates. Utilization of synergistic motor donors in close

proximity to recipient motor end plates minimizes the loss of recipient motor units. Although synergistic donors are the preferable source of axons, previous studies have demonstrated good outcomes using a seemingly unrelated donor (e.g. intercostals) as long as appropriate post-operative physical therapy and motor re-education is pursued[34–38]. Our experience with the motor reeducation in this transfer has shown us that it is imperative to transfer the FDS nerve to the ECRB nerve and the FCR nerve to the PIN. When we reversed this transfer the post-operative reeducation went from simple to very challenging. In one case with a poor outcome we were not able to re-educate the “incorrect” nerve transfer (FCR to ECRB & FDS to PIN) and when we performed subsequent tendon transfers on this patient all the extensor muscles had been reinnervated but could not be “motored” by the patient because we had utilized antagonistic nerve transfers.

Half of our patients underwent additional tendon transfer procedures. Eight patients underwent simultaneous transfer of the PT to the ECRB, while one patient underwent a delayed transfer of the PL to EBL and FCR to EDC. Although it is difficult to know how much power is generated in wrist extension from tendon transfer alone (versus the nerve transfer), simultaneous tendon transfer at the time of initial neurotization offers earlier recovery of wrist extension and avoids some of the potential loss of range of motion that can occur in some patients while nerve regeneration occurs.

We initially described three cases where redundant motor branches of the median nerve were transferred to the PIN and ECRB branch[27,30]. As our experience with this procedure has expanded and evolved along with our experience with post-operative re-education therapy our surgical technique has evolved to reflect this understanding[12]. Ukrit et al[39] recently reported an anatomic feasibility study of FDS to ECRB and two clinical cases of complete brachial plexus avulsion injuries involving C5–C7. The patients underwent neurotization procedures of the FDS to ECRB. At 24 months both patients had regained MRC 4/5 strength in wrist extension with no loss of FDS function. The authors concluded from both anatomical studies as well as from clinical application that the FDS is a useful donor for restoration of wrist extension via ECRB. To the author’s knowledge this represents the only other report for median to radial nerve transfers.

Multiple studies have reported improved outcomes following nerve transfers in a younger patient population[12,40]. In our experience the key to functional recovery was the use of appropriate synergistic nerve transfers. Our first patient was an elderly woman with a painful stiff hand and therefore was not a candidate for nerve grafting or tendon transfers. She recovered excellent radial nerve function with the nerve transfers and required essentially no motor reeducation.

There are situations where tendon transfers or nerve grafts are not feasible for radial nerve palsy. In these situations we would recommend that surgeons consider a median-to-radial nerve transfer using the techniques that we have described above. We continue to use tendon transfers for radial nerve palsy but have really abandoned nerve grafting in favor of median-to-radial nerve transfer. The debate has now moved in our opinion from whether nerve grafting for radial nerve palsy is equal or superior to tendon transfers to whether or not nerve transfers are equal or superior to tendon transfers. In our practice we use a nerve transfer frequently in conjunction with a tendon transfer and consider median-to-radial nerve transfer to have basically replaced nerve grafting for radial nerve injuries. Our experience with median-to-radial nerve transfers is that in the situations where we get an excellent result, the results are almost normal, the patients have fluid, independent finger and thumb extension and the results are superior to tendon transfers. Tendon transfers, however, are tried and true, are an excellent means to reconstruct radial nerve palsy. In this report we simply offer

our experience with median-to-radial nerve transfers to those who might find this useful in the management of some of their patients with this significant problem.

With proximal radial nerve injuries using standard techniques of nerve reconstruction, three months has been the time point recommended for surgical intervention if there is no evidence of clinical or electrical recovery. This is standard protocol in published book chapters and reflects the problem of leaving a fourth or fifth degree injury too long to allow reinnervation in motor targets. Given the fact that nerve transfer techniques bring motor axons closer to target, the standard time point for recommending surgery for closed nerve injuries of three months can be extended. In fact, we have had excellent results with median-to-radial nerve transfer at nine months. By contrast, by twelve months frequently the denervated muscles will demonstrate fatty infiltration and will be past the time point for reconstruction. Currently we would consider median-to-radial nerve transfer at nine months. At twelve months we would recommend tendon transfers.

We report our experience with the use of branches of the median nerve to reinnervate the radial nerve. The consistent topographic anatomy, redundant nature, the high number of donor motor neurons, and the proximity to the radial nerve makes the median nerve an attractive donor for radial nerve palsies. Our understanding of this transfer has evolved over ten years and our early experience with this transfer suggests it provides reliable return of function for wrist extension. Increased experience with post-operative motor re-education has allowed our preferred reinnervation strategy to evolve into its current form of FDS nerve to ECRB nerve and FCR nerve to PIN. We believe that this synergistic alignment is key for the functional success of this transfer. Although further studies are needed we anticipate the synergy of this transfer will provide a promising tool for nerve surgeons treating patients with this devastating injury.

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Figure 1.

Figure 1A) Our initial technique involved utilization of fascicles from the PL and FDS. (Adapted by permission from *Plastics and Reconstructive Surgery*; Elsevier. 2002; 110(3): 836–843, Lowe JB, Tung TR, Mackinnon SE. New Surgical Option for Radial Nerve Paralysis)

Figure 1B) 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. (Adapted by permission from *Hand Clinics*; Elsevier. 2008 Nov; 24(4): 319–340, Brown JM, Mackinnon SE. Nerve transfers of the forearm and hand)

Figure 1C) Illustration of our current preferred technique, FDS nerve to ECRB nerve and FCR nerve to PIN.

Table 1

Patient number	DOS	Age/Sex	Mechanism of Injury	Time of Injury to Surgery	Primary operation	Pre-operative function	Post-operative function	Follow-up Period (mos)
1	10/1/99	51/M	Radial Neuritis	5	FDS nerve & PL nerve to ECRB nerve & PIN	Complete Radial Palsy	4/5 Wrist extension, minimal finger extension	14
2	3/3/00	24/F	Iatrogenic/soft tissue removal	3	FDS nerve & PL nerve to ECRB nerve & PIN	Complete Radial Palsy	4/5 Wrist and finger extension	13
3	11/28/01	60/F	Iatrogenic/hemiarthroplasty	3	PL nerve to ECRB and FDS nerve to PIN	Complete Radial Palsy	4/5 Wrist and finger extension	18
4	3/2/04	32/F	Iatrogenic/humerus fracture repair	7	FDS nerve & FCR nerve to ECRB nerve & PIN	Complete Radial Palsy	4/5 Wrist and finger extension	18
5	3/28/05	27/M	Laceration/plate glass	6	FDS nerve to ECRB nerve and FCR nerve to PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist extension, minimal finger extension	16
6	3/30/06	52/M	MVA	7	FDS nerve & FPL nerve to ECRB & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist and finger extension	13
7	4/14/06	56/F	Tumor	N/A	FCR nerve to ECRB nerve and FDS nerve to PIN	Complete Radial Palsy	4/5 Wrist and finger extension	33
8	7/3/06	26/F	Motorcycle	4	FDS nerve to ECRB nerve & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist and finger extension	25
9	9/19/06	21/M	MVA	6	FCR nerve to ECRB nerve and PIN; PT to ECRB tendon transfer	Complete Radial Palsy	5/5 Wrist and finger extension	23
10	12/18/06	23/M	Motorcycle	3	FDS nerve to ECRB nerve & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist extension, minimal finger extension	27
11	7/21/07	58/M	Elbow dislocation	8	FDS nerve & FCR nerve to ECRB nerve & PIN	Complete Radial Palsy	0/5 Wrist and finger extension	23

Patient number	DOS	Age/Sex	Mechanism of Injury	Time of Injury to Surgery	Primary operation	Pre-operative function	Post-operative function	Follow-up Period (mos)
12	11/7/07	78/F	Iatrogenic/Shoulder surgery	5	FDS nerve to ECRB nerve and PIN	Complete Radial Palsy	4/5 Wrist extension, minimal finger extension	29
13	1/8/08	53/M	Iatrogenic/Shoulder surgery	6	FDS nerve to PIN and FCR nerve to ECRB nerve	Complete Radial Palsy	4/5 Wrist and finger extension	24
14	2/4/08	40/M	MVA	8	FDS nerve to PIN	Finger drop, intact wrist extension	4/5 Finger extension	19
15	2/5/08	24/M	Humerus Fracture	6	FDS nerve & FCR nerve to ECRB nerve & PIN	Complete Radial Palsy	4/5 Wrist extension, 3/5 finger extension	23
16	4/1/08	37/F	MVA	4	FDS nerve & FCR nerve to ECRB nerve & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist and finger extension	22
17	6/11/08	24/M	MVA	6	FDS nerve to PIN PL to EPL tendon transfer & FCR to EDC tendon transfer	Finger drop, intact wrist extension	3/5 finger extension	15
18	9/29/08	68/M	MVA	5	FDS nerve & FCR nerve to ECRB nerve & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist extension, minimal finger extension	19
19	5/20/09	17/F	MVA	10	FDS nerve & FCR nerve to ECRB nerve & PIN; PT to ECRB tendon transfer	Complete Radial Palsy	4/5 Wrist and finger extension	12

- Offer PT to ECRB tendon transfer if hand is supple
- If the PL is preserved we neurolyze this from the FCR branch to use as a fall back for tendon transfer
- One fascicle of FDS or FCR is left for potential tendon transfer
- The supinator nerve and the radial sensory are excluded from the recipient
- All repairs are performed in a tension free manner, dividing the donor distal and the recipient proximally