POSTCOURSE: BRACHIAL PLEXUS: DISTAL NERVE TRANSFERS: RATIONALE, CONTROVERSIES AND SURGICAL DEMONSTRATIONS

Co-Chairs: Peter M. Murray, MD
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Program Syllabus
Saturday, September 20, 2014

69TH ANNUAL MEETING OF THE ASSH
SEPTEMBER 18-20, 2014
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OVERVIEW
Distal nerve transfers are an innovative alternative to reconstruction of the brachial plexus. This multidisciplinary postcourse will blend brief didactic sessions with multimedia surgical demonstration to provide the learner with a comprehensive review on state of the art nerve transfer surgery. The learner will directly observe renowned faculty performing the more commonly indicated nerve transfers. At the conclusion of this half-day skills demonstration course, the learner will understand the indications, surgical techniques and anticipated outcomes of distal nerve transfers. Time for questions and discussion will be permitted after each demonstration to encourage maximum participation.

LEARNING OBJECTIVES:
• Discuss the indications and outcomes for distal nerve transfers in adult brachial plexus palsy.
• Describe the indications and outcomes for distal nerve transfers in obstetrical brachial plexus palsy.
• Identify the proper surgical technique for distal nerve transfers in brachial plexus surgery.

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Postcourse: Brachial Plexus: Distal Nerve Transfers: Rationale, Controversies and Surgical Demonstrations
Saturday, September 20 – 1:30 – 5:30 PM
304, Hynes

Chairs: Peter M. Murray, MD
Alexander Y. Shin, MD

Description:
Distal nerve transfers are an innovative alternative to reconstruction of the brachial plexus. This multidisciplinary postcourse will blend brief didactic sessions with multimedia surgical demonstration to provide the learner with a comprehensive review on state of the art nerve transfer surgery. The learner will directly observe renowned faculty performing the more commonly indicated nerve transfers. At the conclusion of this half-day skills demonstration course, the learner will understand the indications, surgical techniques and anticipated outcomes of distal nerve transfers. Time for questions and discussion will be permitted after each demonstration to encourage maximum participation.

Objectives:
- Discuss the indications and outcomes for distal nerve transfers in adult brachial plexus palsy.
- Describe the indications and outcomes for distal nerve transfers in obstetrical brachial plexus palsy.
- Identify the proper surgical technique for distal nerve transfers in brachial plexus surgery.

Program
1:00 – 1:05 PM
Welcome and Overview
Peter M. Murray, MD & Alexander Y. Shin, MD

1:05 – 1:15 PM
Rationale and role of distal nerve transfers in adult brachial plexus injuries
Scott W. Wolfe, MD
1:15 – 1:25 PM
Historical perspective of nerve transfers
Michael B. Wood, MD

1:25 – 1:50 PM
Case discussions (pediatric and adult) cases from faculty
Michael B. Wood, MD

1:50 – 2:05 PM
Triceps branch to axillary nerve transfer (Leechavengvongs Transfer): indications, pitfalls and outcomes (Presentation and Surgical Demo)
Alexander Y. Shin, MD

2:05 – 2:15 PM
Questions

2:15 – 2:35 PM
Spinal accessory nerve to suprascapular nerve transfer: Why is it so hard to get good results? Indications, pitfalls and outcome (Presentation and Surgical Demo)
Allen T. Bishop, MD

2:35 – 2:45 PM
Questions

2:45 – 3:00 PM
Ulnar nerve fascicle transfer to biceps motor branch (Oberlin Transfer): indications, pitfalls and outcomes (Presentation and Surgical Demo)
Steve K. Lee, MD

3:00 - 3:10 PM
Questions

3:10 – 3:25 PM
Radial nerve palsy transfers: nerve to FCR, FDS, pronator to PIN: indications, pitfalls and outcomes (Presentation and Surgical Demo)
Susan E. Mackinnon, MD

3:25 – 3:35 PM
Critical comparison to tendon transfer for radial nerve palsy
Alexander Y. Shin, MD

3:35 – 3:45 PM
Questions

3:45 – 4:00 PM
AIN to deep branch of ulnar at wrist: indications, pitfall and outcomes (Presentation and Surgical Demo)
Peter M. Murray, MD

4:00 – 4:10 PM
Critical comparison to tendon transfers
Michael B. Wood, MD

4:10 – 4:30 PM
Questions

4:30 – 4:45 PM
Supinater branches to PIN: indications, pitfall and outcomes (Presentation and Surgical Demo)
Jayme A. Bertelli, MD, PhD

4:45 – 5:00 PM
Case discussions: cases from faculty
Scott W. Wolfe, MD
Rationale and Role of Distal Nerve Transfers
Scott W. Wolfe, M.D.
Attending Orthopedic Surgeon
Hospital for Special Surgery
Professor of Orthopedic Surgery
Weill Medical College of Cornell University
wolfes@hss.edu

Goals of the lecture
1. Raise awareness of the benefit of distal nerve transfer
2. Review new concepts in prevention of Schwann cell and muscle degeneration
3. Understand indications and limitations of distal nerve vs. tendon transfer
4. Detail different available motor and sensory transfers for median, ulnar and radial nerves

I. RATIONALE
A. Regeneration distances to forearm and hand are long
   1. Distance to motor endplate insurmountable w/ current techniques (1)
   2. Loss of Schwann cell viability in distal nerve stump (2-4)
   3. Extent of distal atrophy and stiffness cannot be overestimated (5)
   4. Restoration of sensation is critical to therapy, motor recovery (6;7)
B. Distal recovery is historically poor from nerve repair or graft (8)
C. CC7 results unpredictable and incomplete (5;9)
   1. Better sensory recovery than motor (1;5)
D. Tendon transfers predictable but not always available
   1. Traditional tendon transfers (10-12)
   2. Oberlin transfer of recovered biceps to FDP (13)
E. “Push the envelope” of distal recovery
   1. Concept of “Babysitting” (14-17)
      a. Sensory protection of denervated distal stump and muscles
   2. Concept of “reverse end-to-side” RETS (18;19)
   3. Concept of side-to-side nerve bridging (20;21)
   4. Concept of “supercharging” reverse end-to-side (SETS) (22;23)

Figure 1. A) end-to-side and B) reverse end-to-side
From Isaacs et al. (19)

II. WHAT’S AVAILABLE?
A. Motor
   1. End to end (ETE)
      a. Lower trunk or C8-T1 palsy
i. Brachialis to AIN(24)
ii. Supinator to PIN(25;26)
iii. Brachioradialis to AIN(27)
b. Radial nerve transfers(28;29)
   i. FDS to ECRB
   ii. FCR to PIN
c. Median nerve transfers
d. Ulnar nerve transfers
   i. AIN to ulnar motor
e. Combined median and ulnar
      i. Radial to ulnar (30;31)
2. Supercharged reverse end to side (RETS)(18;19;23;32)

B. Sensory
3. Lower trunk or C8-T1 palsy
   a. LABC to ulnar nerve
   b. Median to ulnar (palmar cutaneous?)
4. 3rd webspace to ulnar sensory(33)
5. Radial to median(34)
6. Median to radial end-to-side (sensation and pain control)(35)

II. ROLE OF DISTAL NERVE TRANSFERS
A. Candidates
   1. Traumatic brachial plexus palsy
      a. Lower plexus (C7-8-1)
      b. Lower trunk and high ulnar nerve injury
   2. Post-radiation plexitis
   3. Tetraplegia(25;36-38)
   4. Cervical radiculopathy, post-operative spine surgical deficits
B. Integral component of shoulder to fingertip recovery
   1. Assess deficits, available donors
      a. Tendon
      b. Nerve
   2. Combination solution often required
C. Early intervention critical
D. Consider “supercharge” RETS to maintain Schwann cells and endplates(23)
E. Sensory transfers integral to recovery
   1. Rehabilitation
   2. Pain control
   3. Function
F. Solutions continue to evolve
REFERENCES


Brachial Plexus Reconstruction
Nerve Transfer vs. Tendon Transfer
Michael B. Wood, MD
Professor, Mayo Clinical College of Medicine

Nerve Transfer vs. Tendon Transfer
Sometimes there is no realistic choice
• Long delay post injury
• No active regional muscle or donor
• No available donor nerve or recipient nerve

Nerve Transfer vs. Tendon Transfer
• High quality comparative outcome studies lacking
• Treatment strategy often based on surgeon preference/comfort level
Nerve Transfer vs. Tendon Transfer

My Bias
- In general, a good result from a nerve repair or transfer is better than a good result from a tendon transfer
  - But...
- A tendon transfer yields a more predictable outcome in most surgeon's hands

Specific clinical situations
- Shoulder abduction
- Shoulder external rotation
- Elbow flexion
- Elbow extension
- Wrist extension
- Finger flexion
- Hand intrinsic function

Shoulder abduction nerve transfer (triceps branches) preferred
- Technically simple
- Clinical result generally good
- Alternative tendon transfer (Trapezius) or fusion poor abduction result
**Nerve Transfer vs. Tendon Transfer**

**Shoulder external rotation**
Tendon transfer (lat dorsi) preferred
- Predictable outcome
- Improves internal rotation imbalance
- Nerve transfer (spinal access) to supraspinatus nerve results variable

**Elbow Flexion**
Nerve transfer (ulnar ± median portion) preferred
- Technically simple
- Clinical result generally good
- Intercostal or spinal access second tier choice
- Tendon transfer late backstop option

**Elbow Extension**
Nerve transfer (intercostal) preferred
- rarely tendon transfer option with BPI
Nerve Transfer vs. Tendon Transfer

**Wrist Extension**
Tendon transfer (P.T., FDS, FCU) preferred

**Finger/Thumb flexion**
Tendon transfer (BR, ECRL) preferred
- Plus 1st CMC ± IP fusion of thumb
- Consider free muscle and nerve transfer if donor tendons lacking

**Hand intrinsic function**
Tendon transfer (FDS, ECRL, EIP) preferred
- But for isolated palsy of deep motor branch nerve transfer (AIN) preferred
Nerve Transfer vs. Tendon Transfer

Conclusions

• No simple or consistent answers
• Clinical judgment important
• B.P. surgeons required both skill sets
• Nerve transfer innovation progressing
• Presenter’s personal bias not shared by all
Technique
Described by Leechavengvongs et al.\textsuperscript{1,2}

Incision – posterior deltoid extending distal over quadrilateral space and triangular interval
Look for sensory branch of axillary nerve and trace it back to axillary nerve in quadrilateral space

Hint: obtain excellent hemostasis during dissection, and axillary nerve is often right next to deltoid muscle and can be difficult to see

Develop plane of posterior deltoid and reflect deltoid anteriorly

Trace sensory branch to quadrilateral space

Sensory branch leads to posterior division of axillary nerve, trace to main axillary nerve and search for anterior division

Hint: nerve stimulator will not work, as the axillary nerve is paralytic
Alexander Y. Shin, MD
Triceps nerve transfer to axillary nerve

Place vessel loops around anterior division, posterior division and common axillary nerve to mobilize and to keep anatomy clear.

Separate Anterior Division off of Posterior Division as far anterior as possible. Occasionally, the injury to the axillary nerve may be posterior and this may preclude the application of this transfer.

Divide the anterior division off the main axillary nerve as far anterior as possible. This gives a long recipient nerve. Leave the posterior branch in continuity if there is potential for recovery. If there is no potential for recovery, it can be divided with the anterior division and dissected off later.

Identify the radial nerve in the triangular interval. Using a variable nerve stimulator, identify the triceps branches. Choose the triceps branch that give a good elbow extension, and make sure that the remaining triceps branches can also extend the elbow well. If the radial nerve is partially injured, choose the branch that will not sacrifice too much elbow extension. Mobilize the tricep nerve as much as possible (may require dissection off the proximal radial nerve, or recession of the teres major tendon).

From Leechavengvongs et al.3
Under operative microscope, coapt the triceps branch to the anterior division of the axillary nerve using 9-0 nylon suture.

Post operative course:
- Immobilize shoulder for 3 weeks
- At 3 weeks – activity as tolerated
- EMG at 6-9 months
- Emphasize triceps extension with forward flexion/abduction

Indications
- Isolated axillary nerve injury
- Part of Upper trunk injury with preserved triceps function
- Time from injury ideally <6 months. Will extend to 9 months in
Alexander Y. Shin, MD
Triceps nerve transfer to axillary nerve

younger patients

Contraindications
>12 months from injury
Less than BMRC grade 4 Triceps function

Outcomes
Leechavengvongs et al\(^1\)
7 patients- upper trunk injuries between 3-10 months from injury
all developed M4 strength after surgery
Caveat- definition of BMRC strength with respect to abduction

Lee et al\(^4\)
21 patients with isolated axillary nerve injury
Delay 4-14 months
Outcome: 2-4.5 BMRC abduction – avg 3.5
5 patients failed to obtain more than grade 3
Delay >9 months, greater BMI and Age >40 had worse results
Strict grading of BMRC

Modifications: Posterior Division Axillary nerve transfer to Triceps\(^5\) to obtain extension of elbow in unique situations
References


Alexander Y. Shin, MD
Triceps nerve transfer to axillary nerve

Ulnar nerve fascicle transfer to biceps motor branch (Oberlin Transfer): indications, pitfalls and outcomes (Presentation and Surgical Demo)

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New York, NY

- The “Oberlin transfer” (ulnar nerve fascicle to bicep motor branch) critically altered the modern era of nerve transfers. This “game changer” nerve transfer was introduced in 1994 – was used for upper trunk C5-6 brachial plexus injury.¹
- The “double fascicular transfer” (“DFT”): Mackinnon (2005) and Oberlin (2006) separately introduced both ulnar and median fascicles to biceps and brachialis branches.²,³
Oberlin: “gold standard” for nerve transfers

- Short regeneration length
- Close shot into muscle
- Nearly all motor donor
- No donor deficit
- Synergistic
- Easy to retrain
- Similar size facilitates coaptation
- Similar axon counts
  - **Optimal Axon Counts for Brachial Plexus Nerve Transfers**
      - Axon counts for nerve transfers for elbow flexion
      - Oberlin 1:1 ratio
      - Donor to recipient axon count ratio greater than 0.7 to 1 may be optimal

**INDICATIONS:**
- Primarily upper plexus injury (C5-6 or C5-6, partial 7) – need “good hand”

**SURGICAL TECHNIQUE:**
- Incision in medial arm, just posterior to palpable biceps border
- Landmarks: 17 cm distal to coracoid process = branch to biceps. Mid arm = branch to brachialis
- Dissect out above branches (variation is common, multiple branches possibly – make sure to get all branches)
- Dissect ulnar and median nerves
- Several passing blood vessels – sacrifice as needed to gain exposure
- Once get recipients, dissect them as proximal as possible, then transect with nerve cutting device
- Swing recipients down to donors, dissect out fascicles (“donor distal”)
- At proposed connection site, make sure there will be no tension on connection when the elbow is flexed/extended fully
- Use nerve stimulator to find more wrist than finger action. Take 1 (usually) or 2 fascicles
- Connect with microsurgical technique (APM: usually 2 sutures and fibrin glue)

**PEARLS:**
- Ulnar fascicle to biceps motor (branch from musculocutaneous nerve)
  AND median fascicle to brachialis motor (branch from musculocutaneous nerve). Or vice versa – our usual approach – “fits better”. (APM = author’s preferred method) Make sure connections are LOOSE and test with full elbow flexion/extension.
• More wrist than hand fascicles (use nerve stimulator; fascicles are pluripotential. Just make sure not taking sensory fascicles) taken from the ulnar nerve at brachium and transferred to motor branch to biceps to restore elbow flexion (anatomically very close). Same idea for median nerve.
• Can take 20% of ulnar nerve

PITFALLS:
• Do not take too many fascicles from donors. Donor must be of adequate recovery (at least “decreased” on EMG)4

OUTCOMES (Single Oberlin)
• 1. Leechavengvongs et al. (1998): Single Oberlin. 30 of 32 with M4. 1 with M3.5
• 2. Teboul, Oberlin et al. (2004): 24 or 32 patients with single Oberlin achieved M3 or better. Secondary Steindler flexorplasty done in 10. Final 30 or 32 with either M4 or M3.6
• 3. Bertelli, Ghizoni (2004): 10 patients, single Oberlin. 7 with M4, 3 with M3+.7
• 3. Leechavengvongs et al. (2006): Single Oberlin. 13 of 15 with M4. 2 with M3.8

OUTCOMES (double fascicular transfer - DFT)
• 1. Mackinnon et al. (2005): 6 patients, DFT. Mean elbow flexion M4+.2
• 2. Liverneaux, Oberlin et al. (2006): 10 patients, DFT. All with M4. (“especially useful in cases of C5-7, elderly patients, long preop delay”)3
• 3. Ray, Mackinnon et al. (2011): 29 patients, DFT. 23 with M4 or greater. 4 with M3.9

CONTROVERSY:
• Single versus double fascicular transfer
• Carlsen et al (2011): With numbers tested, single not different from double.10

APM – AUTHOR’S PREFERRED METHOD (Lee, Wolfe JAAOS 2012)11
DOUBLE FASCICULAR TRANSFER IF POSSIBLE
References:


INTRODUCTION
Injury to the radial nerve is common and presents a deficit to wrist, finger, and thumb extension. When spontaneous recovery has not occurred, the traditional method for restoring radial nerve function has been through tendon transfers. This procedure has been known to be among the most successful tendon transfer for the hand. While there are advantages for tendon transfers, there also exists disadvantages, which include extensive muscle dissection, altered muscle biomechanics, prolonged immobilization, donor deficit, potential for tendon rupture and adhesion, and subnormal functional return. Nerve transfers is an alternative reconstructive technique, which can circumvent the challenges of tendon transfers, and provide the potential for superior functional outcome. These outcomes can include independent finger extension and simultaneous full wrist and finger extension. (1,2). In general, the disadvantage of the nerve transfer is a longer (1 year) to recovery function.

Nerve transfer (def) – transfer of an expendable donor nerve or fascicle to a denervated recipient nerve to restore function to the recipient end-organ (skin for sensation or muscle for motor).

Benefits
- Performed closer to recipient target allowing for earlier reinnervation.
- Can be performed outside of the zone of injury and scarred field
- Can be performed on patients with delayed presentations (<1 year)
- Avoids interposition nerve grafting and fosters increased regenerating nerve fibers to reinnervate target end-organ. (3,4)

Goal: Reinnervation of the target muscle within 12-18 months to avoid irreversible atrophy. (5,6)
CLASSIFICATION OF NERVE INJURIES
Nerve injury classification was originally described by Seddon and further modified by Sunderland and later by Mackinnon. Understanding the classification of nerve injuries helps determine if surgical intervention is warranted. These details are outlined in the following table (Table 1).

Table 1. Classification of Nerve Injuries

<table>
<thead>
<tr>
<th>Degree of Injury</th>
<th>Recovery</th>
<th>Rate of Recovery</th>
<th>EMG / NCS (Fibrillations)</th>
<th>EMG / NCS (MUPS)</th>
<th>Surgical Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Neurapraxia</td>
<td>Complete</td>
<td>Up to 12 weeks</td>
<td>-</td>
<td>Normal</td>
<td>-</td>
</tr>
<tr>
<td>II Axonotmesis</td>
<td>Complete</td>
<td>1&quot; per month</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>III Neuroma</td>
<td>Partial</td>
<td>1&quot; per month</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>IV In-continuity</td>
<td>None</td>
<td>None</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>V Neurotmesis</td>
<td>None</td>
<td>None</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>VI Mixed Injury</td>
<td>Some fascicles</td>
<td>Depends on injury (I to V)</td>
<td>-/+</td>
<td>-/+</td>
<td>+</td>
</tr>
</tbody>
</table>

PRINCIPLES OF NERVE TRANSFERS

History and Physical Examination
- Timing from injury
- Extent of involvement (level and degree of nerve injury)
- Current functional limitations
- Presence of potential donor nerves

Donor Selection
- Expendable motor nerve
- Close to motor endplates of the target muscle
- Large number of motor nerve axons and MRC grade 4 strength
- Synergistic muscle function allowing straight-forward motor reeducation

Pre-operative Studies
- EMG/NCS at 10-12 weeks post-injury
  - Identify extent of injury and recovery
  - Identify intact donors

Pearls and Pitfalls
- Remind anesthesiologist—no long acting paralytics
- Short or no tourniquet use to avoid neurapraxia and inability to stimulate nerves
- Evaluate recipient with nerve stimulator before transection
- Evaluate donor with nerve stimulator to confirm function and strength
- “Donor DISTAL, Recipient PROXIMAL”
- Perform coaptations without tension.
MEDIAN TO RADIAL NERVE TRANSFER

Patient Evaluation
- Identify FCR and FDS for minimal MRC grade 4
- Evaluate FCU function for wrist flexion as FCR is donor
- Evaluate median-innervated and ulnar-innervated FDP for finger flexion as FDS is donor
- Acquires patient goals and expectations to determine appropriateness of nerve vs. tendon transfer to restore radial nerve function
- Tendon transfer can acquire outcome faster, however nerve transfer can provide better functional outcome over time

Patient Selection
- No evidence of recovery for radial nerve on EMG by 3-4 months
- Patients who present (1) more than 10 months from injury or (2) direct injury to PIN or ECRB are not good candidates for nerve transfer and consider tendon transfer
- Patients who can’t wait 1 year for reinnervation, they would consider tendon transfers
- Patients with stiff swollen hands, nerve transfers are advantageous due to minimal post-operative immobilization

Surgical Technique
Median (FCR/FDS) to Radial (PIN/ECRB) Nerve Transfer

- FCR (Wrist Flexion) → PIN (Finger Extension)
- FDS (Finger Flexion) → ECRB (Wrist Extension)

+ Pronator Teres to ECRB Tendon Transfer
- PT to ECRB tendon transfer (Pulvertaft repair) can be performed additional to provide early wrist extension while strengthening outcomes, however post-operative rehabilitation protocol changes

Figure 1. Illustrative anatomy for median and radial nerve in the right arm. At this location, the radial nerve has 3 primary nerve branches: RSN, ECRB, and PIN. The supinator branch is located deep to the PIN and courses deep into the supinator for innervation. The median nerve has several nerve branches, which include the PT, FCR/PL, AIN, and 2 FDS branches.
Figure 2. Illustrative anatomy for the median to radial nerve transfer. Two nerve transfers occur in the median to radial nerve transfer for restoration of wrist/finger extension. The donors (green) and recipients (red) occur in the following specific sets for optimal results with post-operative rehabilitation: 1) FCR nerve to PIN and 2) FDS nerve to ECRB. Note that PIN and FDS are antagonistic making rehabilitation difficult.

**Surgical Steps**

Step 1. Mark a lazy-S incision in the proximal forearm extending to the mid-forearm (extend more distal if performing PT to ECRB tendon transfer).

Step 2. Expose and decompress the median nerve through the following steps:
   A. Identify the superficial head of the PT between the radial vessels and RSN (ie, radial to the vessels)
   B. Step-lengthen the PT tendon (If performing tendon transfer: Completely elevate the PT tendon with strip of periosteum)
   C. Identify the median nerve ulnar to the radial vessels, intimate with the radial/deep surface of the superficial head of PT
   D. Release the deep head of the PT
   E. Divide the tendinous leading edge of FDS

Step 3. Identify the branches of the median nerve, and confirm with a nerve stimulator (within 30 minutes if using a tourniquet):
   - FCR and PL nerves: medial/deep aspect of median nerve, you can neurolyzed PL as a separate fascicle
   - FDS nerves: medial aspect of the median nerve, distal to FCR/PL branches
   - PT nerve: the most superficial, proximal branch of the median nerve
   - AIN: lies on the lateral side of the median nerve

Step 4. Dissect the donor nerve branches, FCR and FDS, as distally as possible, and tag with a vessel loop.

Step 5. Expose and decompress the radial nerve through the following steps:
   A. Identify the radial sensory nerve on the undersurface of the BR muscle
   B. Follow the radial sensory nerve proximally to the main radial nerve just distal to the elbow
   C. Release the tendinous leading edge of the ECRB transversely
   D. Divide the tendinous leading edge of the supinator (arcade of Frohse) and decompress the PIN

Step 6. Identify the branches of the radial nerve and confirm there is no function with a nerve stimulator:
   - ECRB nerve (small): lies radial and parallel to the radial sensory nerve
   - PIN (large): lies radial to the ECRB nerve and heads in a posterior oblique direction deep to supinator
   - Supinator nerve: arises from deep surface of PIN, and is excluded from transfer
Step 7. Follow the mantra “donor distal, recipient proximal”
- First, divide the donor nerves (FCR and FDS) distally
- Second, dissect and divide the recipient nerve branches, ECRB and PIN, as proximally as possible (to above elbow crease)
- The usual overlap of donor and recipient nerves is 6–7 cm to avoid any tension

Step 8. Coapt the FDS nerve to the ECRB nerve with 9-0 nylon suture +/- fibrin glue

Step 9. Coapt the FCR nerve to the PIN nerve with 9-0 nylon suture +/- fibrin glue

Step 10. If desired, perform the LABC nerve to RSN transfer and coaptation or RSN end-to-side to median nerve

Step 11. Ensure tension-free nerve coaptations in all ranges of motion of the arm and forearm

Step 12. If performing, complete the PT to ECRB tendon transfer with a Pulvertaft weave
POST-OPERATIVE REHABILITATION
Figure 3. Postoperative rehabilitation and motor re-education timeline. This overview describes the postoperative nerve transfer alone versus the nerve transfer with the pronator to ECRB tendon transfer. After a muscle twitch is palpated in the recipient muscles during examination, splinting protocols are different between the nerve transfer alone versus the nerve transfer with the pronator to ECRB tendon transfer. Two phases are described, with phase 2 initiated after a muscle twitch is palpated in the recipient muscles during examination.
Figure 4. Strategies for postoperative rehabilitation and motor re-education. The cock-up splint is useful for preventing lengthening of the wrist/finger extensor muscles in the wrist-drop position. The gripper is a tool to help create high-frequency and low-load activation of the recipient muscles with grip. High patient compliance with therapy was found with this tool. The exercise putty has multiple uses for actively engaging donor and passively engaging recipient muscles, which include gripping, log-rolling, resisted wrist flexion, and finger digs/pulls. The use of coins prevents resistance from the table during donor flexion at the metacarpophalangeal joints and wrist and recipient extension of the fingers and wrist. Assisted exercises can help the patient determine the appropriate muscle engagements to elicit contraction in the recipient muscles. In addition, the therapist can palpate to determine whether there is a twitch in the recipient muscles as it is reinnervated. During progression, place/hold of individual fingers and thumb can help initially strengthen the recipient muscles. Therapy continues with exercises against gravity and then strengthening with resistance training.
Post-operative Rehabilitation Protocol
- Initial focus to address scar, edema, and passive range of motion of wrist/fingers
- Recommend wrist cock-up split to maximize functional use of hand
- Initiation rehabilitation 10-14 days after surgery
- Patients instructed to remove splits frequently for exercise program, but return to split during functional use and sleep
- Limit overstretching the wrist/finger extensor muscles due to unrestricted wrist/finger flexion
- Preventing overstretching is important months later as extensors exhibit early signs of reinnervation as weak muscles contract in optimal length

Tendon Transfer Rehabilitation Protocol
- If tendon transfer is performed, early intervention is important and defaults to tendon transfer protocol
- Custom splitting starts 2-3 days post-operative with elbow immobilized at 90° flexion, forearm pronated, and wrist extended
- 2 weeks post-operative, discontinue elbow and forearm immobilization
- 4 weeks post-operative, discontinue wrist extension splint

PHASE 1
- High-frequency, low-load activation of donor muscles via active fisting on hourly basis
- 2 weeks post-operative, may remove splint several times a day for active wrist flexion exercises, except when tendon transfer was performed
- 1 month post-operative, light resistance putty with four exercises: fisting, log rolling, resisted wrist flexion, and finger digs/pulls

PHASE 2
- This phase begins when twitches of wrist/finger extensors are palpated (3-6 months post-operative)
- Assisted wrist/finger extension exercise with resisted donor muscle activation
- Place-hold and gravity-lessened exercises
- Baltimore Therapeutic Equipment (BTE; a computerized work tool stimulator) can control resistance level, repetitive training, and monitor progress
- When recipient MRC 2+, patient is weaned from wrist splint and active exercises replace active-assisted exercises with focus on functional ones
- Recipient resistance training is limited until MRC 3+
PATIENT SAFETY EDUCATION
 Numerous safety precautions can be made when performing nerve transfer surgery. Including, but not limited to the following:

- Informed consent – it is important for patients to recall and restate what they have been told during the informed consent process to verify the patient’s understanding of the procedure.

- Pressure relief mattress – the cases are often long thus appropriate use of cushions, mattress and rolls during positioning is critical to prevent pressure ulcers and nerve palsies

- Underbody warmer/bear-hugger – the chest, neck and arm are often exposed during these cases – underbody warmers are critical to maintaining patient warmth and preventing infection from hypothermia.

- Appropriate use of prophylaxis to prevent venous thromboembolism in patients at risk

- Appropriate use of antibiotic prophylaxis in surgical patients to prevent postoperative infections is also critical.

REFERENCES


Anterior Interosseous Nerve Transfer to the Ulnar Motor Nerve Motor Branch

Peter M. Murray, MD
Professor and Chair
Department of Orthopedic Surgery
Consultant, Orthopedic Surgery and Neurosurgery
Mayo Clinic
Jacksonville, FL

Postcourse: Brachial Plexus: Distal Nerve Transfers
ASSH Annual Meeting, Boston, MA
20 September 2014

Indications

• Proximal ulnar nerve or lower trunk repair/reconstruction has poor prognosis
• Permits a nerve reconstruction coaptation near the motor endplates of the intrinsic muscles of the hand

Technique

• AIN is identified at the proximal border of the pronator quadratus muscle with aid of nerve stimulator
• AIN is traced distally until sufficient length obtained.

Results

• Novak, MacKinnon, J of Recon Microsurg, 2002
  • 8 patients, avg 3 mo from injury
  • Mean FU= 18 mo.
  • Avg age= 38 years
  • Lateral pinch improved from 2.2-13.8 lbs
  • Grip improved from 8.8-61.2 lbs.
• Hasse, Chung, Ann Plast Surg, 2002
  • EMG evidence of reinnervation at 11 mo. to intrinsic muscles

Technique

• Deep motor branch of the ulnar nerve identified distally and dissected proximally
• Intrafascicular dissection taken proximally, if necessary, for sufficient length
• End to end nerve coaptation performed without tension

Summary

• Identify the AIN proximally and trace distally
• Identify the ulnar nerve deep motor branch distally and trace proximally
• Employ intrafascicular dissection, if needed, to achieve sufficient length of deep motor branch
• Tension free microneurorraphy with 10-0 nylon
Nerve Transfer vs. Tendon Transfer

Sometimes there is no realistic choice

- Long delay post injury
- No active regional muscle or donor
- No available donor nerve or recipient nerve

Nerve Transfer vs. Tendon Transfer

- High quality comparative outcome studies lacking
- Treatment strategy often based on surgeon preference/comfort level
Nerve Transfer vs. Tendon Transfer

My Bias
• In general, a good result from a nerve repair or transfer is better than a good result from a tendon transfer
  But....
• A tendon transfer yields a more predictable outcome in most surgeon’s hands

Nerve Transfer vs. Tendon Transfer

Specific clinical situations
• Shoulder abduction
• Shoulder external rotation
• Elbow-flexion
• Elbow extension
• Wrist extension
• Finger flexion
• Hand intrinsic function

Optimal conditions and less than 6-9 months post-injury

Nerve Transfer vs. Tendon Transfer

Shoulder abduction
erve transfer (triceps branches) preferred
• Technically simple
• Clinical result generally good
• Alternative tendon transfer (Trapezius) or fusion poor abduction result

Optimal conditions and less than 6-9 months post-injury
Nerve Transfer vs. Tendon Transfer

Shoulder external rotation
Tendon transfer (lat dorsi) preferred
  • Predictable outcome
  • Improves internal rotation imbalance
  • Nerve transfer (spinal access) to supraspinatus nerve results variable

Nerve Transfer vs. Tendon Transfer

Elbow Flexion
Nerve transfer (ulnar ± median portion) preferred
  • Technically simple
  • Clinical result generally good
  • Intercostal or spinal access second tier choice
  • Tendon transfer late backstop option

Nerve Transfer vs. Tendon Transfer

Elbow Extension
Nerve transfer (intercostal) preferred
  • Rarely tendon transfer option with BPI
Nerve Transfer vs. Tendon Transfer

Wrist Extension
Tendon transfer (P.T., FDS, FCU) preferred

Finger/Thumb flexion
Tendon transfer (BR, ECRL) preferred
• Plus 1st CMC ± IP fusion of thumb
• Consider free muscle and nerve transfer if donor tendons lacking

Hand intrinsic function
Tendon transfer (FDS, ECRL, EIP) preferred
• But for isolated palsy of deep motor branch nerve transfer (AIN) preferred
Nerve Transfer vs. Tendon Transfer

Conclusions

- No simple or consistent answers
- Clinical judgment important
- B.P. surgeons required both skill sets
- Nerve transfer innovation progressing
- Presenter's personal bias not shared by all

Mayo Blue

ASSH Instructional Course 2 – 3353904

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Follow-up (years) %

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<th>Row</th>
<th>Color</th>
<th>No.</th>
<th>%</th>
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<td>1</td>
<td>Red</td>
<td>123</td>
<td>47</td>
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<tr>
<td>2</td>
<td>Yellow</td>
<td>459</td>
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<td>3</td>
<td>Green</td>
<td>567</td>
<td>98</td>
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Notes
Supinator Nerve Transfer for Reconstruction of Thumb and Finger Extension

Jayme Augusto Bertelli and Marcos Flávio Ghizoni

The use of the supinator nerve as a donor for transfer to the posterior interosseous nerve was first described by Bertelli et al.\(^1\) in 2009. Initially, it was used for lower-type injuries of the brachial plexus.\(^2\) Since then, its use has been expanded to treat patients with quadriplegia as well.\(^2\)

**Indications**

- For the reconstruction of thumb and fingers extension in C7–T1 root injuries of the brachial plexus, and for patients with quadriplegia with Grades 2 through 5 of the international classification of muscle function.
- Surgery should be performed within 12 months of trauma, ideally roughly 6 months postinjury. However, in patients with lower root avulsion of the brachial plexus, surgery can be performed as early as 3 months after injury. In patients with a spinal cord injury, the nature of the paralysis (i.e., is it an upper or lower motoneuron type of palsy?) should be determined. In the presence of muscle denervation, the need for surgery can be anticipated. Otherwise, the limits of spontaneous recovery should be exhausted, which generally is 6 months posttrauma.
- Wrist extensors and the brachioradialis muscle should be functional, because these muscles share the same spinal level of innervation (i.e., myelomere) as the supinator muscle.

**Contraindications**

- Paralysis of the supinator muscle
- Long-standing lower-type injuries of the brachial plexus (in such palsies, a free muscle transfer reinnervated by the supinator nerve is preferable)
- Long-standing spinal cord injury with an upper motoneuron syndrome (a relative contraindication because, in such palsies, muscles are not actually denervated; however, there is no clinical evidence that nerve transfers can successfully reinnervate these chronically paralyzed muscles)
- Injury that is more than 1 year old

**Examination/Imaging**

- Paralysis of the thumb and finger extensors is evident. Not evident is testing of the supinator muscle, because the biceps can produce supination either with the elbow flexed or extended. We have found it useful to flex the elbow and, while in full pronation, ask the patient to supinate against resistance created by the examiner. The examiner places one hand over the upper third of the proximal dorsal aspect of the patient’s forearm to palpate for supinator contraction. The hand is placed over the extensor digitorum communis, because this muscle is paralyzed; hence, muscle contractions in this position should stem from the supinator muscle.
- Electromyograms of the extensor digitorum communis help to identify denervation and thereby determine the urgency of surgery, particularly with a spinal cord injury. In general, electromyograms of the supinator muscle are not easily obtained. However, in the presence of paralysis of the extensor digitorum communis, recording of electrical activity in the supinator muscle is more reliable. Unfortunately, muscle strength does not correlate with electromyographic findings.
- One thing that is very important is to assess the strength of wrist extension. If wrist extension can be accomplished against resistance, the supinator muscle should be normal.
- Magnetic resonance imaging of the brachial plexus is important to document the presence of any pseudomeningoceles in the lower roots of the brachial plexus. These indicate root avulsion, thereby excluding the possibility of spontaneous recovery.

**Relevant Anatomy**

- The posterior interosseous nerve passes from the anterior aspect of the elbow to the dorsal side of the forearm, by running between the two layers of the supinator muscle.
- The proximal tendinous margin of the supinator muscle is known as Frohse’s arcade. At this point or slight-
ly proximal to it, the main branches to the supinator muscle arise. In general, there is a lateral branch to the superficial head and a medial branch to the deep head of the supinator muscle. For an approximate distance of 20 mm, both branches travel parallel to the posterior interosseous nerve (Fig. 21.1a).

- Near the distal margin of the supinator muscle, the posterior interosseous nerve branch divides into (a) a short superficial division to the extensor digitorum communis, extensor digiti minimi, and extensor carpi ulnaris; and (b) a deep division to the abductor pollicis longus, extensor pollicis brevis and longus, and extensor indicis proprius.
- The number of myelinated fibers within the branches of the supinator muscle corresponds to 70% that of the posterior interosseous nerve distal to the arcade of Frohse (Fig. 21.1b). Detailed biometric data are given in Table 21.1.

<table>
<thead>
<tr>
<th>Table 21.1</th>
<th>Biometric data of the supinator nerves and posterior interosseous nerve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter (mm)</td>
</tr>
<tr>
<td>Posterior interosseous nerve</td>
<td>3.2 (SD ± 0.6)</td>
</tr>
<tr>
<td>Medial branch of the supinator</td>
<td>1.6 (SD ± 0.6)</td>
</tr>
<tr>
<td>Lateral branch of the supinator</td>
<td>1 (SD ± 0.35)</td>
</tr>
</tbody>
</table>

Fig. 21.1a, b  (a) Photograph of the dissection of the posterior interosseous nerve (PI) and its branches on the posterior aspect of the right forearm in the fully pronated position. Dissection of the posterior interosseous nerve was achieved via access between the extensor carpi radialis brevis (ECRB) and extensor digitorum communis (EDC). Note the two main branches that arise proximal to the supinator border (SUMB). The lateral branch is destined for the superficial head, whereas the medial branch is destined for the deep head of the supinator muscle (S). At the distal limit of the supinator muscle, the posterior interosseous nerve divides into a superficial (SB) and deep branch (DB). In this dissection, the superficial branch innervated the extensor digitorum communis, the extensor carpi ulnaris, and the extensor digiti minimi. The deep branch innervated the abductor pollicis longus (ABL), the extensor pollicis brevis (EPB), the extensor pollicis longus, and the extensor indicis proprius. (b) Histological cross sections of the medial and lateral branches of the supinator and the posterior interosseous nerves. On average, the number of myelinated fibers in the supinator branches corresponded to 70% that of the posterior interosseous nerve. H & E, original magnification × 200.
Surgical Technique

- Under general anesthesia and without muscle relaxants, the patient is placed in the supine position with the affected arm on a board under tourniquet control.
- A skin incision 10 cm long and 3 cm distal to the lateral epicondyle is drawn over the interstice between the extensor carpi radialis brevis and extensor digitorum communis (Fig. 21.2a).
- After skin, subcutaneous, and fascial incisions, the extensor digitorum communis is separated from the extensor carpi radialis brevis, thereby exposing the supinator muscle (Fig. 21.2b).
- The supinator muscle is palpated against the radius, and the posterior interosseous nerve is identified (Fig. 21.3).
- The superficial portion of the supinator muscle is divided and the posterior interosseous nerve dissected (Fig. 21.4a,b).
- The motor branches of the supinator are individualized in proximity and parallel to the posterior interosseous nerve. Nerve identity and functionality are confirmed by direct electrical stimulation. Both supinator branches then are sectioned at their muscle entry points (Fig. 21.5a,b).

Before harvesting of the supinator nerves, functionality should be demonstrated by electrical stimulation.

- The posterior interosseous nerve then is sectioned proximally, but distal to the emergence of the supinator nerves. Sectioning the supinator nerves distally and the posterior interosseous nerve proximally allows nerve coaptation without tension (Fig. 21.6a–d).
- Under the microscope, the supinator branches are sutured to the posterior interosseous nerve with 9.0 sutures (Figs. 21.4c; 21.7).
- The extensor digitorum communis and the extensor carpi radialis brevis are sutured, and the subcutaneous tissue and skin closed.
- The wrist is immobilized in 30 degrees of extension for 1 week. Sutures are removed 10 days after surgery.

Fig. 21.2  (a) Schematic representation of the surgical approach. (b) Intraoperative view of the approach to the supinator nerve, accessed between the extensor carpi radialis brevis (ECRB) and the extensor digitorum communis muscle (EDC).
Fig. 21.3  Intraoperative view of palpation over the supinator muscle to identify the posterior interosseous nerve.

Fig. 21.4a–c (a) Intraoperative view of the division of the superficial portion of the supinator muscle to expose the posterior interosseous nerve, which had previously been identified by palpation. (b) Close up view of the exposure of the supinator and posterior interosseous nerve. The superficial portion of the supinator muscle (S) is divided to expose the posterior interosseous nerve and its branches: the branch to the extensor digitorum communis, extensor digiti minimi, and extensor carpi ulnaris (BEM) and the branch to the extensor indicis proprius (BTI). Arrows indicate the transfer of the supinator branches to the posterior interosseous nerve. (c) Intraoperative view of the transfer of the supinator branches to the posterior interosseous nerve.

**Complications/Pitfalls**

- We did not observe any complications in our series.
- One limitation of the supinator nerve as a donor for transfer is the poor capacity to test supinator muscle strength before surgery. It has been recommended that supinator muscle function be tested with the patient’s elbow extended to eliminate the action of the biceps on supination. However, even with the elbow extended, the biceps participates in supination.
- Hence, the integrity of the supinator nerve can be tested only indirectly.
- The sixth cervical segment supplies a wide range of muscles, including, in descending order, the brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, supinator, pronator teres, and flexor carpi radialis. In the presence of strong wrist extensors, the supinator muscle is always functional.
- Provided that the biceps is working, the supinator muscle is expendable because it is not used for transfers in patients with quadriplegia.
**Fig. 21.5a,b**  (a) Intraoperative view of the dissection of the supinator nerves and the posterior interosseous nerve (PIN). (b) Before harvest of the supinator nerves, functionality should be demonstrated by electrical stimulation.

**Fig. 21.6**  (a) Schematic representation of the transfer of the supinator motor branches (SUBs) to the posterior interosseous (PI) nerve. The forearm is prone, and the superficial portion of the supinator muscle (S) is divided. The supinator muscle is reached by dissecting between the extensor carpi radialis brevis and the extensor digitorum communis. EB, extensor carpi radialis brevis motor branch. (b) Intraoperative view of the division of the supinator nerves and the posterior interosseous nerve (PIN); the supinator nerves were sectioned at their muscle entry point, whereas the PIN was sectioned just distal to the emergence of the supinator nerves. (c) Intraoperative view of the dissection of the supinator nerves; note the medial (SMb) and lateral (SLb) branches, and the posterior interosseous nerve (PIN). The particularity in this patient was a proximal division of the PIN into its superficial (SbPIN) and deep (DbPIN) branches. The superficial posterior interosseous innervates the extensor digitorum communis, the extensor digit minimi, and the extensor carpi ulnaris. The deep branch of the posterior interosseous nerve innervates the abductor pollicis longus (Ab), the extensor pollicis longus, and the extensor indicis proprius. **Inset:** The surgical connections of the medial branch of the supinator nerve to the deep branch of the posterior interosseous nerve, and of the lateral branch of the supinator nerve to the superficial branch of the posterior interosseous nerve are seen. (d) Nerve and the medial and lateral branches to the supinator muscle. In contrast to the patient shown in **Fig. 21.2**, in this patient the posterior interosseous nerve did not divide within the supinator muscle. **Inset:** The surgical coaptation of the posterior interosseous nerve with the supinator branches is demonstrated.
Outcomes

Eight patients with lower type injuries of the brachial plexus were operated upon and followed for at least 12 months. All patients recovered thumb and finger extension. Three patients failed to recover proximal interphalangeal joint extension, because of intrinsic muscle palsy and elongation of the extensor apparatus.

Three patients with spinal cord injuries had surgery bilaterally. All these patients recovered full thumb and finger extension within 6 months of surgery. The average distance between the pulp of the thumb and the lateral aspect of the index finger was 5 cm. The strengths of thumb and metacarpophalangeal joint (MCP) extension were rated as Grade 3 in all patients. All patients could grasp and release objects. In the preoperative period, wrist extension had been accompanied by radial deviation. Postoperatively, this disappeared. In fact, all patients could move their wrist from maximal radial deviation to the neutral position. There was no MCP hyperextension after reinnervation of the extensor digitorum communis, because this had been prevented by suturing the A1 pulley to the proximal dermis of the distal palmar crease.

No patient reported experiencing difficulty learning new movements. However, no patient discovered facilitatory motion on his own; they all needed to be instructed that thumb and finger extension were linked to supination.

Patients with spinal cord injuries recovered faster than those with brachial plexus trauma. One explanation for this is that the muscles in the patients with quadriplegia, at the moment of surgery, were not denervated.

All patients readily achieved voluntary control.

Supination was preserved in all patients, with the elbow either flexed or extended.

Fig. 21.7 Intraoperative view of the coaptation of the supinator nerves with the posterior interosseous nerve (PIN). Because of redundancy of the length of the nerve stumps, nerve coaptation was performed without tension.

Pearls

- During resisted supination or pronation, contractions of the supinator muscle and the pronator teres can be palpated even though the intrinsics, and thumb and finger extension is absent.
- Preservation of some function in the pronator teres and flexor carpi radialis is additional evidence of functional preservation of supinator innervation. Electromyograms are of limited help in this instance, because the examination does not correlate well with muscle strength. When the strength of the supinator muscle is in doubt, the strength of supination should be assessed following an anesthetic block of the musculocutaneous nerve.
- In patients with quadriplegia from an upper motorneuron syndrome, stimulation of the paralyzed nerves produces muscle contractions. This is helpful for localization of the posterior interosseous nerve.
- In general, contraction of the extensor digitorum communis is obtained 3 to 4 months after surgery. The patient is taught to supinate the forearm to extend the thumb and fingers. With time, patients learn to extend the thumb and fingers with the forearm either supinated or pronated.
- Before transferring the supinator nerve in patients with quadriplegia and in those with lower root injuries of the brachial plexus, we tried to reconstruct thumb and finger extension (1) by transferring the extensor carpi radialis longus to the extensor digitorum communis; (2) by transferring the brachioradialis to the extensor digitorum communis; or (3) by performing tenodesis of the extensor tendons to the dorsal side of the hand. The thumb was stabilized either by tenodesis of the abductor pollicis longus to the radius or by suturing the rerouted extensor pollicis brevis to the flexor carpi ulnaris. These orthopedic procedures all yielded poor results. Similar disappointing outcomes have been reported elsewhere.

References