Surgical principles of peripheral nerve repair

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Dr Hitesh Kumar Gurjar
Introduction

- Peripheral nerves are the neural structures that connect CNS to the end organs.

- PNS consists of:
  - 12 pairs of cranial nerves
  - 31 pairs of spinal nerves

- Unique power of regeneration
Etiology of nerve injury

- Three major causes:
  - Medium to high energy nerve injuries
  - Low energy compressive or ischemic lesions
  - Complex injuries
1. Medium to high energy—Mechanical

   Transection
     /\  
    /   \
   Partial Complete
     /\     /\  
    /   \   /   \
   With With Sharp Blunt
   lesion-in- lesion-in- transection transection
     continuity continuity

   Contusion/
   stretch/traction
     /\  
    /   \
   With With
   lesion-in-
   continuity continuity

   Avulsion
     /\  
    /   \
   Pre- Post-
   ganglionic ganglionic

2. Low energy compressive/ischemic lesion

   Compressive
   neuropathies

   Compartment
   syndromes

3. Complex

   Chemical/
   injection

   Radiation-induced
   nerve injuries

   Thermal

   Electrical

   Combined

   Direct intraneural

   Indirect perineural

   Combined
## Classification

### TABLE 230-1  -- Nerve Injury Grading (Sunderland Grading Scale)

<table>
<thead>
<tr>
<th>INJURY GRADE</th>
<th>MYELIN</th>
<th>AXON</th>
<th>ENDONEURIUM</th>
<th>PERINEURIUM</th>
<th>EPINEURIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (neurapraxia)*</td>
<td>+/-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II (axonotmesis)*</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>V (neurotmesis)*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+, Anatomic structures affected by injury.

* Seddon grading system.
### Classification of Nerve Injury

<table>
<thead>
<tr>
<th><strong>Seddon</strong></th>
<th><strong>Sunderland</strong></th>
</tr>
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<tbody>
<tr>
<td>Neurapraxia</td>
<td>I</td>
</tr>
<tr>
<td>Axonotmesis</td>
<td>II</td>
</tr>
<tr>
<td>Nerve trunk disruption</td>
<td>V</td>
</tr>
</tbody>
</table>

- Conduction block
- Axonal discontinuity
- Axonal + endoneurial disruption
- Perineurial rupture fascicle disruption
- Nerve trunk discontinuity

Wallerian degeneration =
Approach to the patient

- History: pain, sensory loss, weakness
- Clinical examination: general, inspection, joint mobility, motor & sensory testing, autonomic testing & special tests
- Electrophysiology: NCV, EMG
- Imaging
Time of intervention

- Changes following nerve injury:
  - Central cell death, ischemia & fibrosis
  - Target organ changes: muscle atrophy & disappearance of motor end plates- irreversible with time
  - Proximal injury- worse outcome
Time of intervention: early

- Early nerve repair prevents neuronal loss & improves outcome

- With exception of spinal accessory improved results of early repair are found in median, ulnar, radial, musculocutaneous, sciatic, CPN & closed traction BPI

- Limiting factor for early repair: difficult to determine the extent of stump resection
Primary repair: urgent surgery

- Operations done within 3-5 days of injury
- Indication: sharp transection
- Contraindication: poor clinical condition
- Adv:
  - Scar free field
  - Minimal intraneural scarring-less distortion of intraneural architecture- proper fascicular matching
- Disadvantage: EPS may not be available or feasible
Delayed primary repair

- Done after 2-3 weeks
- Good outcome
- Advantages of primary surgery disappears
Secondary repair

- Performed between 3 weeks to 3 months
- Indications: neuroma in continuity
- Adv: 40% of BPI recovers spontaneously- prevents unnecessary surgery
- Disadvantage : exploration in scarred tissue & intraneural scarring & distortion
Indications for surgery

- Paralysis after trauma over the course of a major nerve- including iatrogenic injuries
- Paralysis following closed traction BPI
- Associated vascular or orthopedic injury requiring treatment
- Worsening or failure to improve within expected time period
- Persistent pain
Contraindications

- Poor general condition of the patient
- Uncertainty about viability of the nerve trunks
- Local & systemic sepsis
- Early signs of recovery
Types of surgery

- Primary procedures
- Alternative methods
- Secondary procedures
Alternative procedures

- Direct muscular neurotization
- Nerve conduits
- Interposed freeze-thawed muscle
- Nerve allograft repair
- Central repair
Secondary procedures

- Tendon transfer
- Functioning free muscle transfer
- Arthodesis
- Tenodesis
- Corrective osteotomy
- Amputation
Principles of nerve repair

- Environment: generous operative field, good illumination, microscope or loupe
- Anesthesia: Short acting paralyzing agent
- Flexibility regarding the position of surgeon & limb
Principles of nerve repair

- Wide exposure
- Sharp dissection in anatomic planes starting from virgin tissues & progressing towards the lesion
- Meticulous hemostasis- bipolar cautery
- Preserving fat & synovium planes- nerve’s gliding planes-

Principles of nerve repair

Preparing nerve stumps:

- Circumferential exposure
- Generous proximal & distal mobilization
- External neurolysis
- Use of intra-operative electro-physiology
- Placement of lateral stay sutures (6-0) - to maintain topographic alignment
Debridement of nerve stumps proximally & distally to remove scar tissue -
scar > scar with some fascicles > pure healthy fascicles (fascicles appear to pout, glossy surface & fine bleeding from vessels)
Principles of nerve repair

- Proper alignment & positioning of nerve stumps & grafts:
  - Longitudinal vessel alignment in epineurium
  - Fascicular alignment
Principles of nerve repair

- Proper suturing:
  - Material: 8-0, 9-0 or 10-0 monofilament nylon
  - Two lateral sutures $180^\circ$ apart
  - Three to four more sutures may also be placed
  - Tensionless
  - Avoid overzealous suturing—every suture induces fibrosis
Principles of nerve repair

- Use of fibrin glue:
  - Secures the position of anastomosis
  - When used alone: does not provide tensile strength or permit to fish-mouth
  - Clump formation to be avoided
Decompression

- Release of a nerve from external compression

- Types:
  - Open
  - Endoscopic
Neurolysis

- Release of nerve or its part from organized scar

- Types:
  - External
  - Internal

- External neurolysis:
  - Nerve is set free from scar, organized hematoma or bony fragments
  - Released in circumferential manner
  - Epineurium is minimally breached
Neurolysis

- Internal neurolysis:
  - Opening or resection the external epineurium to lyse internal scar
  - Plain of dissection: internal epineurium
  - Not to damage perineurium
  - Used for preparation of nerve ends for grafting, dissection of neuroma in continuity & benign nerve sheath tumor
Direct repair

- Possible in most clean lacerating injuries & when co-aptation can be done without undue tension

Types:
1. Epineural repair
2. Grouped fascicular repair
3. Fascicular or perineural repair

Combination of epineural & grouped fascicular repair- most commonly used
Epineural repair

- Traditional method
- Appropriate for monofascicular & diffusely grouped polyfascicular nerve
- Goal: tensionless coaptation of proximal & distal fascicular anatomy
Epineural repair

- Small bite taken from internal & external epineurium
- Perineurium avoided
- Tied with mild to moderate tension
- Disadvantage: precise matching of proximal & distal fascicles may not be possible
Grouped fascicular repair

- Indication:
  - Group of fascicles with specific functions - sensory or motor
  - Nerve requiring split repair
- Debridement & alignment
- Inter-fascicular dissection - within internal epineurium
- Suturing through internal epineurium and perineurium
Fascicular repair

- Indication:
  - Lacerated nerve with identifiable individual motor & sensory fascicles
  - Partial injury to 1-2 fascicles

- Repair under high magnification with 10-0 nylon
- Sutures placed through perineurim
- Avoid endoneurium
- Maximum 2 sutures for each fascicle
- Strengthening by addition of epineural sutures
Epineural vs perineural sutures


Nerve auto graft repair

- Indication: direct repair not possible without undue tension

- Principles:
  - Harvest as much of graft as possible
  - Extremity to be in full extension
  - Proper alignment: proximal nerves- spatial matching & distal nerves- anatomic matching
  - Cable grafting
  - Epineural dissection to create group of fascicles
Nerve auto graft repair

- Graft sutured in epineural & interfascicular epineural technique
- Fish mouth configuration
- 1-2 sutures reinforced with fibrin glue
<table>
<thead>
<tr>
<th>Nerve</th>
<th>Location</th>
<th>Deficit</th>
<th>Contraindication</th>
</tr>
</thead>
<tbody>
<tr>
<td>LACN</td>
<td>Terminal sensory branch of MCN. Located just lateral to biceps tendon in subcutaneous tissue.</td>
<td>Loss of sensation over lateral aspect of forearm</td>
<td>Median nerve injury- significant loss of sensation over dorsolateral thumb</td>
</tr>
<tr>
<td>MACN</td>
<td>Derived from medial cord. Closely follows brachial vein.</td>
<td>Loss of sensation over medial forearm</td>
<td>Ulnar nerve injury</td>
</tr>
<tr>
<td>SSRN</td>
<td>Terminal sensory part of radial nerve. Lies deep to brachioradialis muscle in proximal forearm. Good graft for proximal radial nerve recon.</td>
<td>Anatomical snuff box</td>
<td>Nil</td>
</tr>
<tr>
<td>Sural</td>
<td>Most commonly used donor. Lies deep to deep fascia at proximal leg. Emerge to subcutaneous tissue at midcalf level. Significant contribution from lateral sural branch of peroneal nerve.</td>
<td>Lateral order of the foot</td>
<td>Nil</td>
</tr>
</tbody>
</table>
Harvesting the graft

- **Methods:**
  - Open
  - Endoscopic

- **Incision:**
  - Longitudinal
  - Step wise

- **Proximal division:** deep to deep fascia

- Cut to produce appropriate length
Nerve transfer

- Involves re-assigning an expendable or redundant nerve or its part or branch to a more important nonfunctioning nerve

- Indications:
  - Nerve avulsion
  - Rapid & reliable recovery of motor function in post-ganglionic injury
  - To power free-functioning muscle transfer
Nerve transfer

- **Contraindications:**
  - Absence of donor nerve
  - Fibroed, atrophic recipients
  - Repairable rupture or neuroma
  - Poor quality donor

- **Principles:**
  - Accurate preop documentation & fall-back planning
  - Selection of ideal donor nerve
Nerve transfer

- Transection of recipient as proximal as possible
- Dissection of donor distal to the recipient- to gain length
- Selective neurotization based on fascicular anatomy
- Maintaining orientation
- Tension free repair
Alternative methods

- Direct muscular neurotization:
  - Used when distal nerve stump not available
  - Spreading out fascicle in a fan like manner and burying them in intermysial folds
Interposed freeze-thawed muscle

- Basal lamina of muscle acts as scaffold for axonal growth

- Problem: axonal growth not target oriented but diffusely over the muscle-

- Promising results for sensory nerve repair-
Nerve conduits

- Tissue engineered bio-artificial tube placed between nerve stumps
- Appropriate directional & trophic cues from migrating Schwann cells & soluble growth factors
- Inner diameter of tube - 20% larger than that of stumps
Nerve conduits

- Placement of single microsuture in U fashion
- Reinforced with glue
- Tube is filled with saline
- Good results for defects <3cm in small nerves

Nerve allograft & vascularized nerve grafts

- Risk of immunosuppression prevents wide spread use of allografts-

- Vascularized nerve graft is useful only in contralateral C7 transfer with interposition ulnar vascularized nerve graft-
Central repair

- Central repair: reimplantation of avulsed spinal nerve-

- Functional benefits have been observed in some cases-

Secondary procedures

- Indications:
  - To provide additional function
  - Delay between injury & presentation
  - Improvement following previous procedure is less than satisfactory

- Unlike primary procedures these are time-independent
Tendon transfers

- Principles:
  - Maintenance of tissue equilibrium - correction of contractures, joint stiffness etc
  - Availability: removal of donor should not compromise existing function
  - Muscle strength: >85% of normal power or 4/5 power
  - Excursion: amplitude of motion should match & direction of action should match
  - Synergy: transfer of synergistic muscle facilitate rehab
  - Tension: transferred tendon should be at its resting length
**Tendon transfer**

**Shoulder function:**
- Trapezius transfer to prox humerus - abduction
- Combined LD & teres major transfer - external rotation

**Elbow function:**
- Modified Steindler’s flexorplasty: flexor- pronator mass from medial humerus epicondyle transferred 4cm above elbow to anterior cortex of humerus
  
  

- Pec major flexorplasty: insertion sutured to coracoid process & origin to biceps tendon
  

- Lat dorsi transfer: flexorplasty with soft tissue coverage

**Wrist & hand function:** PT to ECRB transfer, opponensplasty
Functioning free muscle transfer

- Involves micro-neurovascular repair of a transplanted muscle
- To restore elbow flexion, shoulder abduction, elbow extension, finger flexion & extension
- Muscles used: gracilis, rectus femoris, LD, pec major, TFL, adductor longus
Special situations
Brachial plexus injury

Open
Closed
Open BPI
Laceration or transection

- Sharp injury
  - Repair within 72 hours

- Blunt injury
  - Tack to adjacent planes- 2ndary repair at 2-3 weeks
Closed injury

- Neuroma in continuity: clinical/ EPS/ radiographic evaluation
  - No regeneration
  - Regeneration
    - Focal
      - F/U for 2-3 months
    - Lengthy
      - F/U for 4-5 months
Lower limb nerve injury

- Lumbosacral plexus injury can occur following external trauma, orthopedic or obstetric procedures
- Exposure:
  - Obturator & femoral nerve: retroperitoneum & thigh
  - Sciatic nerve: upper sciatic exposure for hip level injury & lower sciatic exposure for thigh level injury
  - Peroneal nerve: exposure is made starting parallel & medial to biceps tendon & extended inferiorly into popliteal fossa & then more laterally over fibular neck
  - Posterior tibial nerve: superior or thigh level exposure & inferior or leg level exposure
Lower limb nerve injury

- Principles of repair are same
- Decision making for surgery within 3-4 months of injury is important
- Results of lower extremity nerve repairs are gratifying
Peripheral nerve tumors

- Benign tumors:
  - Schwannoma:
    - Exposure proximal & distal to tumor
    - Tumor capsule ‘baskets’ nerve fascicles apart- fascicles are adhered & not incorporated into it
    - Intracapsular dissection of tumor with or without internal decompression
    - 1-2 nonfunctioning fascicles enter into the mass- if no NAP- resected with tumor
Peripheral nerve tumors

- **Neurofibroma:**
  - Until recently NFs were considered not resectable without deficit
  - Fascicles are displaced by tumor
  - Fascicles at poles are identified
  - Sub capsular dissection done
  - 2 or more fascicles are incorporated within tumor mass- if no NAP- resected
  - NAP +: fascicles are traced into & out of the tumor & spared

- **Malignant tumors:** complete removal with tumor free margins
Future directions

- Major short-coming of nerve repair is axonal loss
  Nanoscale engineered devices to splice & repair individual axons at cellular level
  Chang WC, Hawkes EA, Kliot M, Sretavan DW:

- Axonal growth is not synchronous but staggered
  Short duration electrical stimulation synchronizes axonal growth & enhances motor re-innervation
  Gordon T, Brushart TM, Amirjani N, Chan KM:
  *The potential of electrical stimulation to promote functional recovery after peripheral nerve injury—comparisons between rats and humans.* Acta Neurochir Suppl 2007; 100:3-11
Future directions

- Use of bio-engineered grafts to allow regenerating axons to respond to appropriate endogenous cues

- Role of stem cells: under investigation
AIIMS data

- Since 1995 to 2002, 505 patients were studied for functional and occupational outcome after surgery for BPI.
- In India BPI is most common due to RTA with Rt side involved in 2/3.
- 40% cases have pan BPI.
- 85% of cable graft yielded improvement in motor power compared 68% in neurotized nerve and 66% in patients undergoing neurolysis.
AIIMS data

- Most effective donor nerve for musculocutaneous neurotization was medial pectoral nerve- 63.6% patient improved
- Accessory nerve was most effective for neurotization of suprascapular nerve (100%)
- Thoracodorsal axillary neurotization gave 66.7% improvement
- 50% patients either remained unemployed or had to change their jobs