

Peripheral nerve injury

Classification of peripheral nerve injury:

I. Seddon classification:

1. Neurapraxia: conduction block with or without demyelination (the axon, endoneurium, perineurium and epineurium are intact)
2. Axonotmesis: axonal injury but the nerve is in continuity
3. Neurotmesis: sectioned nerve

II. Sunderland's classification:

1. Type 1= neurapraxia-good outcome
2. Type 2: injury to the axons, myelin sheath with intact endoneurium, perineurium and epineurium-good outcome as the endoneurium acts as conduit for regenerating axons
3. Type 3: injury to the axon, myelin sheath and endoneurium. The perineurium and epineurium are intact-variable outcome with some regeneration and some fibrosis(sprouting nerve endings in fibrous tissue)
4. Type 4: injury to axones, myelin sheath and endoneurium, perineurium. The epineurium is intact-neuroma in continuity
5. Type 5 + neurotmesis

III. By mechanism of injury:

1. Traction, stretch and contusion: Type 1-type 4. initial treatment is close clinical and electrophysiological follow and elective exploration in 3-6 months if no regeneration
2. Laceration: Type 5. Clean lacerations are treated with primary repair
3. Missiles and gunshots-type 1-4 rarely type 5. Wound debridement and exploration. Delayed repair in 3 weeks is type 5 otherwise in 3-6 months
4. Compression, ischemia: type 1-4
5. Thermal, electrical: type 1-4. Wound debridement, escharotomy. Otherwise as 1
6. Injection: 2-4. close follow up and elective neurolysis in 3-6 months if no recovery (good prognosis)
7. Iatrogenic: 1-5 (reduction of fracture). Early exploration and neurolysis or repair

Describe stretch injury, missile injury and avulsion injury: definition, non-operative management and indications for surgery:

1. Traction, stretch and contusion: blunt forces are the most common causes of nerve injury. Collagen and elastin rich perineural layer provide tensile strength of the nerve. 8% stretch affects the circulation within the nerve and 10-20% stretch leads to structural failure. The majority of produced injuries are in continuity injuries (peroneal nerve in knee dislocation, axillary nerve in shoulder dislocation, radial nerve in radius fracture, brachial plexus injury in motorcyclists, obstetric

- brachial plexus injuries). Exploration and repair in **3-6 months** if no signs of clinical or electrophysiological recovery. The majority of patients recover without surgery
2. Missiles (gunshot wounds): The majority of gunshot injuries result in nerve contusion rather than division (shock, blast, cavitation effect).. The wound is debrided and nerve is inspected. If the nerve is divided the ends are marked and the nerve is repaired in few weeks as described above. In the majority of cases the nerve is in continuity and the patient is followed up clinically and by electrophysiological studies. 70% of patients recover without intervention.
 3. Lacerations: Laceration secondary to blunt cause (chain saw, gunshots, industrial accidents are repaired in **few weeks** (to allow demarcation). The wound is debrided and cleaned, nerve ends.
 4. Thermal and electrical injury: direct and indirect (ischemia under the eschar or compartment syndrome). Treatment includes wound care, escharotomy. The prognosis is variable . For low voltage electrical injury the prognosis is good , however for high grade thermal injuries involving nerves and high voltage electrical shock the prognosis is poor and the results of nerve grafting are disappointing (long segment)..
 5. Injection injuries: damage can be to mechanical trauma and to the toxic effect of injected drug. 10% develop delayed neuropathy. Management is similar to nerve injuries in continuity (clinical and electrophysiological F/U). Exploration in 3-6 months if no recovery (external and internal neurolysis). Prognosis is good in most patients
 6. Iatrogenic injury: reduction of fractures, plasters, patient positioning nerve laceration, burning (accessory nerve in lymph node biopsy, common peroneal nerve etc...). Treatment depends in the cause. Sharp clean lacerations are repaired primarily, removal; of a cast causing pressure.
 7. Compression and ischemia:
 - A. Focal compression: can be acute (Saturday nerve palsy) or chronic (entrapment neuropathies). Usually reversible
 - B. Diffuse (compartment syndrome): the prognosis is variable and depends on the duration of compression. > 6-8 hours may result in irreversible damage to the nerve and muscles leading to Volkmans contracture.

Discuss the optimal timing of surgery for peripheral nerve injuries:

The timing of surgery for peripheral nerve injuries depends on

2. The mechanism of injury :
 - A. Nerve injury secondary to laceration by sharp object is explored and repaired within **24 hours**
 - B. Laceration secondary to blunt cause (chain saw, gunshots, industrial accidents are repaired in **few weeks** (to allow

demarcation). The wound is debrided and cleaned, nerve ends are marked by nonabsorbable sutures.

- C. Traction, stretch injuries usually result in injuries in continuity (peroneal nerve in knee dislocation, axillary nerve in shoulder dislocation, radial nerve in radius fracture, brachial plexus injury in motorcyclists, obstetric brachial plexus injuries). Exploration and repair in **3-6 months** if no signs of clinical or electrophysiological recovery.
3. Location of injury: the more proximal the location, the earlier the intervention. Regeneration of a nerve occurs at a rate of 1 mm /day. If more than a year passes before the regenerating nerve form functional connections with the end organ, irreversible atrophic changes develop in the innervated muscle which prevents functional recovery. Many surgeons advocate early exploration of brachial plexus injuries

Discuss the techniques of nerve repair and grafting:

1. **End to end epineuronal suture:** indicated for shapely transected nerves or after excision of small segment of neuroma in continuity (compensation for the length can be achieved by neurolysis and nerve transposition). Sutures (6/0 nonabsorbable) are placed between the epineurium of the proximal and distal end without tension. Limb is immobilised for 3 weeks with gradual increase in the range of motion.
2. **Grafting** if the segment resected is long and primary suture without tension can't be achieved. Sural nerve, superficial radial, medial and lateral cutaneous antibrachii nerves, superficial ulnar nerve can be used as grafts. There are 2 techniques of repairing the nerve using graft:
 - A. **Interfascicular repair:** the epineurium of both ends is trimmed to expose the nerve fascicles. The graft is divided into segments and anastomosis is done between the corresponding fascicles (few proximal fascicles are connected to their corresponding distal ends using individual graft).
 - B. The graft is sutured between the epineurium of both ends. Less satisfactory results.
4. **Neurotization:** transfer of a nerve with less important function to reinervate a more important motor or sensory territory. Example is brachial plexus injury (transfer of pectoral or intercostal nerve to musculocutaneous nerve, spinal accessory to suprascapular or MC nerve).

Management of nerve injuries:

Pre-Operative Evaluation

1. Clinical Assessment

- Sensory Examination
 - 2-point discrimination
 - Light touch – Ten Test
 - Motor Examination
 - Pinch and grip strength
 - Individual Muscle strength – MRC grades 0-5
 - Tinel's
 - Horner's
 - Associated injuries
2. Imaging
 - X-ray for associated bony injury, CXR for BP injury- action of phrenic
 - MRI for suspected nerve tumours
 - MRI / CT myelogram for suspected nerve root / brachial plexus avulsion
 3. EMG
 - 2-3 weeks post injury (allow for Wallerian degeneration) then serially
 - Evidence of denervation – muscle fibrillations
 - Evidence of reinnervation – motor unit potential
 4. Nerve conduction studies
 - Determining secondary compression sites (limits reinnervation)
 - Avulsion injury (normal distal sensory conduction and motor denervation)
 5. SNAP / SSEP's
 - For brachial plexus injuries to determine if the lesion is preganglionic, postganglionic or a combination

Pre-Operative Management

Physiotherapy – maintain muscle strength in unaffected muscles and range of motion in affected joints

Resting splints to help maintain a more functional resting position
 Sling for brachial plexus injuries (C5 C6) to resist the tendency for glenohumeral subluxation

Exercise and biofeedback strategies for reinnervating muscles

Management of Neuroma in Continuity⁵

Incomplete loss with significant distal sparing

- Most cases improve with conservative treatment. Follow-up by serial clinical and EMG examinations
- Operation may still be required if...
 - Partial lesions associated with expanding masses caused by haematoma, aneurysm, or AV fistula
 - Partial lesions near or in areas of entrapment
 - Lesions in which distal loss is partial or significant may require later operation
 - Neural pain not amenable to medications and physical therapy may require later operation

Complete or almost complete loss with little or no distal sparing

- Focal lesions in continuity caused by fracture or gunshot wound
 - Clinical and EMG examinations for 2-3 months
 - Explore if no clinical or electrical improvement
 - Intra-operative NAP studies to decide for or against resection

- Relatively lengthy lesions in continuity caused by stretch / contusion or shotgun wound
 - Clinical and EMG examinations for 4-5 months
 - Explore if no clinical or electrical improvement
 - No response to stimulation and no NAP recordable resection and repair
 - Intra-operative evoked cortical or somatosensory studies may be necessary to evaluate the reparability of proximal spinal nerves.
 - E.g. Brachial plexus
 - Postganglionic lesion treated with direct repair or grafting
 - Preganglionic lesion requires nerve transfer or neurotization with intercostal or peripheral nerves

Operative Technique

- Adequate exposure
- Magnification with Loupes or Microscope
- Tourniquet for extremities – must be released 15-20 minutes prior to recording NAPs

External Neurolysis⁴

- Initial step in most peripheral nerve dissections
- Freeing of the nerve and injury sites from surrounding connective tissue and scar in a 360 degree fashion using sharp or blunt dissection
- Normal mesoneurium is usually absent at, above and below the lesion
- Proximal and distal extents of injury are then encircled with Penrose drain or Vasaloops.
- Gentle traction at borders of the lesion allows dissection away from scar – working proximal to distal helps to preserve branches
- Establish healthy planes in the nerve both proximal and distal to the lesion
- For lesions in continuity sharp dissection is used to restore form and outline to the

Stimulation and Nerve Action Potential Recording⁴

Rationale for NAP recording⁵

- 60% or more of nerve injuries have some degree of continuity
- If exploration is determined by failure of anticipated recovery, repair, if needed, will be too late
- Operative inspection and palpation of a neuroma in continuity can be misleading
- Operative stimulation and recording (NAPs) can provide early information about significant recovery by 8 weeks after injury
- To transmit an NAP through an area of injury requires at least 4000 axons greater than 5 μ in diameter at the recording site
- Presence of an NAP recorded distally to a lesion in continuity in the early months after an injury promises recovery without resection and repair
- In an occasional case one portion of the cross section of the nerve is more severely injured than the remainder and , despite an NAP recorded distally the lesion requires a split repair

Timing for NAP recording⁵

- 2-4 months for relatively focal contusions caused by fractures, gunshot wounds and for lacerations in continuity

Pathology of peripheral nerves in points:

Changes following nerve injury (Describe Wallerian degeneration and the regeneration process)

1. Wallerian degeneration: the degeneration of distal segment of the axon after mechanical damage or transection (disruption of antegrade axoplasmic transport. The axon contains neurofilaments, microtubules and mitochondria but not ribosomes and Golgi apparatus so it is dependent on the body of the neuron to provide structural proteins). The process is characterised by disappearance of the microtubules and neurofilaments, the axon then dissolves.
2. After injury to the nerve fibre the degeneration spreads proximally to the first Ranvier's nodule. Organelles accumulate at that end which becomes thickened (growth cone)
3. Chromolytic changes: morphologic changes in the cell body induced by axon transection and include cell swelling, dissolution of Nissl bodies found only in the cell, nuclear eccentricity and nuclear enlargement. These changes prepare the cell for axonal regeneration.
4. Initially myelin breakdown occurs within the Schwann cells, but then macrophages take on this role.
5. Proliferation of Schwann cells, these cells form longitudinal continuous cell column (bands of Bungner). These serve to guide the nerve sprouts (finger like processes from the growth cone).
6. After a 10 day latency period axonal regeneration from the growth cone proceed at a speed of 1 mm per day or 1 inch per month. In type 2, 3 injuries. In type 3 and 4 the disruption of connective tissue matrix and the formation of scar tissue may interfere with distal axonal elongation.
7. If the regeneration is delayed beyond 1 -2 years, irreversible atrophic changes take place in the innervated muscle and then even with complete regeneration functional recovery does not take place. This is important factor in deciding the timing of nerve repair.
8. Regenerating axons undergo remyelination
9. Entrapment of neuropathy is the result of mechanical injury and vascular ischemic injury

Segmental demyelination /Remyelination:

1. Primary demyelination can result from Schwann cell dysfunction or direct injury to the myelin (autoimmune).
2. Secondary demyelination happens following nerve injury.

The denuded axons provide stimulus for Schwann cell proliferation which lay down myelin (thin layer of myelin is produced at day 3-5 following injury)

Indications for nerve biopsy:

1. suspicion of vasculitis requiring immunosuppressive therapy
2. Significant peripheral neuropathy of unknown cause

Specimen is sent to the lab fresh and is divided into 4 pieces, one piece is fixed in formalin for routine stains, the second is frozen using liquid nitrogen for immunohistochemistry, the third and fourth are buffered with glutaraldehyde for electron microscopy and teased fibre analysis.

Indications for muscle biopsy

1. Primary myopathy, myodystrophy
2. Secondary muscle disorder (neurogenic, endocrine, drug)
3. Vasculitis.

Similarly 4 specimens are prepared in the lab. Always communicate with the referring physician and the lab technician about the procedure and avoid injecting local into the muscle.