Nerve Injuries and Repair as Seen Through Electrodiagnostic Medicine

An orderly sequence of degeneration and regeneration follows nerve injury.

Using this knowledge, the electromyographer can make clear statements about diagnosis, treatment and prognosis.
Traumatic Nerve Injuries
Wallerian Degeneration

- Waller 1850

- Axoplasmic fragmentation surrounded by myelin

- Macrophages and (simple) Schwann cells proliferate

Nerve Trauma

- Retrograde/Proximal changes also occur.

- Neuronal hypertrophy (alpha motor neuron)

- Altered proximal myelin structure
Re-innervation later after Injury

- Sprouts from survivor motor unit axon innervate orphaned muscle fibers
- Larger number of fibers in motor unit
- Higher density of fibers in area, and of same muscle fiber type

EDX Response: Traumatic Nerve Injuries

- 4-5 days - loss of CMAP (NMJ)
- 5-8 days - loss of NAP (axon)
- Response loss is related to length of degenerating nerve stump
Traumatic Nerve Injuries
Changes in Muscle

- Neuromuscular Transmission failure
- Reduced membrane resting potentials
- Increased sensitivity to Acetylcholine away from endplates
- Fibrillation potentials originate near endplate, later at other sites.
- Muscle cells atrophy

Classification of Injury
Cohen-Seddon, Sunderland, MacKinnon

1. Neurapraxia (Conduction Block/Myelin)
2. Axonotmesis (Axon injury)
3. Endoneurial injury (fascicles disrupted)
4. Loss of Perineurium (scarring of nerve follows)
5. Neurotmesis (Loss of entire nerve continuity)
6. Neuroma in Continuity (Mixed pattern 1 thru 5)
Traumatic Nerve Injuries
Sunderland Classification

- Each axon may respond differently to the cut, stretch, or crush of the injury.
  - In acute phase use needle EMG to search for a motor unit potential(s), the presence of working motor units suggests that the nerve’s perineurium is not completely severed.
  - Blood supply not usually a factor, vasa nervorum is a rich plexus.

Fasicle Anatomy
Traumatic Nerve Injuries
Mixed Injury Types

- MacKinnon has suggested that mixed injuries be considered Type VI
- Injuries may require differing treatments in different fascicles
- Many injuries are mixed in character
- Cut, gouge, contuse, and stretch

Axon Sprouts

- Axonal sprouting can occur within a few days from survivor axons in partial injury
- Sprouts arise from Nodes of Ranvier near nerve terminal and from the terminal branch
Traumatic Nerve Injuries
Nerve regeneration

- Axon regeneration begins within 36 hr
- 1-3 mm/d axon growth for most nerves, faster proximal
- Follow endoneurial tubes, if possible

Sprouting occurs randomly during recovery and growth
- Axons within neural tubes and Schwann cells survive
- Synkinesis can develop as axons branch and sprout into the wrong muscles.
Traumatic Nerve Injuries

- Nerve fascicles do not travel parallel linear paths
- Complicates surgical repair when a proximal segment is missing

![Diagram of nerve fascicles](image)

MacKinnon, ‘88

Traumatic Nerve Injuries

- Nerve conduction velocity can approach, but not reach the normal speed (60-85%).
- Axon diameter smaller (60%). Myelin thinner, internodes shorter.
- CMAP amplitude correlates with muscle mass.
Traumatic Nerve Injuries
Regeneration

- Recovery over short median nerve segment.
- Recruitment order random rather than according to “size principle.”
- Note amplitude reduction between 22 and 29 months.

Progressive improvement in amplitude and latency of CMAP
- Note gain adjustments
- Loss of clear “motor point” zone, hard to get good “take-off”
- Sprouting leads to new NMJ locations
Traumatic Nerve Injuries
Nerve Repair-Anastomosis

- Post-operative motor nerve response 3 years post CN XI repair (R).
- Surgical mishap
- Latency delayed and duration increased (temporal dispersion), with peak amplitude normal.

When recording F-waves, “A” waves can appear.
- The A-wave represents aberrant conduction at the injury site
  - Ephaptic
  - Axon sprout
Axon (A) Wave

Injury Site

Stim

"M"

"A"

"F"

Note: A wave can appear before or after the F wave

Traumatic Nerve Injuries
This is an exciting finding!

- First regenerated axons produce nascent potentials;
  - Small, polyphasic units which fatigue easily.
  - Can be confused with fibrils since only 1 or 2 muscle fibers may be active.
  - Muscle movement may not visible.
  - Muscle reinnervation, finally

100 µV
10 ms
- Slow firing rate
- Polyphasic
- Unstable
- Fatigues easily
  - Allow rest during needle study

**Nascent Potential**

1st sign of axon regrowth

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**Traumatic Nerve Injuries Regeneration**

- Regeneration progresses which produces polyphasic MUPs of larger size, and continued abnormal recruitment.
- Unstable motor unit potentials (immature NMJ’s) with variation in subsequent appearances.
Polyphasic and Unstable MUP

Larger Amplitude, Polyphasic MUAPs with Shorter Duration
Traumatic Nerve Injuries Regeneration

- Complete regeneration leaves continued abnormal recruitment, decreased number of MUPs.
- Large amplitude MUPs @ 30-40 Hz.
- Fiber density abnormal on SFEMG, although jitter (stability) may return to normal.

Traumatic Nerve Injuries Stretch Injury

- Stretch injury to nerve, relation of strain to injury
- With strain (lengthening) of 6%, there is transient nerve dysfunction
- With strain (lengthening) of 12%, there is persisting injury to most axons

Figure 3-5. The amplitude of the compound nerve action potential (CNAP), expressed as a percentage of the baseline values prior to nerve stretch. Significant decreases with 6% and 12% strains are seen. Upon release of the strains, the 6% group shows good recovery, while the 12% group shows incomplete recovery.
Traumatic Nerve Injuries
Spontaneous Recovery

- How long to wait!? 
  - When no MUP or CMAP seen!
- Spontaneous healing of nerve occurs in 4-6 months (80-90%)
- Between 4-6 mon is time to consider surgical repair.

Recommends surgery for nerve repair if EMG does not show function at three months

Active hand therapy during waiting/observation
Surgery Recommendations

- Surgery immediate for sharp and vascular;
- Or Wait:
  - 2-3 weeks for blunt/dull penetrating (✓EMG);
  - 3 months for GSW;
  - 4 months for closed injury

- Outcome 3yr grade 3 recovery or better (prox=4/5, distal=3/5)
- 81% neurolysis
- 61% graft
- 40% neurotization
  - Transfer 2nd nerve

Dubuisson AS, *Neurosurgery* 2002;51:673

Poor outcomes associated with delayed surgery (when surgery is needed)

*FIGURE 3.* Scatterplot of postoperative outcomes at 3-year follow-up in 25 patients with C5–C6 or C6–C7 stretch injuries that were repaired by nerve grafting, according to timing of surgery.

Dubuisson AS, *Neurosurgery* 2002;51:673
Traumatic Nerve Injuries

Nerve repair

- Post-operative recovery after nerve repair improves with:
  - Younger age
  - Shorter distance to muscle
  - 90% recovery in young, distal injury
- Sensation will partially recover before strength
  - CNS amplifies input

Graft for repair

- Nerve conduction velocity 50-75%, at best
- Vascular supply is from nerve anastomosis
- Auto grafts preferred, but allografts (transplant) can be used since graft is temporary conduit for axon regrowth, and is replaced
  - Immunosuppression is temporary
### Traumatic Nerve Injuries

#### EMG Phases of Recovery

- **After Injury (immediate)**
  - ↓ # Motor Unit Potentials (MUP)
- **After Wallerian Degeneration**
  - ↓ Amp CMAP, NAP (sensory or mixed)
  - + Abundant Fibs, PSW
- **After Axon Sprouting**
  - Complex Polyphasic MUP, Unstable
  - ↑ Size CMAP
  - ↑ Size MUP, Gradually
- **After Axon Regeneration**
  - ↑ Number MUPs, Nascent Potentials
  - Muscle Hypertrophy-all working MUPs
  - Additional size MUPs
- **Continued Remodeling of mature MUP**
  - MUPs approach normal size

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### Traumatic Nerve Injuries

#### Clinical Phases of Recovery - Strength

![Diagram](image.png)

- 100%
- Strength (CMAP)
- Injury
- Axon Regeneration
- Muscle Fiber Hypertrophy
- Distal Axon Sprouting
- Resolution of Conduction Block
- Time → 12-24 mon.

Modified From Robinson LR; Muscle Nerve 2000
Prognosis According to Classification of Injury

1. Neurapraxia-complete recovery days to 3 months
2. Axonotmesis-growth \(1\) mm/d, near-complete
3. Endoneurial injury-partial recovery, 1 mm/d
4. Loss of Perineurium-does not recover
5. Neurotmesis-needs surgery, then like 3
6. Neuroma in Continuity (Mixed recovery pattern)

Note: Prognosis worsens for proximal injury

Prognosis According to Motor Nerve Response (CMAP)

- At 10 to 15 days post-injury, Compare with contralateral nerve (or reference value)
  - If loss is <50%, Prognosis is Excellent
  - If loss is 50-80%, Prognosis is fair to good (more than 20% of axons survive)
  - If loss is >90%, Prognosis is poor
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Sprouting will reinnervate

Neural tube still viable for new axons

Intraneural adhesions blocking recovery

Neuropathic Weakness Rehab Treatment

1. "Overuse can damage muscles, sometimes to the point of no recovery"
   - (Herbison GJ; APMR 1983)

Series of experiments on rats with sciatic nerve injuries; overuse by tenotomy of synergist
Not-so-Therapeutic Exercise

- Overload work of muscles produced by excision of agonist.
  - i.e. Tib anterior exercised after removal of Extensor Dig.
  - 1. Reduced strength with tetanic twitch by stimulation.
  - 2. Slowed twitch response

Exercise after Nerve Injury

- Edx showed recovery of CMAP and decreasing fibs at 3 weeks post-injury
- Strenuous exercise begun at 2 weeks retarded recovery of muscle size and fiber protein
- Strenuous exercise begun after 3 weeks recovery results in normal muscle hypertrophy
  - Exert muscle only after fibs are gone

Herbison GJ; Exp Neurol 1973
Exercise in Rehab
After Nerve Injury

1. Maintain motion/flexibility

2. Avoid strenuous progressive resistive exercises
   - (no 10RM-DeLorme exercise)
   - No exercise to fatigue
   - Avoid eccentric exercise
   - Adapt to reduce frequency of eccentric work in ADLs

STRENGTHENING EXERCISE
Sub-maximal

Maintenance of strength is usually achieved with a regular program of 20% MVC of muscle contraction
The KEY word

- AMPLITUDE
- AMPLITUDE
- AMPLITUDE
- AMPLITUDE
- AMPLITUDE
- AMPLITUDE

References

- Davis LE, Neurology 2004;63:1070
- Dawson, Hallett & Wilbourn, *Entrapment Neuropathies* (text)
- Dubuisson AS, Neurosurgery 2002;51:673
- *Johnson’s Practical EMG*, 2007 (text)
- Robinson LR, Muscle Nerve 2000;23:863
The Chief Wheelie!!

Go to Youtube: “Johnson Wheelie”
For Instruction

More Questions?

Wexner Medical Center
Questions?

- William S. Pease, M.D.
- Ernest W. Johnson Professor of PM&R
- William.pease@osumc.edu