Nerve Repair: How to Avoid Complications

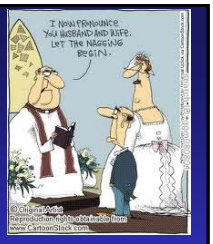
Mark Rekant MD
Associate Professor
Philadelphia Hand to Shoulder Center
Thomas Jefferson University

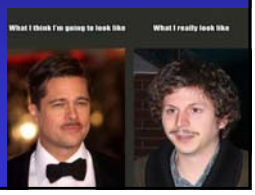
Avoiding Pitfalls

- Proper Diagnosis
- Treatment Decisions
- Nerve Preparation
- Nerve Repair Strategies
- Post-Operative Management

Preoperative Considerations

- Patient expectations
  - Patient characteristics
  - Injury characteristics
  - 50-80% good/functional recovery
    - M3/S3 or better



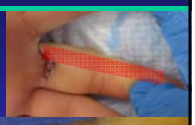


Preoperative Considerations

Discuss treatment options
- Repair/reconstruct/transfer
- Graft options


Office Evaluation

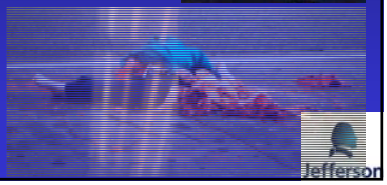
Sensorimotor deficits that correlate with laceration injury
- Proceed with exploration



Global Injury Assessment

Wound assessment
- Contamination
- Soft tissue defects

Associated injuries
- Tendons
- Vascular
- Fractures

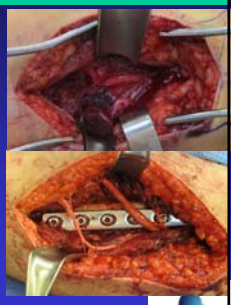
Requirements for Success

1. Healthy proximal and distal nerve stumps
   - MOST IMPORTANT
2. Proper alignment of proximal and distal stumps
3. Potential Nerve Gap Management
4. Tension-free neurorraphy (repair)
5. Atraumatic and secure coaptation

Timing of Surgery

Gunshot wounds and open fractures

- Treat like closed injuries
- Explore if part of surgical treatment of other injury



Timing of Surgery

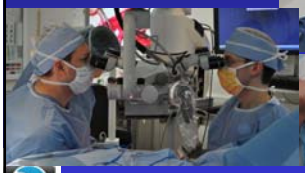
High-energy injuries

- May initially underestimate the zone of injury
- Tag nerve ends
- Wait ~3 weeks for definitive treatment

Intraoperative Considerations

Patient positioning
- Stable access to site

Microscope available



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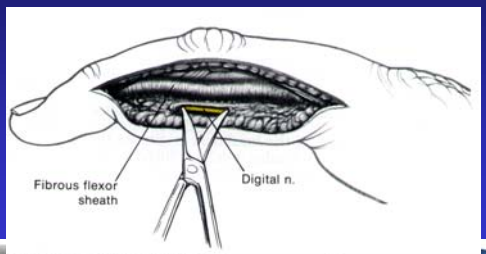
Instruments

- Specialized microsurgical instruments
  - Preferably at least 10 cm long
  - Fine spring loaded needle holders and scissors
- Surgical loupes
  - (see wealthy relative or win lotto)
- Operative microscope
  - (at least 20X)

Dissection



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Healthy Nerve Stumps

This is the MOST important step

- Appreciate the zone of injury
- Need to remove damaged tissue both proximally and distally
- Do resection BEFORE determining final repair technique

Resection Matters

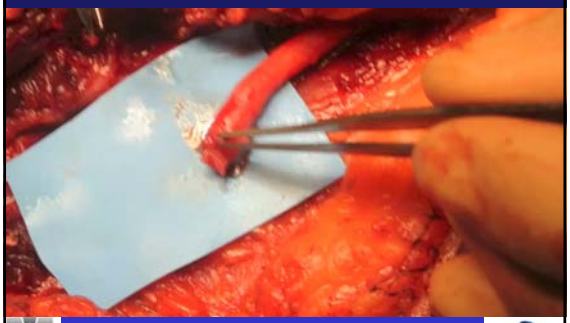
- Suturing Scarred Nerve Provides Limited Value
- Scar Inhibits Revascularization, Axonal Regeneration and Schwann Cell Migration
- Proximal Stump should have at least 75% preserved neural elements (Wolfe et al., 2013)

Berocal et al. 2013

Nerve Debridement

- Morphologic features of healthy nerve ends:
  - Normal fascicular architecture
  - Pliability / tactile feel of nerve
  - Appearance of “pouting” fascicles
  - Punctate endoneurial bleeding
- Tourniquet?

How much do I trim?



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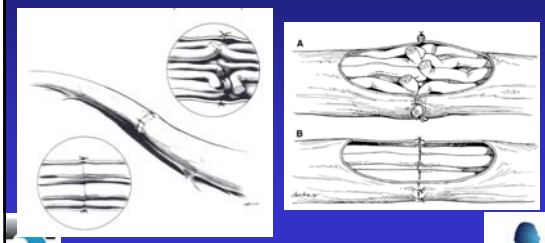
Respect the Coaptation

Tension may compromise the nerve repair and lead to ischemia within the nerve



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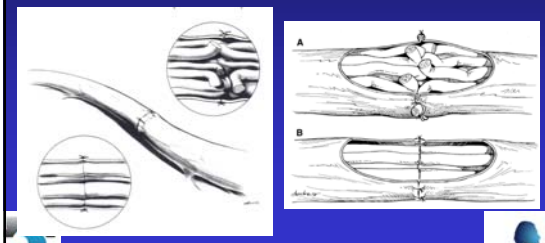
Tension Matters

However, “Bunching” may prevent the new fascicles from regenerating properly



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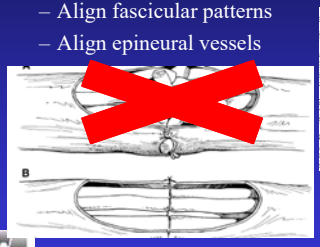
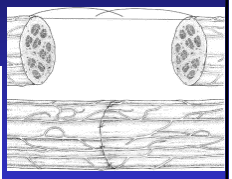
Proper Alignment

Assess fascicular alignment
- Align fascicular patterns
- Align epineural vessels

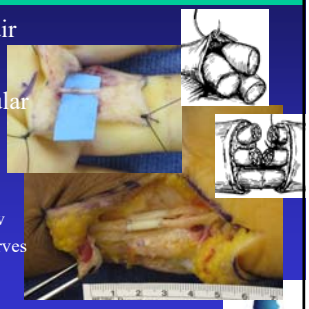




Proper Alignment

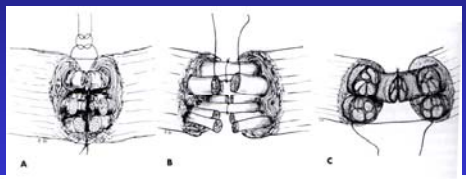
Perform epineural repair

Consider group fascicular repair
- Sutured at inner epineurium
  - Radial nerve at elbow
  - Median and ulnar nerves at wrist



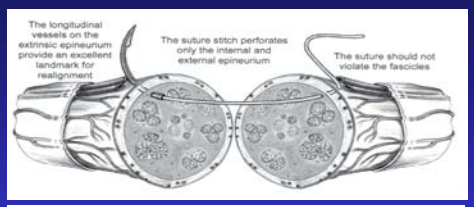
Nerve Repair

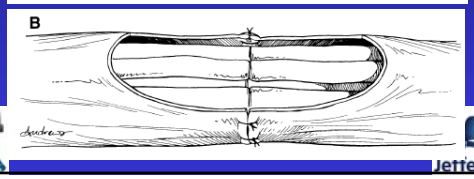
- **Fascicular repair**
  - Most common indications for grouped fascicular repair
    - Median nerve in distal third of forearm
    - Ulnar nerve in distal third of forearm
    - Sciatic nerve in thigh



Epineural | Fascicular Repair | Grouped Fascicular

The Coaptation





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Tension-Free Neurorraphy

Assessing tension

- Epineural sutures with 9-0 nylon
- Nerve ends "kissing" / "just touching"
- No gapping with extremity ROM

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Tension-Free Neurorraphy

Neutral posture of adjacent joints limits:

- Joint contractures
- Pain from tension during rehab
- Failure of repair

Nerve transposition/Mobilization ?

- Not much gain, increased devascularization

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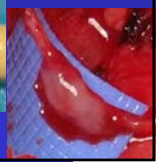
Atraumatic and Secure Coaptation

- Appropriate number of sutures
- Conduit/connecter-assisted
- Fibrin glue
  - Decreases gapping
  - Does not improve strength



Isaacs 2010 JHSAm. Isaacs 2008 JHSAm.

Tension Causes Restriction in the Blood Supply

Tension at the repair site: **8% stretch impedes venous return**

16% stretch causes arterial ischemia

<5% ELONGATION

At minimal elongation, there is slight scarring but blood vessels are not constricted.

5-10% ELONGATION

With increased elongation, first signs of tissue injury are observed along with ~50% reduction in blood flow.

>11% ELONGATION

Excessive elongation can cause complete blockage of blood vessels.

References:
Lundborg and Rydevik., 1973, J Bone Joint Surg.
Clark, Trumble, et al., 1992 J Hand Surg Am.

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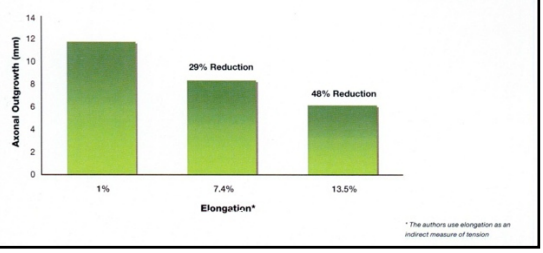
If attempt to repair gap creates **tension** → primary repair results in suboptimal outcome

Increased tension showed impaired axonal growth in a preclinical model.[2]



What About the Gap

Nerve Gap Reconstruction Options

- Conduits
  - Autologous Vein Graft Entubulation
  - Commercially available Hollow Tube Conduits
    - Integra Lifesciences - NeuraGen™ and NeuraWrap™ (bovine collagen)
    - Synovis - Neurotube® (PGA)
    - Polyganics - Neurolac® (poly-ester)
    - AxoGuard Nerve Connector/Protector (porcine submucosa)
- Processed Nerve Allografts
  - Avance® Nerve Graft
- Autologous Nerve Grafts (Autograft)

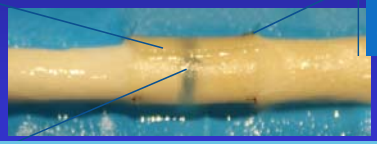
Role of Tube Conduits

- Tubes play an important role in modern nerve repair
- Consideration should be given to:
  - The function of the nerve
    - Typically reserved for non-critical sensory nerves
  - The length of the gap
    - Less than 20mm
  - The diameter of the nerve
    - The larger the diameter, the shorter the gap should be
    - Less than 6 mm in mixed nerves
- Resurgence as an aid to direct repair with very short gap (<5mm)

Connector Assisted Coaptation: Providing Alignment and Avoiding Tension at the Coaptation

Entubulation of the Coaptation

Barrier to Axonal Escape, Scarring and Inflam-matory Infiltration



Sutures moved away from Coaptation Site

No forced mismatch from overly tight repair

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Conduits– as Coaptation Aids

- Place nerve ends in and suture to epineurium
- Allow a very small gap (less than 5mm) between the face of the nerve ends to ensure no misalignment.
- Reduces tension and fibrosis the of the sutures
- Allows the regenerating nerve fibers to find the optimum path

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Entubulation Technique Summary

Trim to healthy nerve

Measure Nerve

Horizontal Mattress Suture Technique

Flush with Saline

Suture Second Side

Flush with Saline

Completed Nerve Repair

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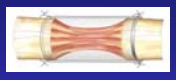
Length Limitations of Conduits

Increasing Gap Length

Decreasing Efficacy



Fibrin cable is robust enough to allow regeneration at short gaps.

Thinning restricts the regenerative space at longer gaps.

The cable does not form when length limits are exceeded. This can result in no regeneration or a neuroma.

References:
Zhao, et al., 1993, Res Neurol and Neurosci.
Whitlock et al., 2009 Muscle and Nerve

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Tube Assisted Coaptation Clinical Outcomes

Gaps <6 mm Literature

Study	Nerve Injury Types	Test Article	Gap	Outcomes*
Lundborg 1998	Mixed	Silicone Coaptation Aid vs. Suture	<5mm	Comparable to Suture, better sensation
Weber et al., 2000	Sensory	PGA Coaptation Aid vs. Suture	<5mm	91% Coaptation Aid, 49% Suture
Farole et al. 2009	Sensory	Wrapping vs. Non-Wrapping	<2mm	<Pain with Wrapping
Boeckstyns et al. 2013	Sensory Nerves	Collagen Coaptation Aid vs. Suture	< 6mm	Comparable to Suture at 2 years

*As reported, based on individual study parameters for positive outcomes

Conduits Limitations

- Length
  - Impacts reliability of Outcomes
    - Schmauss et al J. Recon Micro 2014, Lohmeyer et al., J. Recon Micro 2009
- Diameter
  - Proper size match is essential >1mm larger decrease efficacy.
    - Isaacs et al JBJS 2014, Moore et al., Hand 2010
- Response to Materials
  - Extrusion.
    - Rinker et al., JHS 2010, Weber J. Plas Recon 2000, Chiriac JHS EU 2011
  - Encapsulation/Scar.
    - Moore et al., Hand 2010, Liodaki J Recon Micro 2013

Isaacs et al., Major Peripheral Nerve Repair. Hand Clinics 2014

Liodaki et al., Journal Recon Micro. 2013

Chiriac et al., JHS-EU 2011

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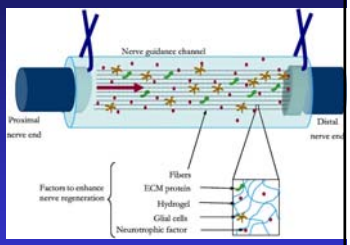
Limitations to Gap size?

Reports from Published Literature:

- Lundborg et al. (199?)
  - 5mm gap
  - Silicone conduit equivalent to direct repair
- Weber et al. (2000)
  - <5mm 100% recovered Static 2PD
  - ≥5mm 66% recovered Static 2PD
- Battiston et al. (2005)
  - Only 4/19 good/excellent results
    - 3/4 for 3-4cm gaps poor
- Lohmeyer et al. (2009)
  - Greater than 15mm no recovery

Future of Tube Conduits

- ECM Components
- Internal Architecture
- Lumenal Fillers
- Neurotrophic Factors
- Neurtropic Factors
- Cell Delivery
- Electro-conductive



Bellamkonda et al., Biomaterials 2011

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Tension-Free Neurorraphy

Deleterious effects of tension
- Ischemia, Fibrosis

Limitations of nerve stretch:
- 8% causes transient ischemia
- 10% may be acceptable in pliable nerves
- 15% leads to irreversible ischemia

Isaacs 2010 JHSAm. Isaacs 2008 JHSAm.

Nerve Repairs

- **Direct muscular neurotization**
  - insert proximal nerve stump into affected muscle belly
  - results in less than normal function but is indicated in certain cases
- **Epineural Repair**
  - Primary repair of the epineurium in a tension free fashion
  - First resect proximal neuroma and distal glioma
  - It is critical to properly align nerve ends during repair to maximize potential of recovery

Nerve Repairs

- **Nerve grafting**
  - Autologous graft
    - remains the gold standard of repair for segmental defects > 5cm is autologous nerve grafting ___
    - digital nerve defects
      - Wrist to common digital nerve bifurcation - use sural nerve
      - MCP to DIP level –
        - Use LABC, AIN, PIN or MABC
  - Collagen conduit
    - defects up to 1.5 cm
      - quality of nerve recovery drops with gaps >5mm
  - Allograft
    - off-the-shelf option for defects up to 7cm

What do I use ?

- 9-0 nylon for digital nerve repairs
- 8-0 nylon for median and ulnar nerve repair (wrist and above)
- 8-0 nylon for synthetic nerve conduits

Postoperative Care

Splint extremity for soft tissue rest

Benefit of tension-free neurorraphy:

- Begin hand therapy according to associated injuries
  - Flexor tendons
  - Fractures
- Isolated nerve injuries
  - Initiate ROM 5-10 days following repair
  - Initiate ROM 2-3 weeks following nerve transfers

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Case Example

- 42YO o/w healthy RDM male
  - Numbness L thumb and index
  - Thumb weakness
  - Minimal/no pain
  - Irritating, does not interfere w/ ADL

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History

- Started 1 ½ years ago
  - Diagnosed w/ CTS (w/ NCS)
  - Endoscopic CTR
    - Uneventful according to op report
  - Immed. post op:
    - Patient reports worsening pain/numbness and inability to abduct thumb
    - Surgeon's notes: sens intact to LT and motor fx normal
      - Sees patient regularly for 9 months
        - » Inconsistent exam, symptoms improving
        - » Subjective complaints noted

History continued

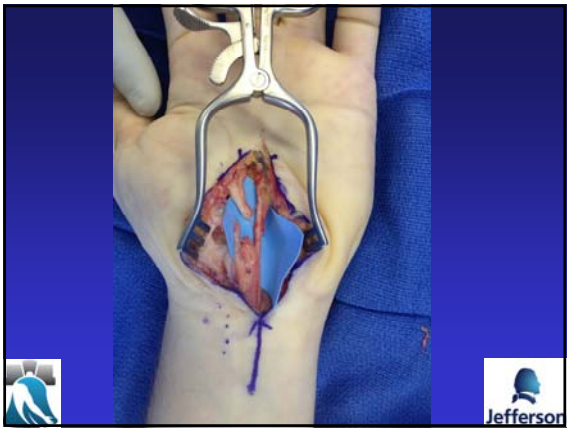
- Undergoes 3 separate NCS and ultrasound
  - Increased latency and decreased amplitude
  - EMG c/w denervation of APB
  - U/S: c/w nerve constriction one cm distal to crease
- Patient told to "exercise" thumb
- After 9 months scheduled for revision CTR
  - Case postponed when surgeon in car accident

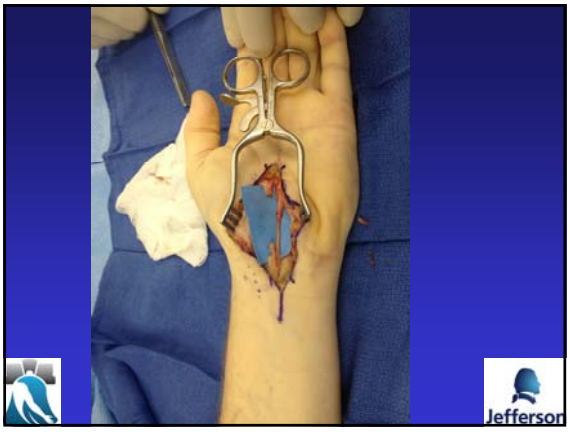
Exam

- Thenar atrophy
- Inability to abduct thumb
- No sharp/dull discrimination thumb, index, radial half of middle finger
- Strong but non-focal Tinel's over carpal tunnel

Now what?

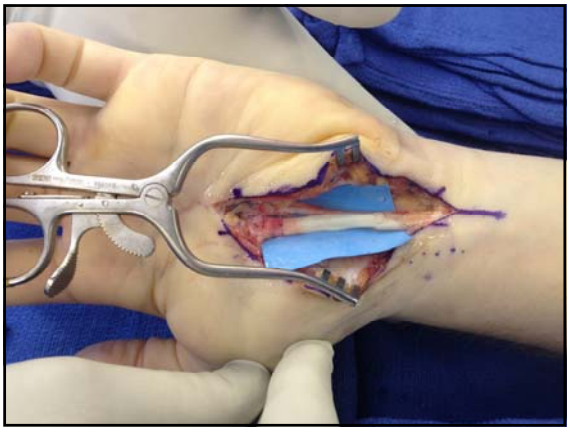
- More exercises?
- More time?
- More studies?
- Live with it?
- Surgery?

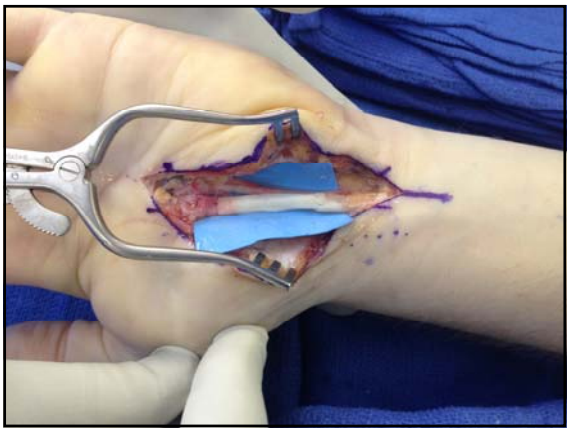




Repair options?

- Conduit?
- Autograft?
- Allograft?





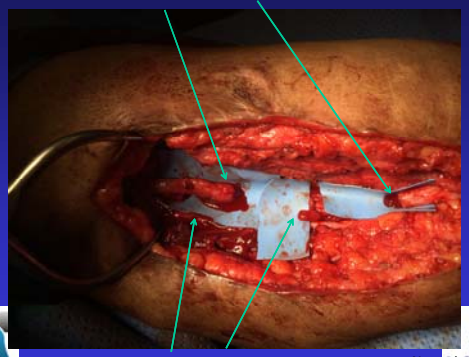
Case 2

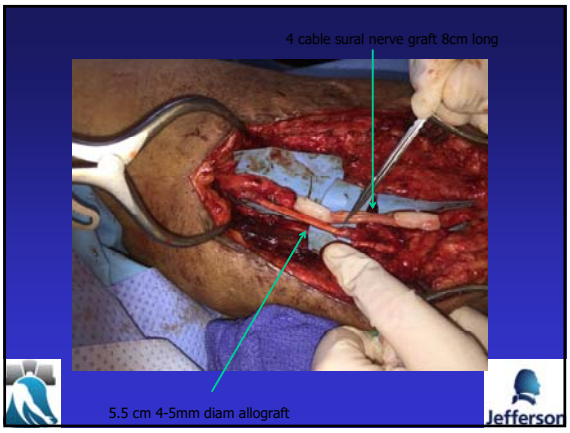
- 71 yo taken to the OR emergently by trauma service for accidental self inflicted shot gun blast to left medial brachium (+ETOH)
  - Emergent vein grafting to brachial artery
  - Hand team (not me) identified median nerve which was intact
  - Ulnar nerve not explored

- Sent to me 3 mos out with no median or ulnar nerve function
  - Supported by NCS/EMG
- Now what?
  - Wait it out?
  - Nerve transfers?
  - Tendon transfers?
  - Explore
    - How to repair?

Surgical exploration

- 4 mos post injury
- Nerves intact
  - Median N. feels fibrotic.. Multiple areas of "neuroma-in-continuity"
  - Ulnar nerve not as bad.. But not normal
- Now what?
  - Intra-operative nerve studies did not reveal any regenerating axons




4 cable sural nerve graft 8cm long
5.5 cm 4-5mm diam allograft
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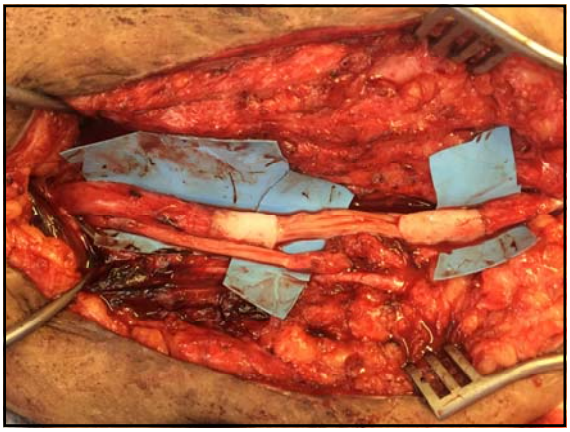


Fibrin glue added… since we had it out already
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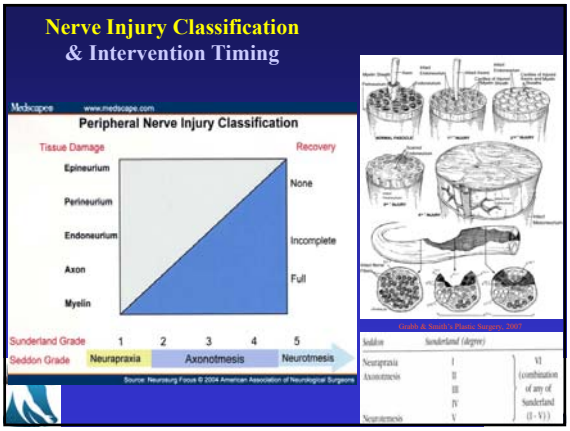
Nerve Injury Classification & Intervention Timing



Grabb & Smith's Plastic Surgery, 2007

Seddon	Sunderland (degree)	
Neurapraxia	I	VI (combination of any of Sunderland (I - V))
Axonotmesis	II	
	III	
	IV	
Neurotmesis	V	