PRIMARY NERVE REPAIR
History

- Galen 130-200 “Partially injured nerve should be severed completely to prevent convulsions”
- Ferara 1608 first documented nerve repair
- Waller (believed in distal axon degeneration proximal stays alive)
• Ramon & Cajal silver staining- elucidate details
• Tinel WW I Tinel sign
• Sir Herbert Seddon WW II (primary & secondary repair using nerve grafts)
• Hanno Millesi nerve repair without tension
Tinel Sign

- Strongly positive sign over lesion soon after injury indicates rupture/severance

- Successful repair- centrifugally moving Tinel is stronger than that at suture line

- Impending failure- Tinel stronger at suture line
Anatomy of a Nerve
Motor ending

Sensory ending

Dendrite

Myelin sheath

Neurilemma

Neurofibril node

Perineurium

Endoneurium (supports the nerve fibers)

Intrafascicular vessel

Epineurium

Cylindrical bundle of nerve fibers (fasciculus)

Interfascicular vessels

Peripheral nerve
Number of axons 10-15000
<table>
<thead>
<tr>
<th>Component</th>
<th>Velocity</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANTEROGRADE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groups I and II</td>
<td>20–410 mm/day</td>
<td>Membrane-Associated Materials</td>
</tr>
<tr>
<td>Group III</td>
<td>4–8 mm/day</td>
<td>Membrane constituents, transmitter-associated enzymes, various small-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>molecular-weight materials (eg, amino acids)</td>
</tr>
<tr>
<td>Slow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group IV (SCb)</td>
<td>2–30 mm/day</td>
<td>Polypeptides (eg, myosin-like actin-binding polypeptide)</td>
</tr>
<tr>
<td>Group V (SCa)</td>
<td>0.1–15 mm/day</td>
<td><strong>Cytoskeletal and Associated Proteins</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elements of axoplasmic or microtrabecular matrix (eg, actin, clathrin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>eg, tubulin, neurofilament triplet</td>
</tr>
<tr>
<td><strong>RETROGRADE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>≤300 mm/day</td>
<td>“Recycled materials,” neuronotrophic factors (eg, NGF)</td>
</tr>
<tr>
<td>Slow</td>
<td>3–8 mm/day</td>
<td>Single protein</td>
</tr>
</tbody>
</table>
Microtubules & neurofilaments
PERINEURIUM

- Outer and inner basement membrane
- 15 layers of lamellae
- Collagen and elastic fibers
- Mechanically very strong (350-750 mm Hg before rupturing)
Mushrooming phenomenon

- Positive intrafascicular pressure +1.2-1.5
  → Mushrooming phenomenon
Perineurial diffusion barrier

- Both directions
- Tight mechanical junction between perineurial cells
- Effective filter against ions, proteins and other hazardous substances
Perineurial diffusion barrier
(albumin-fluorescein)
Perineurial vessels
Perineurial compartments

- Very susceptible on crush injuries and compression-
EPINEURIUM

- Soft connective tissue
- Protects fascicles—cushioning effect
- Abundant near joints up to 75% (friction)
- Gliding function—nerve excursion during movement
Exursion

- 15 mm at wrist for median and ulnar with wrist extension to flexion

Elbow

- 7.3 mm prox and 5 mm distal for MEDIAN
- 10 mm prox and 3 mm distal for ULNAR
Neural microvascular system

Three pattern
Breidenbach-Terzis 1987

a) No dominant pedicle
b) One dominant pedicle
c) Multiple dominant pedicles
Intrinsic and extrinsic vascular system

- Intrinsic and extrinsic system $\rightarrow$ Equilibrium btw.
- Able to compensate each other for vascular disturbances
Impulse conduction

- Axon membrane in polarized state – selectively permeable to K at rest -70
- During repolarization select. Perm to Na
- Axon thickness and insulation: conduction velocity
- Nonmyelinated 2-4 m/s
- Myelinated up to 150 m/s
Neuromuscular junction

- Transfer action potential to muscle fibers-chemical reaction –acetilholine
- Susceptible to ischemia and different pharmacological agents
Sensory receptors

- Unencapsulated (free nerve endings)
- Cold, warm, pain, and deep pressure
- Innervated by A\(\delta\) and C fibers.
Encapsulated receptors

- Pacinian, 256 SA
- Meissner-30 QA
  $\text{A}\delta$ myelinated fibers
- Merkel and Ruffini – SA
  $\text{A}\beta$ myelinated fibers
FASCICULAR PATTERN

- Number of fascicles may vary e.g.
- Median 3 – 40
- Ulnar 3-25
Classification of Nerve Injury

- **Seddon**
  - Neuropraxia: Conduction Block
  - Axonotmesis: Endoneurium, Axon
  -神经损伤：神经束
  - Neurotmesis: Perineurium, Epineurium

- **Sunderland**
  - Neuropraxia: Conduction Block
  - Axonotmesis: Endoneurium, Axon
  - Neurotmesis: Perineurium, Epineurium
Sixth degree (Mackinnon)

- Combination of any of I-V
- Neuroma in continuity
- Most challenging for treatment
Nerve regeneration-neuron changes

- Neuron kariolysis → Nissl bodies = rough citoplasmic reticulum ↑ production of proteins
- 27% neuron death in proximal injuries.
- 6% in distal injuries
- Age related > in older
Walerian degeneration axon sprouting
Chemotactic effect of NGF
Ganderson & Barrett 1979
Neurotrophism effect of NGF on growth of nerve cells  Manthorpe 1982
End plate changes

- End motor changes after 4 weeks, disappearing after 16 weeks (Zhonguo 1999)
- Histologic changes of muscle degenerations 3 days post injury (Personius 1998)
Primary repair timing

- Primary 0-7 days
  - immediately 0-48 h
  - delayed 3-7 days
- Secondary: after 1 week
  - early 1-3 week
  - late after 3 week
Open injuries

- Require early exploration
- Sharp and clean = immediately repair
- If in doubt about contamination and soft tissue damage? Primary delayed
Contaminated and crushed injuries

- If gross contamination and crush injury with significant damage of soft tissue → secondary repair – 3 weeks later
- Distal ends of nerve should be tagged and sutured to prevent significant retraction and allow easy identification
- Approximated using fascicular alignment to help topographical alignment in sec. repair.
General Principles In Surgical Repair

- Preparation of the stumps
- Trial approximation
  - 2 8-0 sutures
  - Modest tension vs tension free (Wood 1991)
  - Moderate Tension vs. graft (Hentz et al 1993)
- Maintenance of coaptation
Factors Influencing Recovery

- Age
- Level of Transection
- Delay
- Cause Of Injury
- Nature Of Nerve Injured
Age

Children excellent and good in up to 90%
Teenagers and younger excellent and good 75%
Adults 20-50 exc. and good 50-70 %
Over 50 Only 25% good and excellent
(regeneration abilities, brain plasticity)
Mechanism of injury

- Soft tissue damage (tidy vs. untidy)
- Vascular damage, tendon injury etc.
- Good Results (Omer 1974, 1981, 1984)
  - Sharp & clean 60-90%
  - Laceration 44%
  - Gunshot-low velocity 31%
    - high velocity 23%
Level of injury

- Distal injuries better prognosis
  1. Retrograde degeneration of cell body
     proximal > distal (both sensory and motor)
  2. Proximal more mixture of nerves -> chance for misalignment
  3. Longer way -> chance for terminal organ degeneration
Timing of repair

- Most authors agree < 6 months better prognosis
- Excellent /Good results (Omer)
  - 75% < 6m, 20% >6 m
- Seddon and Zachary After 9-18 months no functional motor recovery
- Reasonable sensory recovery after 18 months (Sensory after 14 years 1 case Terzis)
TIMING OF REPAIR

- primary repair within 1 week
- Immediately primary Clean and sharp injuries—
- Delayed primary after 3-4 days in moderately contaminated injuries without or with some soft tissue injury (e.g. table saw injury, slow velocity gunshot injury)
Blunt, crush, gunshot injury

- No reliable method to assess nonviable nerve tissue
- Secondary nerve reconstruction is recommendable
Why is primary repair preferred?

- Better alignment
- Shorter gap (fibrotic reaction & Walerian degeneration)
- Shorter time for end plate and sensory receptors degeneration
Primary vs. secondary

- Primary optimal approach whenever wound and patient general condition allows
- Nerve repair ASAP as better
Factors influencing nerve recovery. What we can do?

1. Age
2. Genetical ability of nerve to recover
3. Nerve type
4. Specific nerve
5. Mechanism of injury
6. Extent of nerve injury
7. Level of injury
8. Type of repair
9. Timing of repair
10. Bed vascularity
11. Rehabilitation
TYPE OF REPAIR

- Primary preferred if:
  1. Wound characteristic: No significant contamination, crush, avulsion, blast, gunshot inj.
  2. Patient overall condition: No serious associated injury or life threatening states
  3. Tension free coaptation possible
Type of repair

- Epineural
- Group fascicular
- Fascicular
- Nerve graft (trunk, pedicle, fascicular, group fascicular, free vascularized)
- Neurotization
- Suture vs. alternatives
Epineurial repair

- Sharp, clean cut,
- No defect

Alignment by:
- Epineural vessels
- Appearance of fascicles
Epineural pitfalls - disadvantages

- Fascicular misalignment
- More prevalent in larger nerves (ulnar, median, radial)
- Might be present even in digital nerve repair
Group fascicular repair

- Millesi H 1972,
- Sunderland S 1978, Jabaley M 1985
- Chow JA 1986
Fascicular groups identification and separation
Group Fascicle Identification

- Mirror Image
- Electrical Stimulation in the Awake pt
- Immunohistochemistry
  - Blue-Sab staining for sensory fascicles (Gu)
  - Carbonic Anhydrase (sensory) and Acetylcholinesterase (motor)
Group fascicular technique

- Interfascicular
  - internal epineural suture
  - 10/0-microscope 2-3 suture
  - Ext. epineurium flap dissection
Fascicular pitfalls

- More manipulation
  ⇒ more sutures
  ⇒ nerve damaging ⇒ more scaring

Difficult if polifascicular (30-40) fascicles
Potential perineurium damage ⇒ serious metabolic disturb.
No significant data or evidence indicates that any one technique is better than the other
What if gap is present?

- Secondary to...
  - retraction of nerve stump (elastic recoil)
  - nerve defect from injury
  - nerve defect from debridement
  - fibrotic retraction
  - wallerian degeneration
What is safe gap–tension for primary suture?
Difficult question in clinical setting

- Panel discussion 1977
- Millesi, Buck Gramcko, Brunelli, Freilanger, Samii 1.5-2 cm;
- Kutz, Wilgis 4 cm;
- Urbaniak, Gaul 6-7 cm
Tension effect on microcirculation

- Miyamoto Y 1978
- Lundborg 1973 5% elongation ↓ circul.,
- 15% complete cessation of circul.
Tension effect on NCV

Lundborg G, 1973
Experiment on rabbits
Measured CNAP
Mind the Gap

- Proximal and distal mobilization of nerve
- Anterior transposition of nerve
  - Ulnar and Radial gain is 3 cm
- Joint positioning
- Humeral shortening
How to overcome gap

Nerve mobilization

- Dissection 2 cm↑ scar formation (Ogata et all 1985)
- Dissection 3 cm ↓ blood flow (Rodkey et al 1980)
Nerve graft

- Nerve graft introduced by Balance and Duell 1932
- Used only in extreme defects
- Millesi et al 1966, 1972, proliferation of connective tissue as a result of tension-mainly from epineurium
- Rarely used in primary neuroraphy
Joint positioning

- Souttar 1917, Forester Brown 1921, Grantham 1948, Seddon 1949, Brooks 1955, (experience from WW I and WW II) Correction of joint 2-3 wks after repair 10% each week

<table>
<thead>
<tr>
<th>Joint Position</th>
<th>Increased Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist 40° dorsiflexion or palmar flexion</td>
<td>2</td>
</tr>
<tr>
<td>Elbow 90° flexion</td>
<td>4</td>
</tr>
<tr>
<td>Shoulder abduction (to 90°)</td>
<td>2</td>
</tr>
</tbody>
</table>
Nerve rerouting and transposition

- Ulnar nerve at the elbow
- Median nerve at the elbow by release lacertus fibrosus, PT and FDS
- Recurrent motor branch of ulnar nerve at wrist level (into carpal tunnel)
Bone shortening

- Humeral shortening when multiple nerve defect are present
Primary nerve graft- conduits

- Primary nerve graft Saito 2003, Chalfoun 2003, Sud, Lineaweaver 2001
- Conduits: silicon, PGA, vein, epineural sheath
- Allograft (after tumor resection) Mackinnon 2001 - immunosuppression - cyclosporin
Allograft & end to side

- Allograft (after tumor resection) Mackinnon 2001 - immunosuppression - cyclosporin

Partial nerve injury
Sutureless method

- Fibrin glue Young & Medawar 1940
- Tarlow 1943 (significant scarring)
- Ventura 1980 positive experience exp.
Closure and Postop Care

- Local Anesthetic
Closure and Postop Care

- Elbow, wrist and hand must be restricted to protect flexor tendon and nerve repairs
Closure and Postop Care

- Splint elbow at 90 degrees flexion
- Wrist 30-40 degrees flexion
- MCP J to 70 degrees flexion
- Bandage to restrict motion but not immobilize
- Encourage active finger and thumb flexion
Closure and Postop Care

- Change splint at 3 weeks
- New splint does not restrict elbow
- If repair at elbow then hinged elbow splint
Closure and Postop Care

- D/C all splints at 6 weeks
Rehabilitation

- Starting after return pain and temperature and start returning 30cps (moving 2 PD)
- Late phase starts when return some of static 2PD
- Return topographic orientation in brain cortex (brain plasticity)
REHABILITATION - Why is sensory reeducation necessary?

- Mismatch connection→ misdirection between axons and end receptors.... misinterpretation
Brain Misinterpretation

NORMAL HAND

HAND WITH REPAIRED MEDIAN NERVE
Outcomes

- 500 ulnar n cases (Strickland)
  - Functional motor recovery 35% of cases
  - Functional sensory in 30-68%
- 110 ulnar secondary microsurgical repairs (Vastamaki)
  - 52% useful recovery
- 132 late repair median nerve (Vastamaki)
  - 49% useful recovery
  - Age pt, level of injury, delay interval, length of lesion
Outcomes

- Trevett and Assoc. advise early tendon transfers in manual laborers with high lesions
Outcomes

- Radial N
  - Early tendon transfer advised in high traction rupture, injury above spiral groove, defect > 10 cm, interval from injury greater than 12 mos.
Outcomes

- Digital Nerves
  - Coates et al...74 DNR within 48 hrs
    - 1 excellent
    - 33 good
    - 24 fair
    - 16 poor
Can the injury be repaired primarily without having to overcome a segmental defect in the nerve?

- **YES**
  - Proceed with primary repair.
- **NO**
  - Are the end organs (skin, muscle) supplied by the nerve
    - **YES**
      - Proceed with neurovascular island flaps or tendon transfers.
    - **NO**
      - Is the proximal portion of the nerve available for repair?
        - **YES**
          - Is the distal end of the nerve available for repair?
            - **YES**
              - Can the nerve ends be approximated with mobilization, bone shortening slight tension, or transposition?
            - **NO**
              - Consider neurotization.
        - **NO**
          - Consider nerve transfer, e.g., intercostal n. transfer to the musculocutaneous n.
Consider nerve transfer, eg, intercostal n. transfer to the musculocutaneous n.

Is the distal end of the nerve available for repair?

Consider neurotization.

Can the nerve ends be approximated with mobilization, bone shortening slight tension, or transposition?

Bridge nerve defect with intercalary graft.

Repair end-to-end.