Brachial Plexus Injuries and Shoulder Girdle Injuries

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Overview

- Review of Plexus anatomy
- Basics of Nerve Injury and Repair
- Brachial Plexus Birth Palsy
- Other Etiologies
- Operative Repair and Reconstruction of Plexus Lesions
- Sternoclavicular and Acromioclavicular injuries
Anatomy

- typically C5 - T1 (ventral rami) Commonly also includes input from C4 and T2
- prefixed C4 - C8 - 3%-40%
- postfixied C6 - T2 - rare
- divided into Roots, Trunks, Divisions, Cords, and Branches (nerves)
- C5 & C6 form upper trunk at Erb’s Point
  - suprascapular n. exits distal to Erb’s
Note: usual composition shown. Prefixed plexus has large C4 contribution but lacks T1. Postfixed plexus lacks C5 but has T2 contribution.

3 trunks
5 roots (ventral rami)

3 cords
3 anterior divisions
3 posterior divisions

Terminal branches
Musculocutaneous nerve (C5, 6, 7)
Axillary nerve (C5, 6)
Radial nerve (C5, 6, 7, 8, T1)
Median nerve (C5, 6, 7, 8, T1)
Ulnar nerve (C7, 8, T1)

Lateral pectoral nerve (C5, 6, 7)

Suprascapular nerve (C5, 6)
To subclavian muscle (C5, 6)

Dorsal scapular nerve (C5)
To phrenic nerve

Superior
Middle
Interior

1st rib

Medial pectoral nerve (C8, T1)
Medial brachial cutaneous nerve (T1)
Medial antobrachial cutaneous nerve (C8, T1)
Upper subscapular nerve (C5, 6)
Thoracodorsal (middle subscapular) nerve (C5, 6, 7, 8)
Lower subscapular nerve (C5, 6)

Contribution from C4
Dorsal ramus

Contribution from T2
To longus colli and scalene muscles (C5, 6, 7, 8)
1st intercostal nerve

Long thoracic nerve (C5, 6, 7)

Inconstant contribution
Basics of Nerve Injury and Repair

- **Neurapraxia**: minor contusion or compression, possible minor edema or myelin breakdown
- **Axonotmesis**: axon breakdown and distal Wallerian degeneration but preservation of Schwann cell and endoneurial tubes
- **Neurotmesis**: complete severance or significant avulsion or crush; axon, Schwann cell, endoneurium completely disrupted; perineurium and epineurium disrupted to varying degrees
<table>
<thead>
<tr>
<th>Degree of Injury</th>
<th>Histopathological Changes</th>
<th>Tinel Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Myelin</td>
<td>Axon</td>
</tr>
<tr>
<td>Sunderland</td>
<td>Seddon</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Neurapraxia</td>
<td>+/-</td>
</tr>
<tr>
<td>II</td>
<td>Axonotmesis</td>
<td>+</td>
</tr>
<tr>
<td>III</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>V</td>
<td>Neurotmesis</td>
<td>+</td>
</tr>
</tbody>
</table>
Repair

- **Endoneurolysis**
  - Epineurium is incised only in area of lesion
  - Flaps of epineurium are undermined
  - Funiculi are separated with care to protect interfascicular plexus

- **Partial Neurorrhaphy**
  - Partially damaged nerve
  - Only large nerves

- **Neurorrhaphy**
  - Epineurial neurorrhaphy
  - Perineurial neurorrhaphy
  - Nerve grafting
Neurorrhaphy

Fig. 59-13   Epineurial neurorrhaphy (see text).

Fig. 59-14   Perineurial (fascicular) neurorrhaphy (see text).
History

- 1764, Smellie first described birth palsy
- 1872, Duchenne proposed traction mechanism
- 1874, Erb, vulnerable point
- 1900, William Thornburn
  - 1st report of successful surgery
  - 16 yo female, tx’d by secondary suture
- 1920, Taylor
  - series of 70 birth palsy tx’d surgically
- 1963, Sir Herbert Seddon
  - “repair of the brachial plexus has proved so disappointing that it should not be done except for the upper trunk”
- 1970’s
  - technical improvement in microsurgery
  - many reported their improved experience
Leffert Classification

I Open

II Closed (traction)
- A supraclavicular
  - preganglionic: proximal to DRG, avulsion of nerve roots, no proximal stump, no neuroma, pseudomeningocele on CT/MRI, horner’s (T1, ptosis, miosis, anhydrosis)
  - postganglionic: distal to DRG, roots intact, proximal stump, neuroma, no pseudomeningocele
- B infraclavicular
  - usually involves the trunks

C combined

D postanesthetic palsy
- general anesthesia
- regional anesthesia

III Radiation induced

IV Obstetric
- IVA Erb’s (upper roots)
- IVB Klumpke (lower roots)
Brachial Plexus Birth Palsy (BPBP)

- Mechanism is forceful separation of head from the shoulder by lateral flexion of the cervical spine and depression of the shoulder during birth
- Primary risk is macrosomia (caused by maternal diabetes and multiparity)
- Other factors include prolonged gestation, prolonged labor, oxytocin, forceps or suction, maternal birth injuries
- BPBP in an older sibling is best predictor
Figure 165.3. Breech (A) and Vertex births (B), showing wide separation of the head from the downside shoulder.
Diagnosis

- Asymmetric upper extremity motion
- Generally holds shoulder internally rotated, elbow extended and wrist flexed
- Differential includes hemiparesis, septic shoulder, Sprengel’s deformity, clavicle fracture
- Horner’s syndrome and hemidiaphragm paralysis associated and portend worse prognosis
Types

- **Erb’s palsy**
  - Upper trunk (C5-6) often at Erb’s point
  - Most common type

- **Global palsy**
  - Next most common

- **Klumpke’s palsy**
  - Lower trunk (C8-T1)
  - Least common
  - May represent partial recovery from global lesion
Goals

- Prevent contractures during recovery
- Restore neurological function
- Augment muscle weakness
- Limit deformities
Management

- Teach parents PROM shoulder exercises at 3-4 weeks of age
- Follow every 1-2 months using infant active movement scale
- Elbow flexion is best to monitor
  - Easy to follow
  - Antigravity elbow flexion with shoulder abduction at 3 months suggests good prognosis
<table>
<thead>
<tr>
<th>Observation</th>
<th>Muscle grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity eliminated</td>
<td></td>
</tr>
<tr>
<td>No contraction</td>
<td>0</td>
</tr>
<tr>
<td>Contraction, no motion</td>
<td>1</td>
</tr>
<tr>
<td>Motion ≤1/2 range</td>
<td>2</td>
</tr>
<tr>
<td>Motion &gt;1/2 range</td>
<td>3</td>
</tr>
<tr>
<td>Full motion</td>
<td>4</td>
</tr>
<tr>
<td>Against gravity</td>
<td></td>
</tr>
<tr>
<td>Motion ≤1/2 range</td>
<td>5</td>
</tr>
<tr>
<td>Motion &gt;1/2 range</td>
<td>6</td>
</tr>
<tr>
<td>Full motion</td>
<td>7</td>
</tr>
</tbody>
</table>

Surgical Treatment

- Wait until at least 3 months of age
- Poor results for plexus reconstruction after 12 months
- If possible surgical candidate then consider studies:
  - EMG and Nerve conduction to differentiate neuropraxia from axonal degeneration
  - MRI / CT myelogram identify root avulsions
  - All require sedation and myelogram is invasive so only indicated for pre-op planning
Exploration and Repair

- Unique to BPBP
- Neurotization is rarely necessary
  - At least one root is usually available as proximal source of neurons
- Plexus is often shifted distally, changing anatomic relationships
- Clavicular osteotomy usually not necessary
Late Reconstruction

- Unopposed internal rotation leads to deformity and dislocation
- **1925 Sever**
  - Release of Pec Major and Subscap
- **1934 L’Episcopo**
  - Sever plus Teres major tx to proximal humerus to give active ext rot
- **Hoffer**
  - Tx of Lat Dorsi & Teres Maj to Supraspinatis w/ release of Pec Major only
- **Covey**
  - Lat dorsi and Teres major rerouting around proximal humerus
Figure 165.14. Tendon transfer procedure (84). A: Pectoralis major release. B: Teres major and latissimus dorsi, before attachment from humerus. (continued)
Figure 165.14. (continued) C: Teres major and latissimus dorsi, after detachment from humerus. D: Teres major and latissimus dorsi transferred to rotator cuff.
Figure 165.17. Tendon rerouting procedure. A: Latissimus dorsi tendon and teres major tendon pulled through a split in the deltoid. B: Latissimus dorsi tendon and teres major tendon after anastomosis. Reprinted from ref. 39, with permission.
Noncongenital Plexus Lesion

- Most are from motorcycle accidents
- May be open, closed, radiation, etc
Open Injuries

- **Sharp Injuries**
  - may be accompanied by life or limb threatening injuries
    - if present, mandates immediate exploration
    - if not, consider nature of wound
  - sharp instrument, knife or glass
    - assume a division of nerve rather than contusion
    - merits exploration if
      - significant neural deficit w/ expected benefit
      - children; repaired as much as possible; regenerate
  - surgical repair can be done as soon as pt’s condition permits
    - Leffert: within 24 hours

- open wounds of lower trunks
  - worse prognosis, far more vascular injuries
  - expanding aneurysm can cause deficits by compression
Gunshot Wounds

- rarely causes complete palsy
  - if they did, quickly resolve to partial
- concussive effect may deform the nerves
  - temporary disruption
- high-velocity wounds
  - severe stretch - as devastating as transection
- best surgical outcome w/ upper trunk, lateral and posterior cord (Kline)
- conservative treatment advocated
- exploration if
  - no recovery seen within 3 months
  - a major area of neurologic deficit
Iatrogenic Injury - rare

- subclavian lines or arteriography
  - explore as soon as evidence of increasing local or referred pain, or neuro deficit

- operative/sharp injuries
  - immediate repair
  - missed until pt awakened, becomes difficult to distinguish between traction injury
    - latter usually resolves within 6 weeks, observe

- transaxillary 1st rib resection
  - injury to lower trunk - poor prognosis
  - injury to long thoracic nerve - serratus anterior paralysis
Closed Injuries

- Supraclavicular Injuries
  - most from MCA or MVA where head and shoulder are forcibly separated
  - many combination of injury depending on position at time of impact
  - variable clinical pictures of motor and sensory

- Infraclavicular Injuries
  - local compression or traction, often from closed shoulder girdle injuries
  - extent of nerve damage usually less than supraclavicular 2º to limited excursion of soft tissue
  - conservative management
    - unless evidence of transection by sharp bone fragments or vascular
    - explore if no recovery at 3 – 6 months
    - good prognosis
Postoperative Palsy

- following general anesthesia
  - due to positioning on table
  - traction, 1st degree injury/neurapraxia
  - good prognosis, usually recovers in 6 weeks, even with total paralysis within 11 months
  - attention to positioning
    - avoid hyperabduction of arms, excessive lateral flexion of neck; neutral head and neck in lateral decubitus positions

- following regional block
  - persistence of symptoms are rare
  - injury due to use of long-bevel needles, multiple probing
  - intraneuronal hematoma
Radiation Injury

- increasing frequency of radiotherapy for breast cancer
- related to total dose, fractionation schedule, number & extent of fields
- axonal effect of radiation on peripheral nerves
  - from swelling and hyperemia to degeneration and Schwann cell proliferation, progressive scarring and eventual neural elements disappearance
- difficult to distinguish radiation vs recurrent tumor
  - radiation- generalized plexus involvement
  - Horner’s more consistent with neoplastic infiltration
  - CT, MRI, or exploration
- no consensus on treatment
  - simple neurolysis, neurolysis w/ transplantation of omentum, prevention
Burner/Stinger

- stretching injury usually of upper roots (C5, 6)
  - sudden shoulder depression with extension or lateral deviation of neck to contralateral side
  - direct blow to supraclavicular fossa at Erb’s point
  - compression from ipsilateral lateral flexion and hyperextension
- burning pain radiating from shoulder to arm to hand; no pain in the neck, good ROM
- weakness of shoulder abductors, external rotators, biceps
- lasts minutes to months
- study by U.S. Military Academy concluded that injury resulted from compression of fixed plexus between shoulder pad and superior medial scapula into Erb’s point
Level 1- root avulsion, separation of rootlets from spinal cord, can be partial, affecting motor or sensory, or both

Level 2- lesions of the anterior branch of spinal nerves outside the foramina, more common with C5-7; lower trunks due to “scissor effect” between 1st rib and clavicle

Level 3- retroclavicular lesions, almost never involves medial cord

Level 4- distal part of cords

Level 5- lesions of the main nerves
## Combined Evaluation of Sunderland and Millesi

<table>
<thead>
<tr>
<th>Degree</th>
<th>Continuity</th>
<th>Fibrosis</th>
<th>Prognosis</th>
<th>Surgical procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conduction block</td>
<td>None</td>
<td>Spontaneous recovery</td>
<td>None</td>
</tr>
<tr>
<td>1A</td>
<td>Conduction block</td>
<td>Fibrosis of epifascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineuriotomy</td>
</tr>
<tr>
<td>1B</td>
<td>Conduction block</td>
<td>Fibrosis of interfascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineurietomy; interfascicular epineurietomy (for partial lesion)</td>
</tr>
<tr>
<td>2</td>
<td>Axons interrupted</td>
<td>None</td>
<td>Spontaneous recovery</td>
<td>None</td>
</tr>
<tr>
<td>2A</td>
<td>Axons interrupted</td>
<td>Fibrosis of epifascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineuriotomy</td>
</tr>
<tr>
<td>2B</td>
<td>Axons interrupted</td>
<td>Fibrosis of interfascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineurietomy; interfascicular epineurietomy (for partial lesion)</td>
</tr>
<tr>
<td>3a</td>
<td>Axons interrupted; endoneural structures damaged; perineurium intact</td>
<td>None</td>
<td>Partial spontaneous recovery</td>
<td>None</td>
</tr>
<tr>
<td>3A</td>
<td>Axons interrupted; endoneural structures damaged; perineurium intact</td>
<td>Fibrosis of epifascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineuriotomy</td>
</tr>
<tr>
<td>3B</td>
<td>Axons interrupted; endoneural structures damaged; perineurium intact</td>
<td>Fibrosis of interfascicular epineurium</td>
<td>No spontaneous recovery</td>
<td>Epifascicular epineurietomy; interfascicular epineurietomy (for partial lesion)</td>
</tr>
<tr>
<td>3C</td>
<td>Axons interrupted; endoneural structures damaged; perineurium intact</td>
<td>Fibrosis of endoneurium</td>
<td>No spontaneous recovery</td>
<td>Resection plus nerve grafting</td>
</tr>
<tr>
<td>Degree</td>
<td>Continuity&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Fibrosis&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Prognosis</td>
<td>Surgical procedure</td>
</tr>
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</tr>
<tr>
<td>4N</td>
<td>Fascicular structures interrupted; continuity preserved by fibrotic connective tissue with ingrowing neuroma</td>
<td>Continuity preserved by fibrotic connective tissue with (ingrowing neuroma)&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>No useful spontaneous recovery</td>
<td>Resection plus nerve grafting</td>
</tr>
<tr>
<td>4S</td>
<td>Fascicular structures interrupted</td>
<td>Continuity preserved by fibrotic tissue only (no conduction possible)</td>
<td>No spontaneous recovery</td>
<td>Resection plus nerve grafting</td>
</tr>
<tr>
<td>5</td>
<td>Complete loss of continuity</td>
<td>No spontaneous recovery</td>
<td>Nerve grafting; nerve transfer</td>
<td></td>
</tr>
</tbody>
</table>


<sup>b</sup> Extremely rare because with this amount of damage fibrosis will almost always develop.

<sup>c</sup> A few nerve fibers may reach the distal stump and produce some conduction along the damaged segment.
Erb’s Palsy

- neuropraxia of C5, 6; axillary, musculocutaneous, suprascapular nerves affected
- birth injury, violent displacement of head from shoulder, compression
- deficit – deltoid, rotator cuff, elbow flexors, wrist & hand extensors, sensation along outer arm;
- “waiter’s tip” – shoulder add/IR, elbow ext, wrist flex & pronated
80-90% attain normal or near normal function

gentle ROM exercises first 6 months to retain ext. rotation and abduction

follow with EMG

treatments include: nerve grafting, release of contracture, tendon transfer
Klumpke’s Palsy

- neuropraxia of lower roots (C8, T1), ulnar nerve affected
- forceful abduction of shoulder, cervical rib compression, abnormal scalene insertion
- deficit – wrist flexors, intrinsiccs, sensation of medial arm, forearm, hand, triceps reflex
- claw hand, wrist extended
- poorer prognosis than Erb’s
Other Injuries

- **Crutch Palsy**
  improper use of crutches, radial nerve, wrist drop, sensory loss

- **Brachial Neuritis**
  acute severe pain in neck, arm, and hand with variable weakness and sensory deficit; pain is constant and aggravated by arm motion; recovery in weeks to months; treat with rest and analgesic

- **Parsonage-Turner syndrome**
  unknown etiology, may follow immunization or viral illness; pain usually limited to shoulder, variable weakness
Clinical Evaluation

- **CSF**
  - bleeding w/ root avulsion

- **Axon Reflex Testing**
  - **Histamine Flare Test**
    - positive flare/wheal – preganglionic
    - negative flare/wheal – postganglionic
  - **Cold Vasodilation Test**
    - vasodilation – preganglionic
    - no vasodilation – postganglionic

- **Electrodiagnosis**
  - Motor Nerve Conduction & Electromyography
  - Sensory Nerve Conduction
Radiological Exam
- Angiograms – r/o vascular injuries
- Diaphragm – C3,4,5 root avulsions, birth palsy
- CT Myelography – early may show filling defect from intrathecal hematoma; after hematoma resolves either seals dura rent and normalizes exam or creates meningocele. Cord may distort from tethering to meningocele.
- MRI – T2 image may reveal pseudomeningoceles, changes in dura space or cord; best test

Exploration and Intraoperative Electrodiagnosis
- Somatosensory Evoked Potentials
- Evoked Spinal Cord Potentials
- Choline Acetyltransferase activity
  - Hattori & Doi, 2000
  - CAT activity <500cpm – preganglionic, >2000cpm – postganglionic
  - higher activity in motor fascicles, donor nerves resulted in stronger motor recovery of reinnervated muscles
Fig. 59-19  Types of injuries suffered by roots of brachial plexus. (Spinal cord is viewed from posteriorly.) Left. Types of injuries and prognosis in each at postganglionic (infraganglionic) and preganglionic (supraganglionic) levels. Right. Myelographic appearances for various injuries. 1, Normal nerve root. 2. An injury in continuity distal to posterior root ganglion. All axons degenerate; axon reflex tests are negative, and there is no nerve conduction. Some recovery is possible if regenerating axons can penetrate intraneural scar. 3. The same, but there has been disruption of the nerve. Repair is impossible because of extensive intraneural damage; 2 and 3 are distinguishable only by exploration in the posterior triangle of the neck. 4. Recent supraganglionic lesion. Nerve root has been torn out of cord, and there is intrathecal effusion that shows as filling defect in myelogram. Posterior root ganglion cell bodies are intact. Whereas their central connections degenerate (there is no way of demonstrating this), their peripheral axons are intact, as can be shown by axon reflex tests and by nerve conduction. 5. Same, but rent in dura matter has healed and myelographic appearance is normal. 6. If rent in dura does not heal, saccular protrusion forms traumatic meningocele, easily visible in myelogram. Nerve root here is shown as having suffered extensive interstitial damage, sufficient to destroy posterior root ganglion cells. Axon reflex tests and nerve conduction would therefore be negative, suggesting infraganglionic lesion—but for myelographic demonstration of meningocele. 7. Rare distortion of spinal cord, late consequence of supraganglionic rupture of nerve root. (Redrawn from Seddon H: Surgical disorders of the peripheral nerves, Edinburgh, 1972,
<table>
<thead>
<tr>
<th></th>
<th>Preganglionic (Root Avulsion) Injury</th>
<th>Postganglionic Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinel's sign</td>
<td>Present in some cases</td>
<td>Present in C5 and/or C6 nerve injury</td>
</tr>
<tr>
<td>Fractures in transverse process of</td>
<td>Present in most of cases</td>
<td>Absent</td>
</tr>
<tr>
<td>the cervical spine and first rib and</td>
<td></td>
<td></td>
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<tr>
<td>dislocation of the costotransverse</td>
<td></td>
<td></td>
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<tr>
<td>articulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial injury</td>
<td>Present frequently in subclavian arterial injury</td>
<td>Present mostly in axillary arterial injury</td>
</tr>
<tr>
<td>Horner's syndrome</td>
<td>Present in association with T1 root avulsion</td>
<td>Absent or transient</td>
</tr>
<tr>
<td>Denervation in the area of the</td>
<td>Present if detected denervation potentials in the paravertebral muscles</td>
<td>Absent</td>
</tr>
<tr>
<td>posterior ramus of the spinal nerves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axon reflex test by subdermal</td>
<td>Present in the anesthetic skin</td>
<td>Present if a negative response of axon reflex test</td>
</tr>
<tr>
<td>histamine injection</td>
<td></td>
<td>False positive response in some cases</td>
</tr>
<tr>
<td>Sensory nerve evoked potential</td>
<td>Present</td>
<td>Not detected</td>
</tr>
<tr>
<td>recording in the anesthetic skin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervical myelography and CT myelography</td>
<td>Present if dural defect and pseudomeningocele and no rootlets configuration</td>
<td>Normal or slight abnormality of the dura with rootlet configuration in most of cases</td>
</tr>
<tr>
<td>MRI of cervical spine</td>
<td>Dural injury or cerebrospinal fluid outflow from the dura and signal changes in the spinal cord</td>
<td>Signal change in the brachial plexus but no changes in the spinal cord</td>
</tr>
<tr>
<td>Electrodiagnosis during operation to</td>
<td>Absent in the response of somatosensory evoked potentials(SEPs) and evoked spinal cord potentials(ESCPs)</td>
<td>Present in the response of somatosensory evoked potentials(SEPs) and evoked spinal cord potentials(ESCPs)</td>
</tr>
<tr>
<td>explore the brachial plexus</td>
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<td></td>
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<tr>
<td>Histological examination of the</td>
<td>Denervation and decreased acetylcholinesterase activity</td>
<td>Preservation of the axons and good acetylcholinesterase activity</td>
</tr>
<tr>
<td>examined root</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Clinical Evaluation

- all preop exams are indirect and none is totally reliable
- radiologic imaging and EMG delayed for 1 month w/ a totally flail, anesthetic limb
  - 3 weeks for development of fibrillation seen w/ denervation
- Horner’s, severe neuropathic pain, fx’s of clavicle and cervical transverse processes, winged scapula, scapulothoracic dissociation all indicate poorer prognosis
- combination of CT and myelography provided the accuracy of diagnosis to 94.3% (Roger et al, 1988)
- histamine flare test very difficult interpretation
General Consideration of Surgical Treatment

- pt must able to tolerate 8 – 10 hours of general anesthesia
- draping to allow extensile exposure from neck to shoulder girdle, chest, & arm; access to both legs for nerve grafts
- blood available for inadvertent injury to large vessels
- delay of >6 months will diminish chances of functional recovery
- surgical approach
- root avulsion repair not usually done
  - Carlstedt et al 1996, in Stockholm, able to restore continuity between cord and ventral roots, w/ some motor recovery; one pt w/ reimplanted C6,7 had voluntary activity of deltoid, biceps, & triceps at 3 years
Neurolysis

- Used to decompress nerves from internal fibrosis or from surrounding tissue
- Not helpful if nerve is discontinuous
- 3 types
  - Epifascicular epineuretiotom
  - Epifascicular epineuresectomy
  - Interfascicular epineuresectomy
Neurorrhaphy

- Useful in early repair of clean transections (stab injuries)
- Otherwise tension is usually too great to allow this method
End-to-side Coaptation

- End of a denervated nerve is brought in contact with the side of an innervated nerve
- Epineurial window is made
- Neurotization occurs
- Works in small single function nerves
- Allows repair without destroying the donor nerve
Nerve Grafting

- Direct suture repair generally impossible 2° to traction, use of intercalated grafts of autogenous nerve.
- Sural, antebrachial medial cutaneous, superficial radial, lateral femoral cutaneous, saphenous, lateral antebrachial cutaneous, ulnar (w/documentated avulsion of C8 & T1).
- Reconstruct as much as possible when adequate root stock.
- Length of graft should be increased by 15% to allow for shrinkage.
- Free grafting between upper trunk and lateral cord or musculocutaneous → restores elbow flex in 75%; better outcome than any tendon transfer.
- Ulnar n. on sup ulnar collateral a. or Saphenous n. may be used as free microvascular transfer.
- Vascularized nerve grafting – no long term advantage.
Neurotization (nerve transfer)

- Anterior nerves of cervical plexus
- Contralateral C7 may be used
  - Most people can sacrifice w/o detriment
  - Test either intraop or by temporarily placing ligature before surgery
  - Requires one to conciously use non-paralyzed side to move injured side
- Intercostals
  - 1961 by Yeoman & Seddon- 3rd & 4th intercostal to musculocutaneous
  - Initially elbow flexion is synchronous w/ inspiration and involuntarily w/ coughing or sneezing
  - Eventually achieved independent, voluntary elbow flexion
  - II & III may be used directly
  - Others may also be used but usually require grafts
• long thoracic, spinal accessory, intercostals

  • Accessory n., especially after first branch to Trapezius, allows some fxn to remain, also possibility of delayed muscle transfer

  • large series reported by Hentz, Narakas

  • good elbow flexion in more than half of pts

• phrenic nerve

  • 180 pts, by Gu & Ma 1996

  • 84.6% w/ good flexion

  • Not to be combined w/ intercostals
Figure 51-15. This procedure was done in a 17-year-old boy with a total brachial plexus palsy. Only the C-5 nerve root was intact, with connection to the spinal cord, but distal rupture. A combined nerve repair consisted of intercostal neurotization to the median nerve and the ulnar nerve and spinal accessory neurotization to the musculocutaneous nerve. Nerve grafts using two 8-cm medial cutaneous nerves from the forearm were inserted from C-5 to the posterior cord. The shoulder was subsequently fused, and a reinnervated brachioradialis was transferred to the extensor pollicis longus. The patient was reported at 2 year follow-up to be able to flex and extend his elbow as well as his wrist and had side pinch. Protective sensation was said to be present in the hand. (From Kawai et al. 56 with permission.)
Reconstruction of Irreparable Injuries

- no evidence of recovery after 1 – 2 years indicates suboptimal plateau (9 – 12 months for the shoulder)

- prerequisites for peripheral reconstruction
  - joint mobility, adequate soft-tissue cover, absence of edema, & adequate strength and length of donor muscle

- shoulder arthrodesis
  - Leffert – posterior approach, IF w/pelvic recon plates over spine of scapula and acromion down over the prox humerus, long lag screw through glenohumeral joint
  - 20-30 degrees of abduction, 30 degrees of forward flexion, 30-40 degrees of internal rotation
Shoulder Reconstruction

- trapezius for restoration of abduction
  - Aziz et al, transfer of trapezius to prox. humerus, preop avg. abduction 3.5° → 45.4° postop, all subluxation corrected
- loss of muscle in paralysis, not replaced by tendon transfer, not normal strength, mobility and control may be enhanced by multiple transfers
- L’Episcopo procedure
  - insertion of latissmus dorsi & teres major transposed posterolaterally to enhance active lateral rotation
  - Leffert – 70% good result, 30% improved
Restoration of Elbow Flexion

- Tendon transfer more predictable than reconstruction of the plexus

- Prerequisite – functional arc of passive motion in the elbow, >90

- Steindler Flexorplasty
  - Arthur Steindler 1918
  - Flexor-pronator muscles arising from medial epicondyle transposed to a more proximal point on the humerus
  - Active control, useful range against gravity, rarely able to lift >5 lbs
  - Mayer & Green modification – bony fixation to anterior aspect of humerus

- Pectoralis Major Transfer
  - Clark 1954
  - Transfer of the sternocostal portion to be inserted into the biceps tendon at elbow
  - Leffert had better results than with Steindler
- **Latissimus Dorsi Transfer**
  - Schottstaedt et al 1955
  - used less commonly for elbow extension
  - shares same innervation, C5, 6, 7, as flexors; often abnormal; limited ROM & strength; disappointing outcome

- **Triceps Transfer**
  - entire muscle brought forward & attaches to biceps tendon
  - impair crutch walking and getting out of chairs in pts w/ bilateral disease

- **Sternocleidomastoid Transfer**
  - obtain excellent flexion
  - cause web in neck, grotesque manipulation of face and neck to activate transfer

- **Leffert’s preference**
  - pectoral transfer – strongest flexion; Steindler – weaker; triceps transfer – if unilateral & no better alternative
Wrist
- maintain mobility when possible
- arthrodesis if
  - 2 tendons of adequate power not available for flex/ext
  - interferes with reconstruction of a functional hand
  - distal ulna as bone graft across radiocarpal joint
  - iliac graft slotted between radius and bases of 2\textsuperscript{nd} and 3\textsuperscript{rd} metacarpals

Hand
- should be reconstructed before the remainder of the limb
- tendon transfers provide very favorable outcomes, can not achieve similar results with neurologic reconstruction
Figure 2. The initial operative procedure for reconstruction of prehension following complete brachial plexus avulsion is a free-muscle transfer to restore finger extension and elbow flexion simultaneously. Either the gracilis or latissimus dorsi is transferred and is innervated by the spinal accessory nerve. A, Accessory nerve; B, motor branch of the muscle transplant; C, thoracoacromial artery and branches of the cephalic vein; D, nutrient artery and veins of the muscle transplant; E, muscle transplant; F, the brachioradialis and wrist extensors serving as a pulley; G, extensor digitorum communis tendon. (From Doi K, Sakai K, Kuwata N, et al: Double-muscle technique for reconstruction of prehension after complete avulsion of brachial plexus. J Hand Surg Am 20:408, 1995; with permission.)
Figure 3. The second operative procedure for reconstruction of prehension following complete brachial plexus avulsion is a second free-muscle transfer to restore finger flexion. Either the gracilis or latissimus dorsi is transferred and is innervated by the fifth and sixth intercostal nerves. A, The fifth and sixth intercostal nerves; B, motor branch of the muscle transplant; C, thoracodorsal artery and vein; D, nutrient artery and veins of the muscle transplant; E, muscle transplant; F, pronator teres and wrist flexors serving as a pulley; G, long finger flexor tendons. (From Doi K, Sakai K, Kuwata N, et al: Double-muscle technique for reconstruction of prehension after complete avulsion of brachial plexus. J Hand Surg Am 20:408, 1995; with permission.)
Figure 4. Nerve-crossing of the third and fourth intercostal nerves to the motor branch of the triceps brachi muscle to restore elbow extension and stabilization following complete brachial plexus avulsion. A, The third and fourth intercostal nerves; B, motor branch of the triceps brachi muscle; C, triceps brachi muscle. (From Doi K, Sakai K, Kuwata N, et al: Double-muscle technique for reconstruction of prehension after complete avulsion of brachial plexus. J Hand Surg Am 20:408, 1995; with permission.)
Acromioclavicular injuries

- Anatomy
  - Acromioclavicular ligaments - minimal coronal plane stability; significant stabilizers in AP direction
  - Coracoclavicular ligaments
    - Trapezoid laterally, conoid medially
    - Primary Sup-Inf restraints
  - Deltoid and trapezius muscles also assist with stabilization
Types of AC injuries

- I
  - Sprain of AC ligament, CC intact
  - Joint intact

- II
  - AC joint/ligaments disrupted
  - Minimal bony movement
  - CC ligaments sprained
Cont

- **III**
  - AC joint dislocated
  - AC and CC ligaments disrupted
  - Deltoid and Trapezius usually detached from distal clavical
  - CC space increased by 25-100%
  - Variants include: Coracoid fx, physeal injury

- **IV**
  - Like III except clavicle displaced posteriorly into or trapezius
Cont

V

- Like III/IV except
- Large disparity between clavicle and scapula
  - 100% to 300%
- Deltoid and Trapezius detached from distal ½ of clavicle

VI

- Rare (some say theoretical only)
- CC ligaments disrupted in subcoracoid and intact in subacromial
- Clavicle inferior to Acromion or coracoid
Studies

- AP and axillary of shoulder
- Zanca (AP w/ 10 deg Cephalad tilt)
- Styker notch view (AP w/ 10 Cephalad tilt and Humerus flexed to 120 deg)
- Stress views
Treatment

- I and II
  - Always non-op acutely
  - Occasionally may require late procedure including meniscal debridement, mumford, or AC reconstruction

- III
  - Acute-mainly conservative- 1-2 weeks of sling, NSAIDs, early motion
  - Operative AC joint fixation/repair, CC fixation, or weaver/dunn
Treatment

- IV and V
  - Open vs. Closed reduction
  - Surgical treatment as for III’s

- VI
  - Open reduction
  - Repair and fixation and/or ligament transfer
Chronic injuries

- Pain is generally treated with distal clavicle excision—either open or arthoscopic.
- Instability is usually treated with Weaver-Dunn procedure (transfer of CA ligament from acromion to clavicle).
- Use both if have pain and instability.
Sternoclavicular Injuries

- **Joint Anatomy**
  - Intra-articular disc
  - Anterior and Posterior sternoclavicular ligaments
  - Interclavicular ligament
  - Costoclavicular ligament

- **Underlying structures**
Figure 21A1–3. The sternoclavicular joint is stabilized by the interclavicular ligament, the anterior and posterior capsular structures, the costoclavicular ligaments, and the intra-articular disc. Ant., anterior; lig., ligament.
Physeal fractures

- Medial clavicular physis does not fuse until 23 - 25 years (incomplete union has been seen at 31 years)
- Many sternoclavicular dislocations may be fractures through the physis up to late twenties
Mechanism

- Anterior Dislocation
  - Posteriorly directed blow to shoulder

- Posterior Dislocation
  - Direct blow
  - Anteriorly directed blow to shoulder
Serendipity View

- 40 deg cephalic tilt
- Pt supine
- Adults tube is 60” from sternum
- Children 45” from sternum
- Set as for CXR
Treatment

- **Anterior**
  - Shoulder retraction and direct pressure
  - Immobilize in Figure of eight or sling at least 6 weeks
  - Can consider Fixation if very unstable

- **Posterior**
  - High incidence of injury to important structures
  - Contact consultant before undertaking reduction if suspect complication
  - Abduction traction
  - Adduction traction
  - Sterile towel clip
  - Figure of eight for 4-6 weeks
Operative

- Open reduction with care to preserve anterior capsule
- Resection of medial 1-1½ inches
- Ligamentous reconstruction
THE END
**Law of Seven Seventies (Narakas)**

- 70% traumatic lesions due to traffic accidents
- 70% traffic accidents involve a cycle or motorcycle
- 70% of these pts have multiple injuries
- 70% supraclavicular injuries
- 70% of pts w/ supraclavicular lesions will have one or several roots avulsed from the spinal cord
- 70% of pts w/ root avulsions will have lower roots C7, C8, or T1 avulsed
- 70% of pts w/ lower root avulsion will have persistent pain
Experience at the Buncke Clinic
Apr. 2002, Microsurgery

- comparable functional outcome
- older pts w/ traumatic plexus injuries
- use 2-3 intercostals as motor input
- split the spinal accessory to harvest the branch to vertical element of trapezius; preserve horizontal function for movement of shoulder girdle
- intercostals not used if pt has had injury to phrenic nerve, to avoid ventilation problems
- trapezius transfer to deltoid for shoulder abduction, instead of shoulder fusion
  - retain supple, movable joint
  - more comfortable
  - transfer can be reversed
Shoulder fusion and free-functioning gracilis transplantation in patients with elbow and shoulder paralysis caused by poliomyelitis
Baliarsing, Doi, & Hattori, Oct. 2002
J. Hand Surgery

- case study of a child with bilateral birth palsy involving C5 & C6 nerve roots
- shoulder abduction, elbow extension, wrist & finger movements recovered by 1 year of age; elbow flexion did not recover
- free gracilis transfers at 20 months & 28 months
- gracilis placed anterior to deltoid & upper arm, tendon sutured to radial tuberosity, origin sutured to acromion;
- thoracoacromial art., cephalic vein, spinal accessory nerve;
- reinnervation at 3 months on EMG, visible contractions at 4 months, active flexion at 10 months
Doi, Jan 1997, Clinics in Plastic Surgery

- double free muscle transfer (on 24 patients)
  1) free muscle (contralateral gracillis) transfer, neurotized by spinal accessory, for elbow flexion & finger extension
  2) 2nd free muscle transfer, neurotized by 5th & 6th intercostal nerves, for finger flexion, 2 - 3 months after 1st transfer
  3) nerve crossing procedure, 3rd & 4th intercostals to neurotize motor branch to triceps, elbow extension
  4) nerve crossing procedure, supraclavicular or intercostal sensory rami to median nerve, restore sensibility to hand
  5) arthrodesis of glenohumeral joint to increase stability

- results
  - all flaps survived
  - reinnervation of transferred muscles detected on EMG between 3-6 months (avg 3 months for spinal accessory, 4.5 for intercostals)
  - voluntary contraction 2 months later
  - elbow AROM varied from 15 - 120º, flexion power 3-5, extension power 2-3
  - finger AROM varied from 40 - 110º, flex power 2-5
  - sensory restoration in hand was variable
Obstetric/Birth Palsy

- traction, fetal malposition, cephalopelvic disproportion, use of forceps
- asymmetric active upper limbs or clavicle fx
- contracture (supination) & bony deformities (elbow region/post subluxation of radial head)
- historically treated conservatively
- Gilbert 1977 – 1982
  - operated on 100 neonates
  - paralyzed biceps at 3 months – indication for surgery
  - explored each root individually, if 3 intact roots are available, entire plexus is repaired; preference to musculocutaneous, suprascapular, & median nerves
  - favorable outcome when compared to control/untreated group
  - Hentz & Meyer in 1991 – similar conclusions
- L’Episcopo & rotational osteotomy of humerus for late reconstruction