Brachial Plexus Injuries and Shoulder Girdle Injuries

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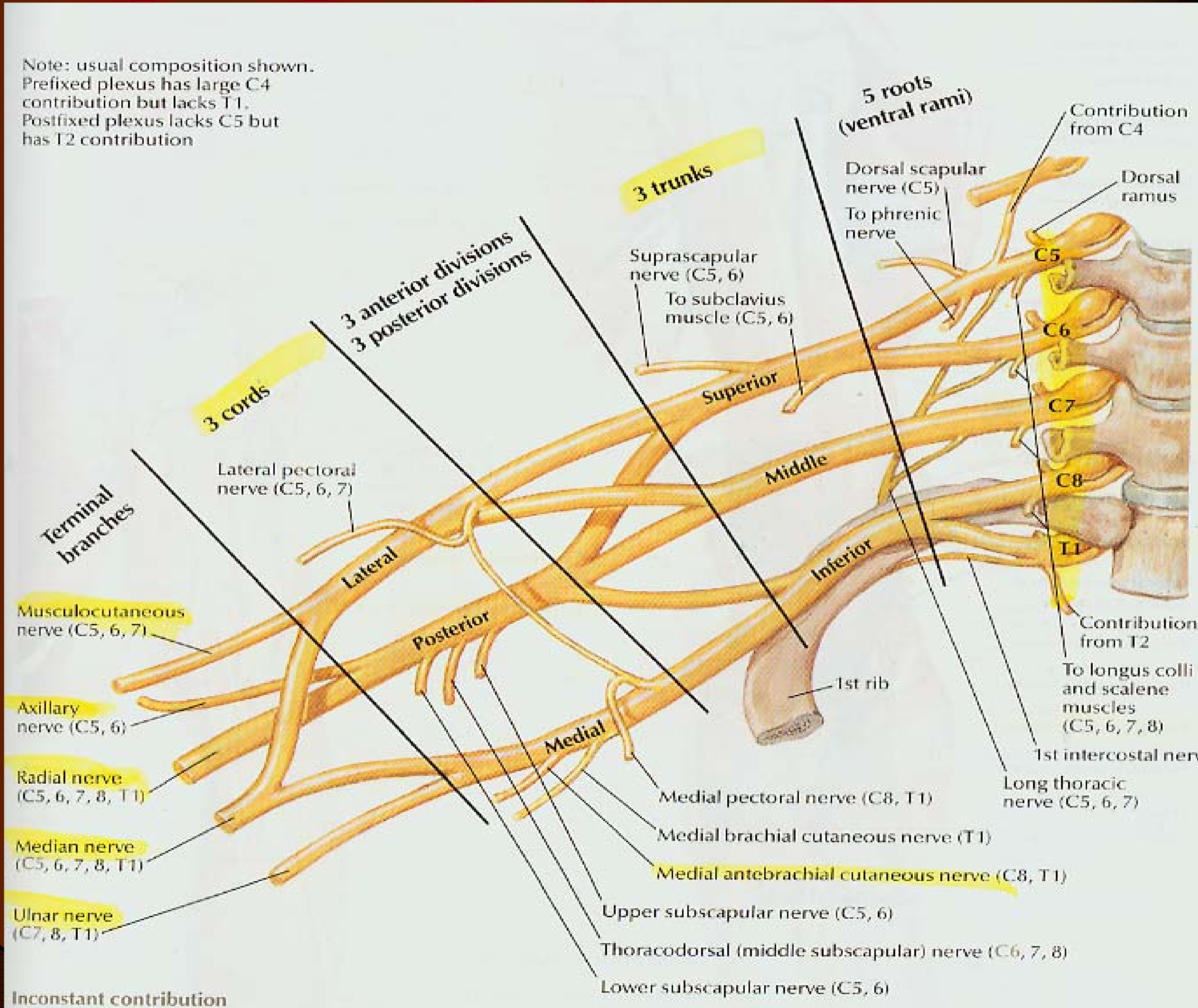
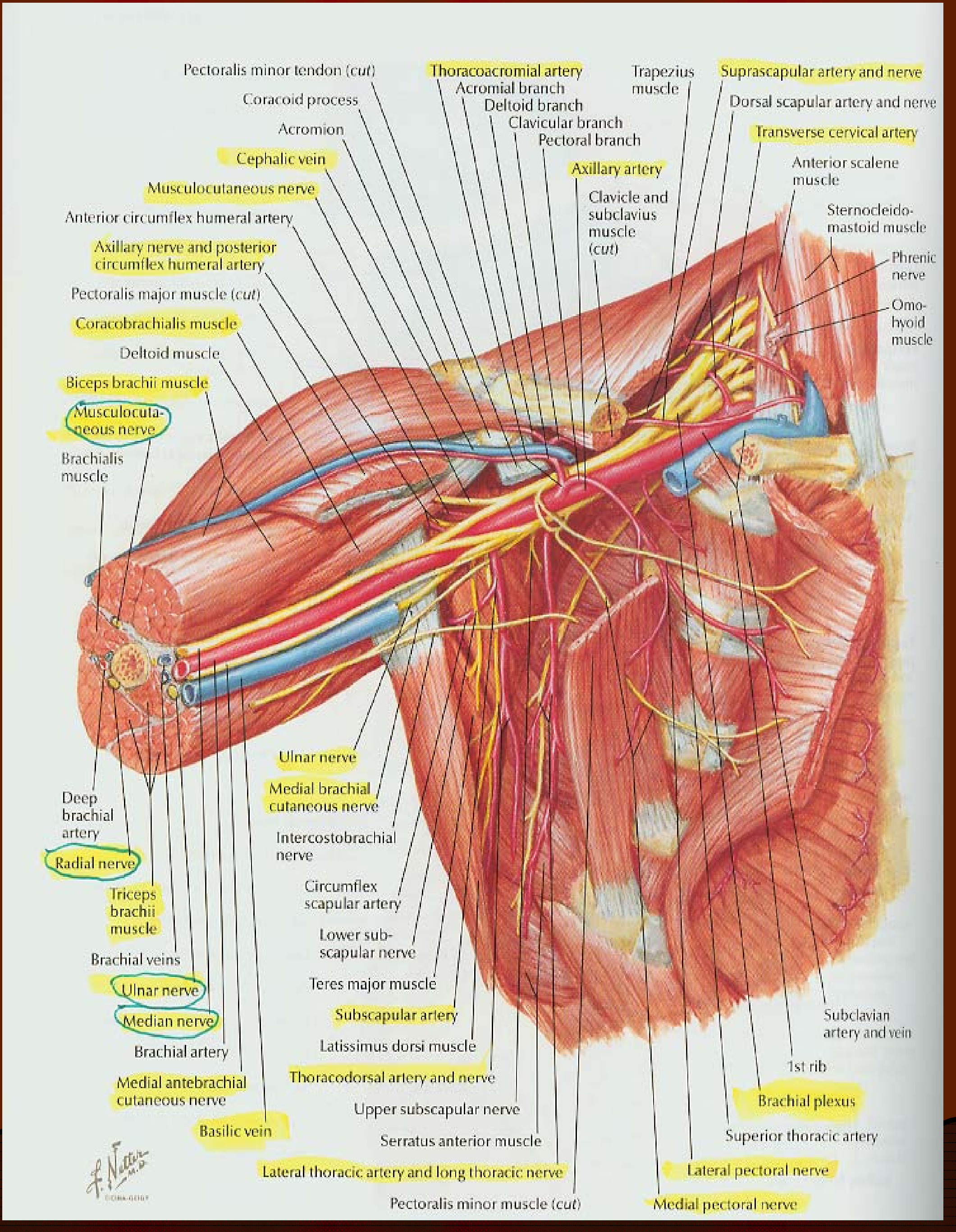
Overview

- 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%
- postfixed 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
5 roots (ventral rami)
Contribution from C4
Dorsal scapular nerve (C5)
Dorsal ramus
To phrenic nerve
3 trunks
Suprascapular nerve (C5, 6)
To subclavius muscle (C5, 6)
3 anterior divisions
3 posterior divisions
3 cords
C5
C6
C7
C8
T1
Superior
Middle
Inferior
Lateral pectoral nerve (C5, 6, 7)
Terminal branches
Lateral
Posterior
Medial
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)
1st rib
Contribution from T2
To longus colli and scalene muscles (C5, 6, 7, 8)
1st intercostal nerve
Long thoracic nerve (C5, 6, 7)
Medial pectoral nerve (C8, T1)
Medial brachial cutaneous nerve (T1)
Medial antebrachial cutaneous nerve (C8, T1)
Upper subscapular nerve (C5, 6)
Thoracodorsal (middle subscapular) nerve (C6, 7, 8)
Lower subscapular nerve (C5, 6)
Inconstant contribution



Pectoralis minor tendon (cut)
Coracoid process
Acromion
Cephalic vein
Musculocutaneous nerve
Anterior circumflex humeral artery
Axillary nerve and posterior circumflex humeral artery
Pectoralis major muscle (cut)
Coracobrachialis muscle
Deltoid muscle
Biceps brachii muscle
Musculocutaneous nerve
Brachialis muscle
Deep brachial artery
Radial nerve
Triceps brachii muscle
Brachial veins
Ulnar nerve
Median nerve
Brachial artery
Medial antebrachial cutaneous nerve
Basilic vein
Thoracoacromial artery
Acromial branch
Deltoid branch
Clavicular branch
Pectoral branch
Trapezius muscle
Axillary artery
Clavicle and subclavius muscle (cut)
Suprascapular artery and nerve
Dorsal scapular artery and nerve
Transverse cervical artery
Anterior scalene muscle
Sternocleido-mastoid muscle
Phrenic nerve
Omo-hyoid muscle
Ulnar nerve
Medial brachial cutaneous nerve
Intercostobrachial nerve
Circumflex scapular artery
Lower sub-scapular nerve
Teres major muscle
Subscapular artery
Latissimus dorsi muscle
Thoracodorsal artery and nerve
Upper subscapular nerve
Serratus anterior muscle
Lateral thoracic artery and long thoracic nerve
Pectoralis minor muscle (cut)
Subclavian artery and vein
1st rib
Brachial plexus
Superior thoracic artery
Lateral pectoral nerve
Medial pectoral nerve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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, Schann cell, endoneurium completely disrupted; perineurium and epineurium disrupted to varying degrees

Table 59-1 Classification of Nerve Injuries

Degree of Injury		Histopathological Changes: Myelin	Axon	Endoneurium	Perineurium	Epineurium	Tinel Sign: Present	Progresses Distally
Sunderland	Seddon							
I	Neurapraxia	+/–					–	–
II	Axonotmesis	+	+				+	+
III		+	+	+			+	+
IV		+	+	+	+		+	–
V	Neurotmesis	+	+	+	+	+	+	–

Repair

- Endoneurolysis
  - Epineurium is incised only in area of lesion
  - Flaps of epineurium are undermined
  - Funiculi are separated w/ care to protect interfascicular plexus
- Partial Neurorrhaphy
  - Partially damaged nerve
  - Only large nerves
- Neurorhaphy
  - Epineurial neurorrhaphy
  - Perineurial neurorrhaphy
  - Nerve grafting

Neurorrhaphy

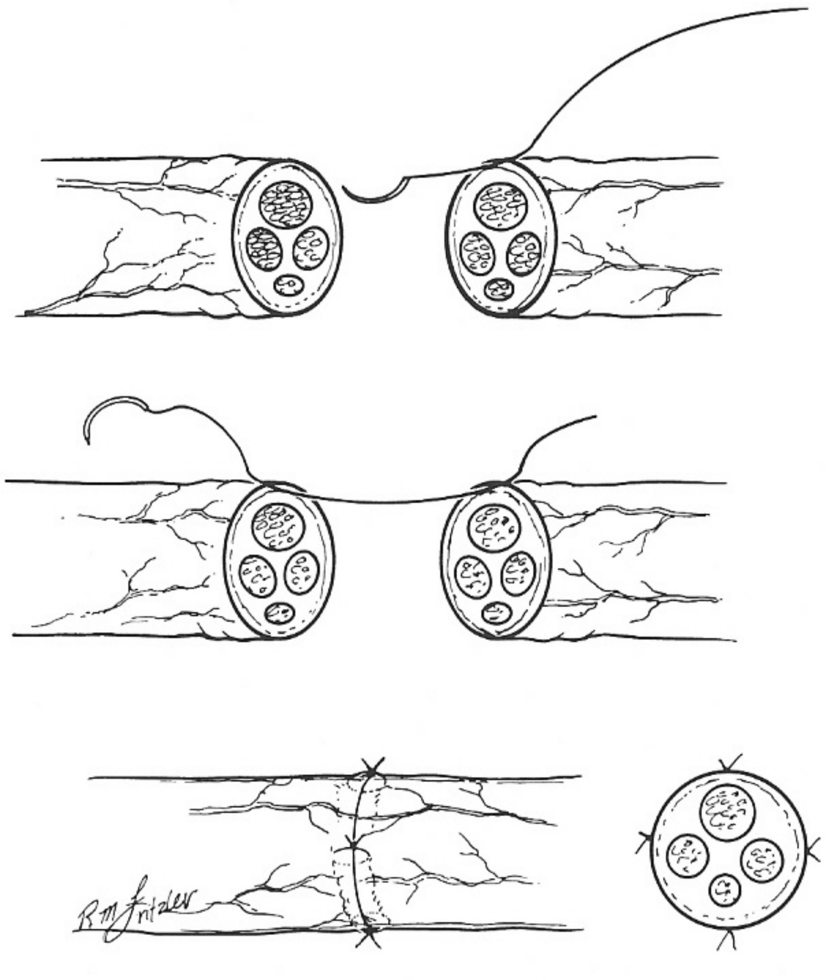


Fig. 59-13 Epineurial neurorrhaphy (see text).

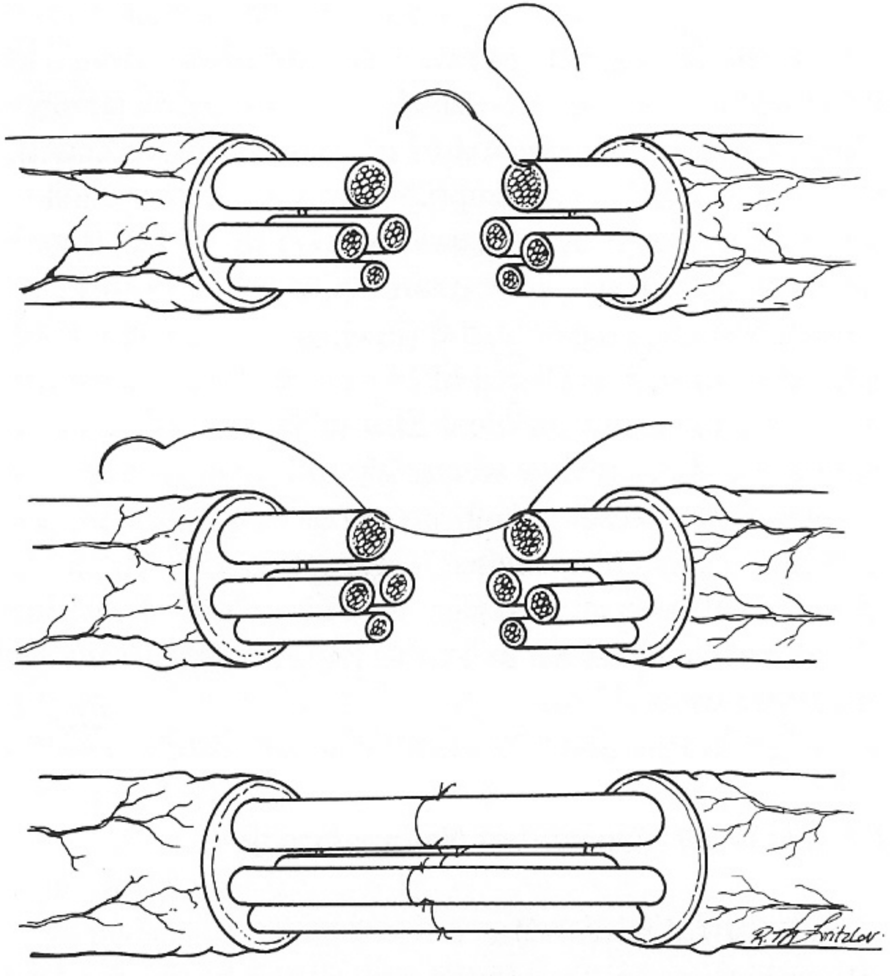


Fig. 59-14 Perineurial (fascicular) neurorrhaphy (see text).

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 and older sibling is best predictor

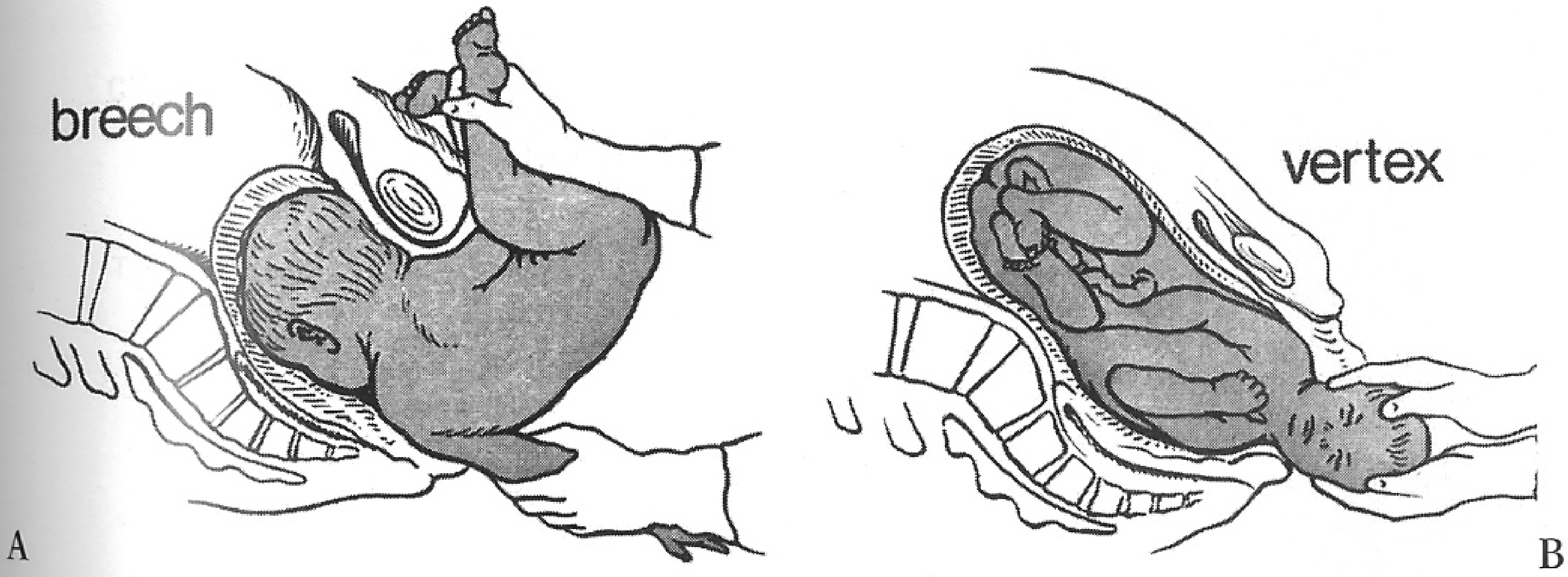
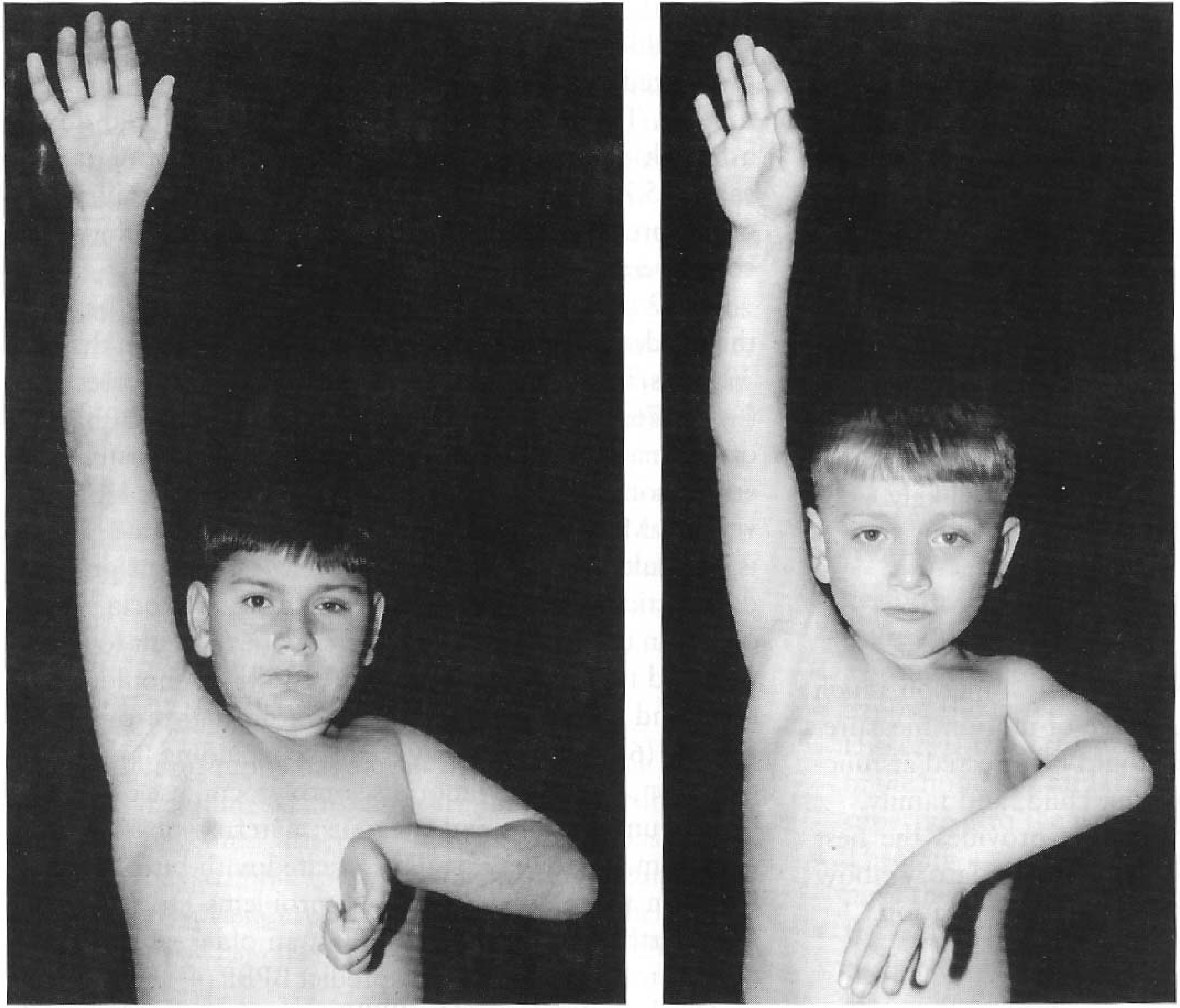


Figure 165.3. Breech (**A**) and Vertex births (**B**), showing wide separation of the head from the downside shoulder.

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



A B

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 excercises 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 165.1. Infant Active Movement Scale

Observation	*Muscle grade*
Gravity eliminated	
No contraction	0
Contraction, no motion	1
Motion ≤1/2 range	2
Motion >1/2 range	3
Full motion	4
Against gravity	
Motion ≤1/2 range	5
Motion >1/2 range	6
Full motion	7

From Clarke HM, Curtis CG. An Approach to Obstetrical Brachial Plexus Injuries. *Hand Clin* 1995;11:563, with permission.

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

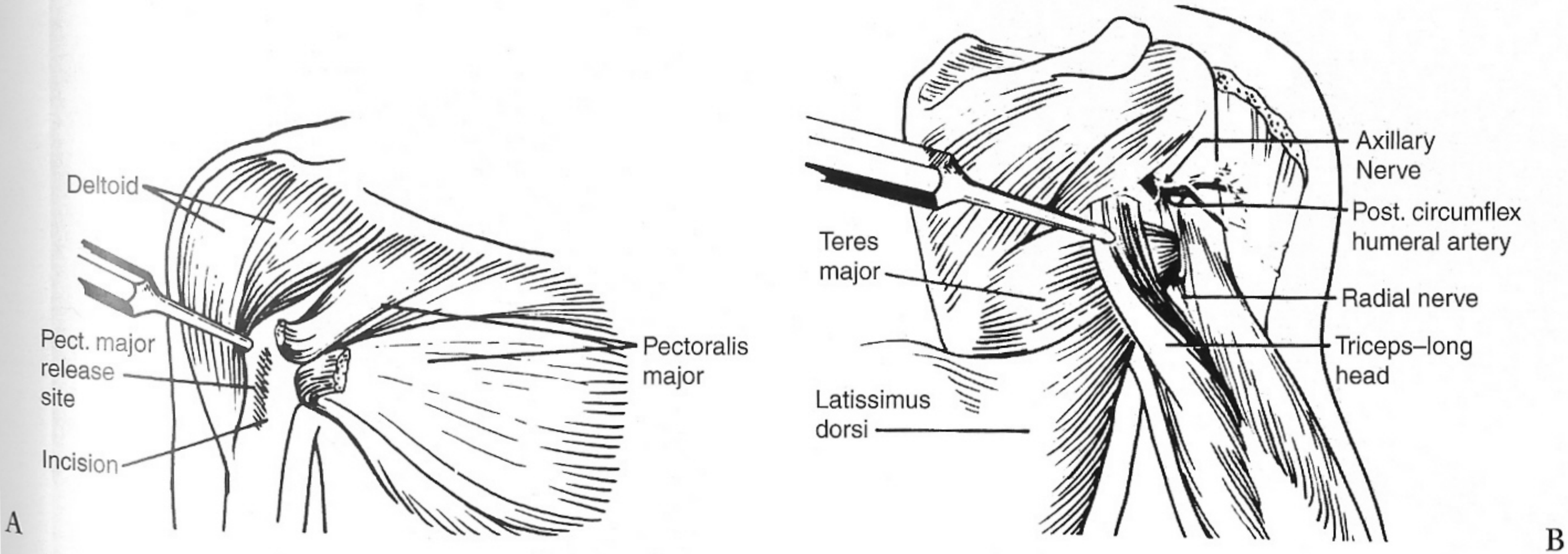


Figure 165.14. Tendon transfer procedure (84). **A:** Pectoralis major release. **B:** Teres major and latissimus dorsi, before attachment from humerus. *(continued)*

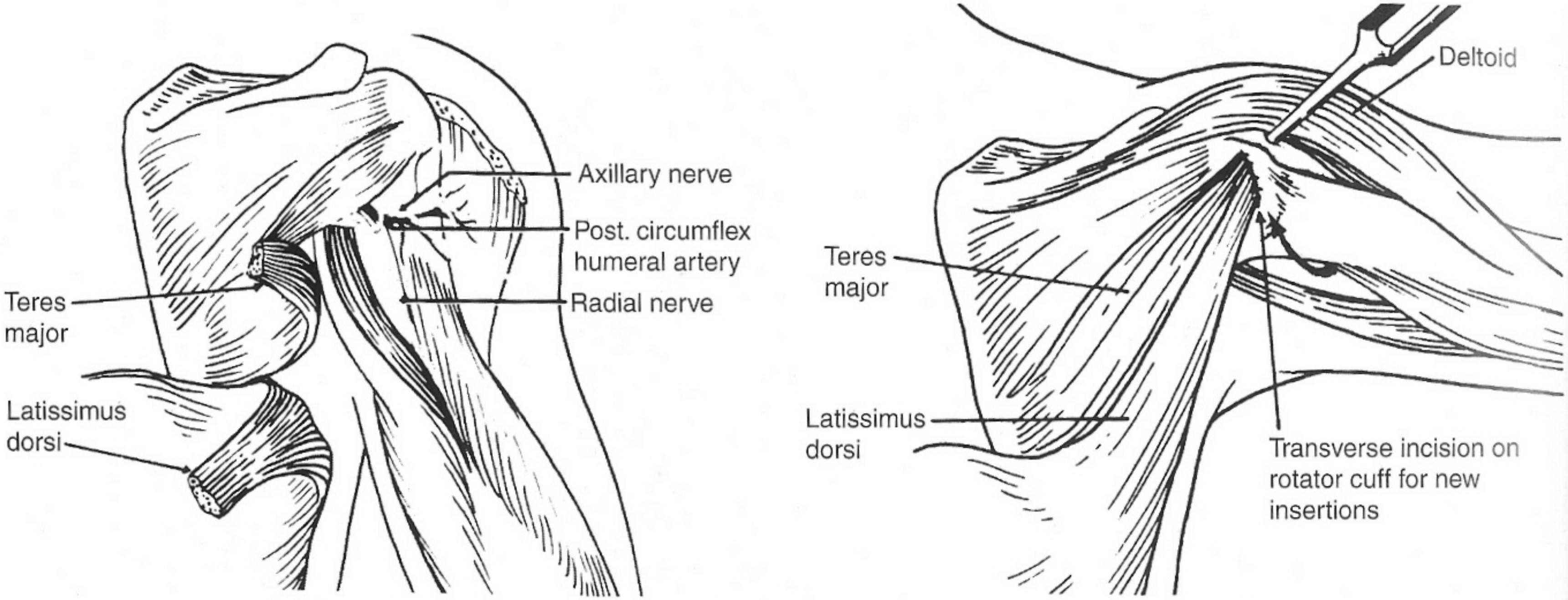
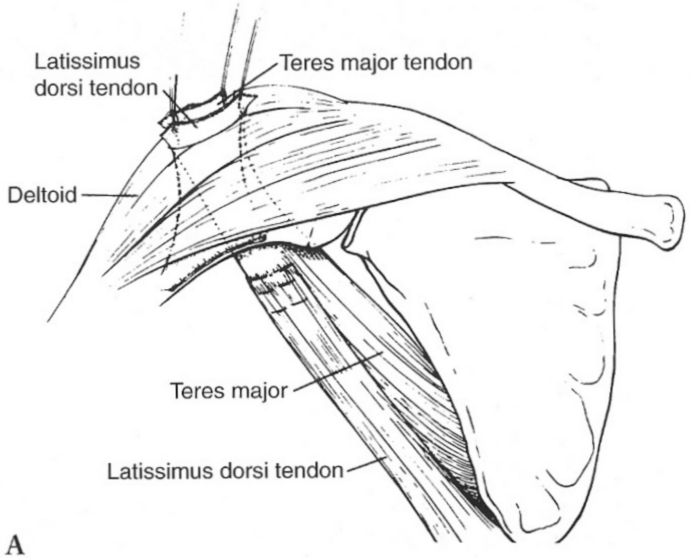


Figure 165.14. *(continued)* C: Teres major and latissimus dorsi, after detachment from humerus. D: Teres major and latissimus dorsi transferred to rotator cuff.



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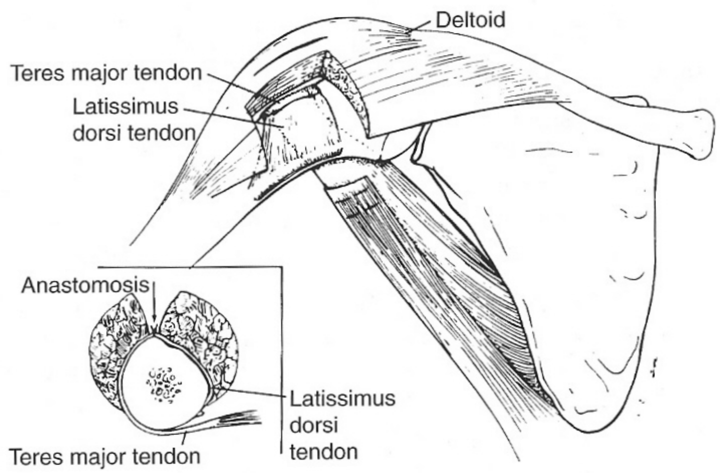


B

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

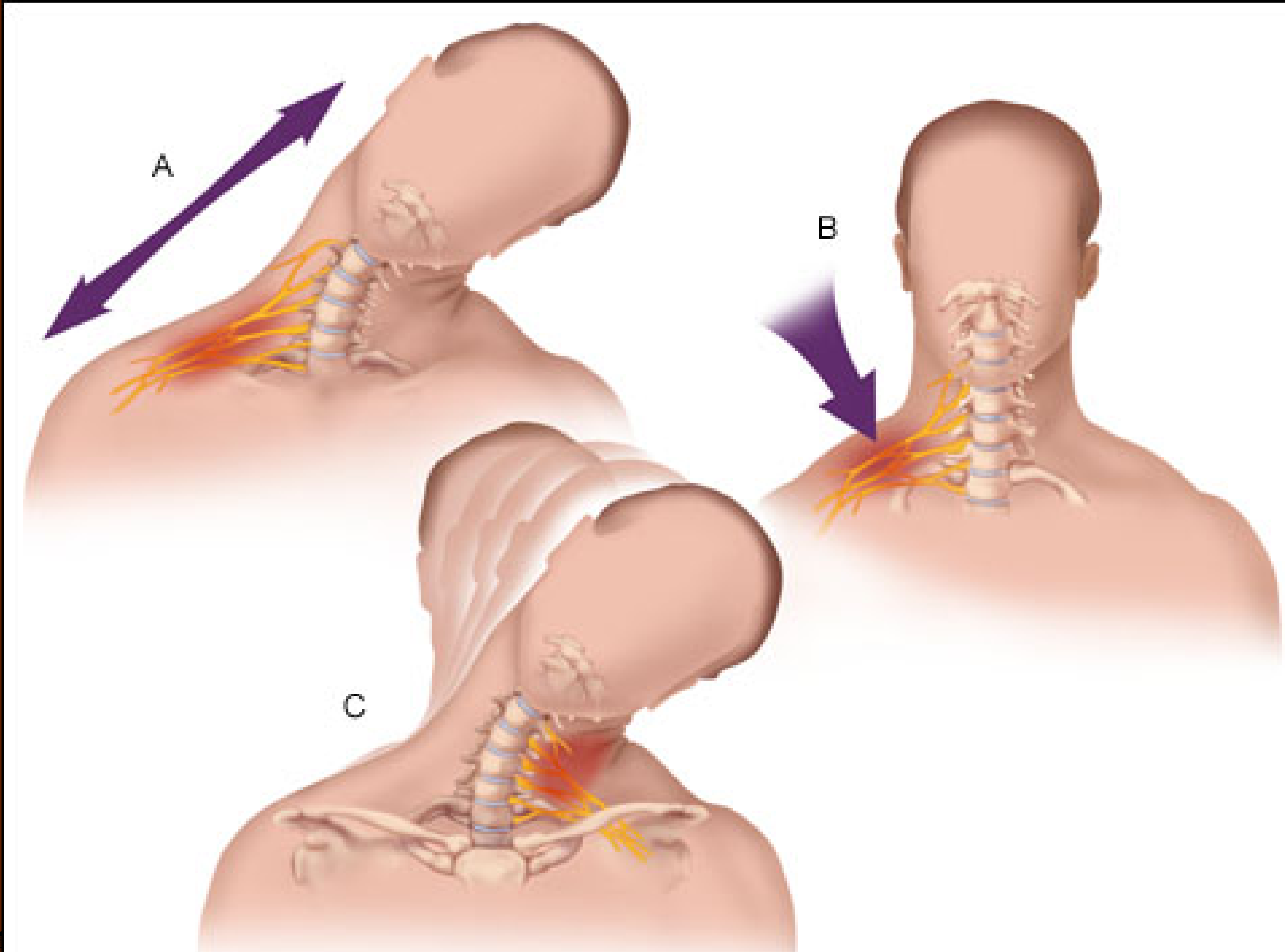
- following general anesthesia
  - due to positioning on table
  - traction, 1st degree injury/neurapraxia
  - good prognosis, usually recovers in 6 weeks, even w/ total paralysis within 11 months
  - attention to positioning
    - avoid hyperabduction of arms, excessive lateral flexion of neck; neutral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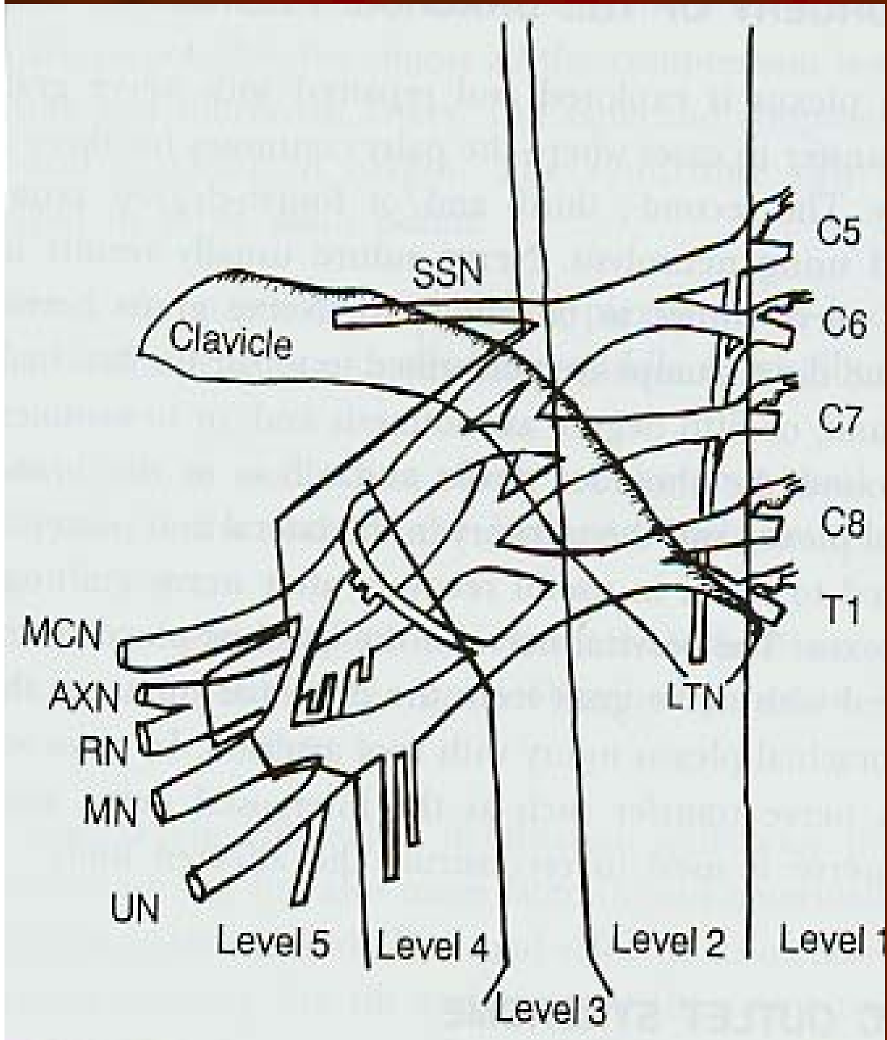
Location of Lesions



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 60.7. Combined Evaluation System for Extent of Brachial Plexus Injuries

Degree	*Continuity*[a]	*Fibrosis*[a]	*Prognosis*	*Surgical procedure*
1	Conduction block	None	Spontaneous recovery	None
1A	Conduction block	Fibrosis of epifascicular epineurium	No spontaneous recovery	Epifascicular epineuriotomy
1B	Conduction block	Fibrosis of interfascicular epineurium	No spontaneous recovery	Epifascicular epineuriectomy; interfascicular epineuriectomy (for partial lesion)
2	Axons interrupted	None	Spontaneous recovery	None
2A	Axons interrupted	Fibrosis of epifascicular epineurium	No spontaneous recovery	Epifascicular epineuriotomy
2B	Axons interrupted	Fibrosis of interfascicular epineurium	No spontaneous recovery	Epifascicular epineuriectomy; interfascicular epineuriectomy (for partial lesion)
3[b]	Axons interrupted; endoneural structures damaged; perineurium intact	None	Partial spontaneous recovery	None
3A	Axons interrupted; endoneural structures damaged; perineurium intact	Fibrosis of epifascicular epineurium	No spontaneous recovery	Epifascicular epineuriotomy
3B	Axons interrupted; endoneural structures damaged; perineurium intact	Fibrosis of interfascicular epineurium	No spontaneous recovery	Epifascicular epineuriectomy; interfascicular epineuriectomy (for partial lesion)
3C	Axons interrupted; endoneural structures damaged; perineurium intact	Fibrosis of endoneurium	No spontaneous recovery	Resection plus nerve grafting

Table 60.7. (continued)

Degree	*Continuity*[a]	*Fibrosis*[a]	*Prognosis*	*Surgical procedure*
4N	Fascicular structures interrupted; continuity preserved by fibrotic connective tissue with ingrowing neuroma	Continuity preserved by fibrotic connective tissue with (ingrowing neuroma)[b,c]	No useful spontaneous recovery	Resection plus nerve grafting
4S	Fascicular structures interrupted	Continuity preserved by fibrotic tissue only (no conduction possible)	No spontaneous recovery	Resection plus nerve grafting
5	Complete loss of continuity		No spontaneous recovery	Nerve grafting; nerve transfer

[a] Continuity rating from Sunderland S. A Classification of Peripheral Nerve Injuries Producing Loss of Function. *Brain* 1951;74:491. Fibrosis rating from Millesi H. Eingriffe an peripheren Nerven. In: Gschnitzer F, Kern E, Schwelberer L, (eds). *Chirurgische Operationslehre*. Baltimore Urban & Schwarzenberg, 1986.

[b] Extremely rare because with this amount of damage fibrosis will almost always develop.

[c] 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, intrinsics, 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 AcetylTranferase 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

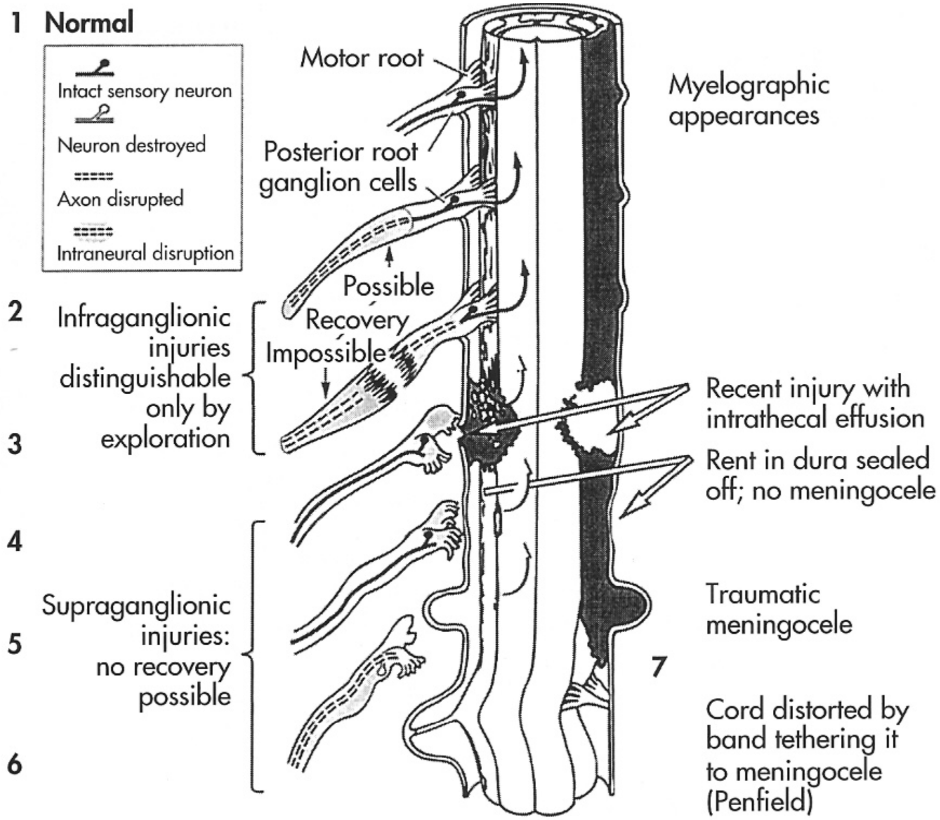


Fig. 59-19 Types of injuries suffered by roots of brachial plexus. (Spinal cord is viewed from posteriorly.) *Left,* Types of injuries and prognosis in each at postganglionic (infraganglionic) and preganglionic (supraganglionic) levels. *Right,* Myelographic appearances for various injuries. *1,* Normal 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 4.2 Differential Diagnosis between Preganglionic (Root Avulsion) and Postganglionic Injuries of the Brachial Plexus

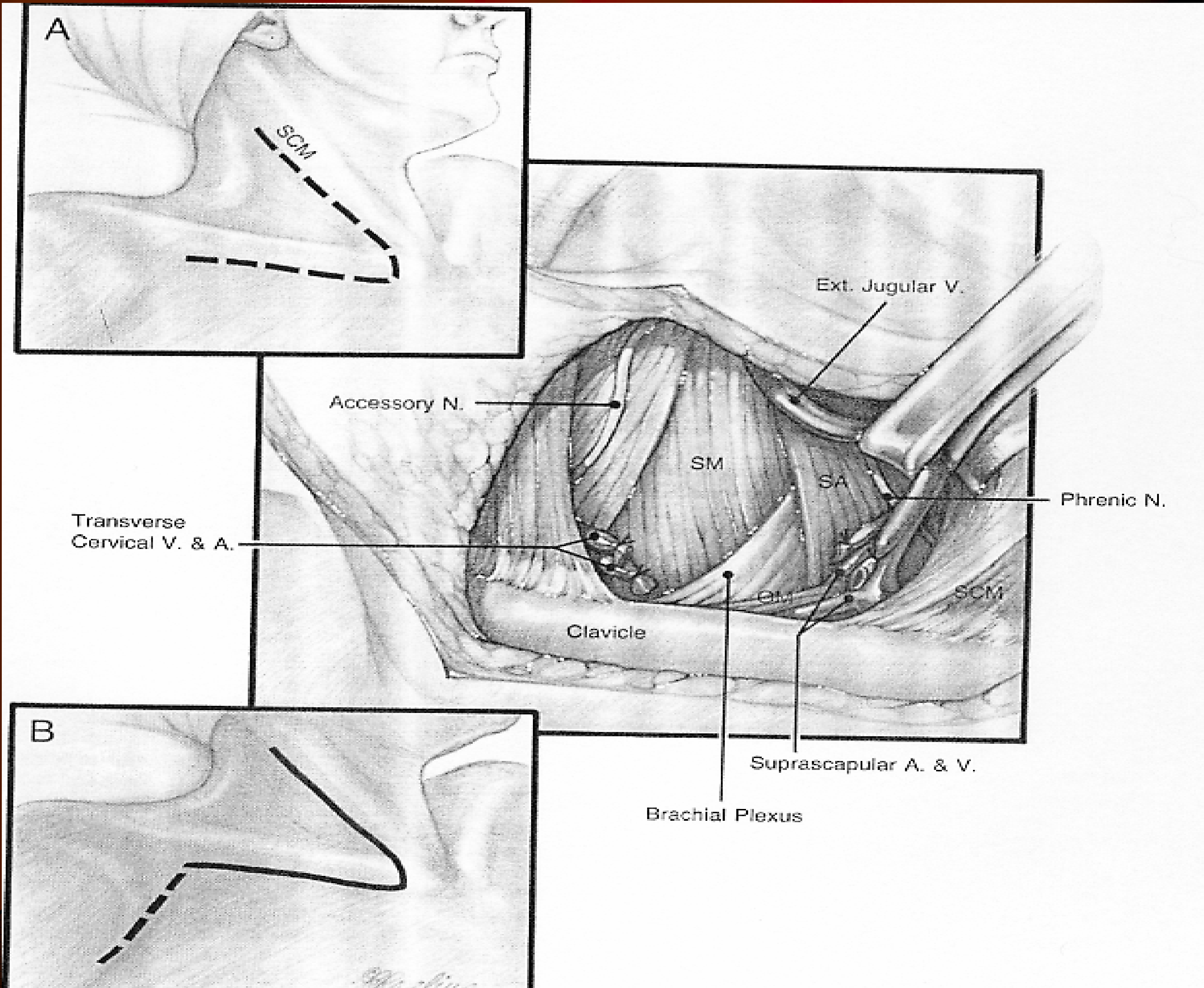
	Preganglionic (Root Avulsion) Injury	Postganglionic Injury
Tinel's sign	Present in some cases	Present in C5 and/or C6 nerve injury
Fractures in transverse process of the cervical spine and first rib and dislocation of the costotransverse articulation	Present in most of cases	Absent
Arterial injury	Present frequently in subclavian arterial injury	Present mostly in axillary arterial injury
Horner's syndrome	Present in association with T1 root avulsion	Absent or transient
Denervation in the area of the posterior ramus of the spinal nerves	Present if detected denervation potentials in the paravertebral muscles	Absent
Axon reflex test by subdermal histamine injection	Present in the anesthetic skin	Presént if a negative response of axon reflex test False positive response in some cases
Sensory nerve evoked potential recording in the anesthetic skin	Present	Not detected
Cervical myelography and CT myelography	Present if dural defect and pseudomeningocele and no rootlets configuration	Normal or slight abnormality of the dura with rootlet configuration in most of cases
MRI of cervical spine	Dural injury or cerebrospinal fluid outflow from the dura and signal changes in the spinal cord	Signal change in the brachial plexus but no changes in the spinal cord
Electrodiagnosis during operation to explore the brachial plexus	Absent in the response of somatosensory evoked potentials(SEPs) and evoked spinal cord potentials(ESCPs)	Present in the response of somatosensory evoked potentials(SEPs) and evoked spinal cord potentials(ESCPs)
Histological examination of the examined root	Denervation and decreased acetylcholinesterase activity	Preservation of the axons and good acetylcholinesterase activity

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


A
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Ext. Jugular V.
Accessory N.
SM
SA
Phrenic N.
Transverse
Cervical V. & A.
OM
SCM
Clavicle
Suprascapular A. & V.
Brachial Plexus
B

Neurolysis

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

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 2º to traction, use of intercalated grafts of autogenous nerve
- sural, antebrachial medial cutaneous, superficial radial, lateral femoral cutaneous, saphenous, lateral antebrachial cutaneous, ulnar (w/documented 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

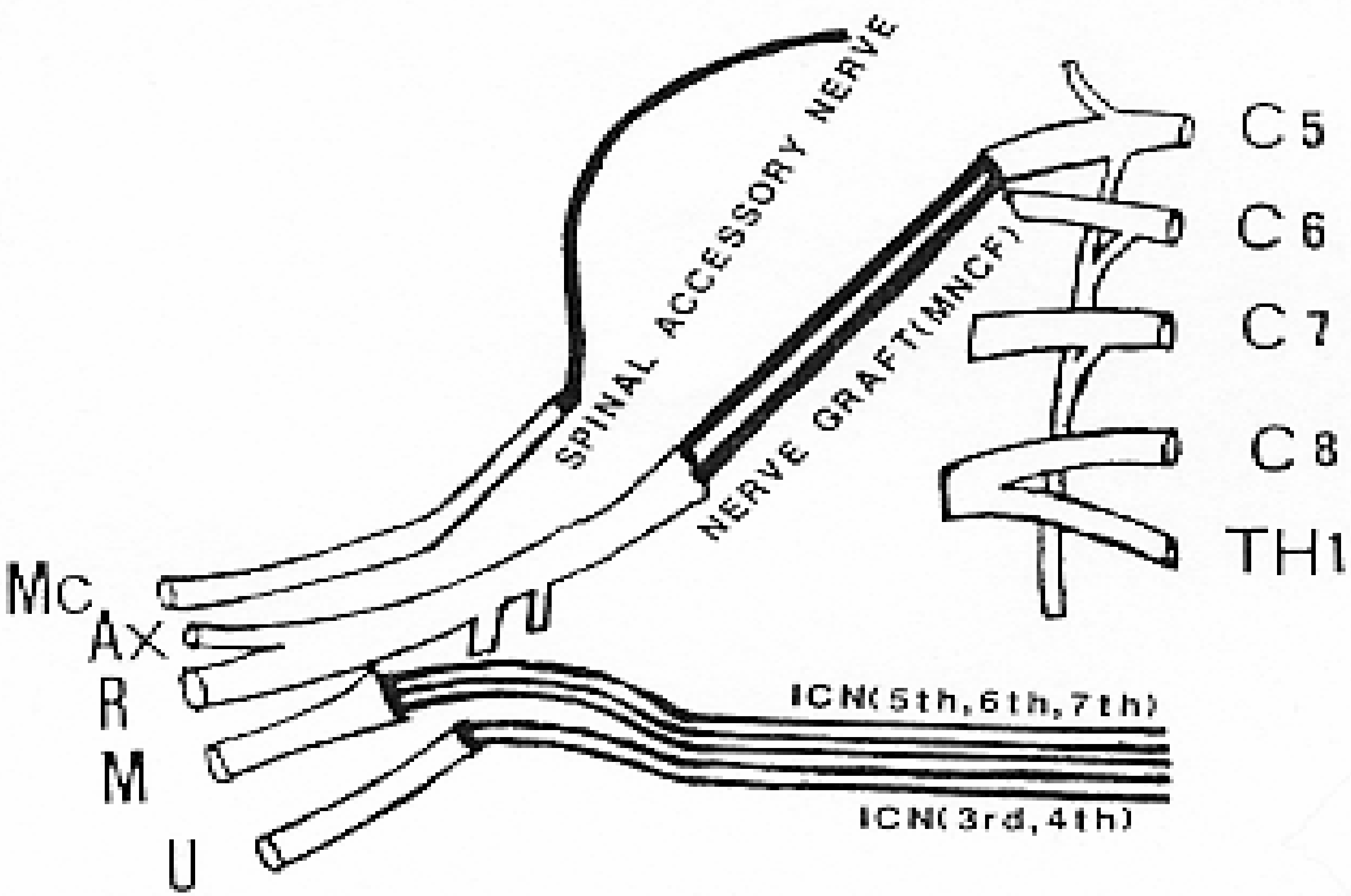


Figure 51–15. This procedure was done in a 17-year-old boy with a total brachial plexus palsy. Only the C-5 nerve root was intact, with connection to the spinal cord, but distal rupture. A combined nerve repair consisted of intercostal neurotization to the median nerve and the ulnar nerve and spinal 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.[96] with permission.)

Reconstruction of Irreparable Injuries

- no evidence of recovery after 1 – 2 years indicates suboptimal plateau (9 – 12 months for the shoulder)
- prerequistes 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 3.5º → 45.4º 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
- prerequiste – 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 w/ 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 2nd and 3rd 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

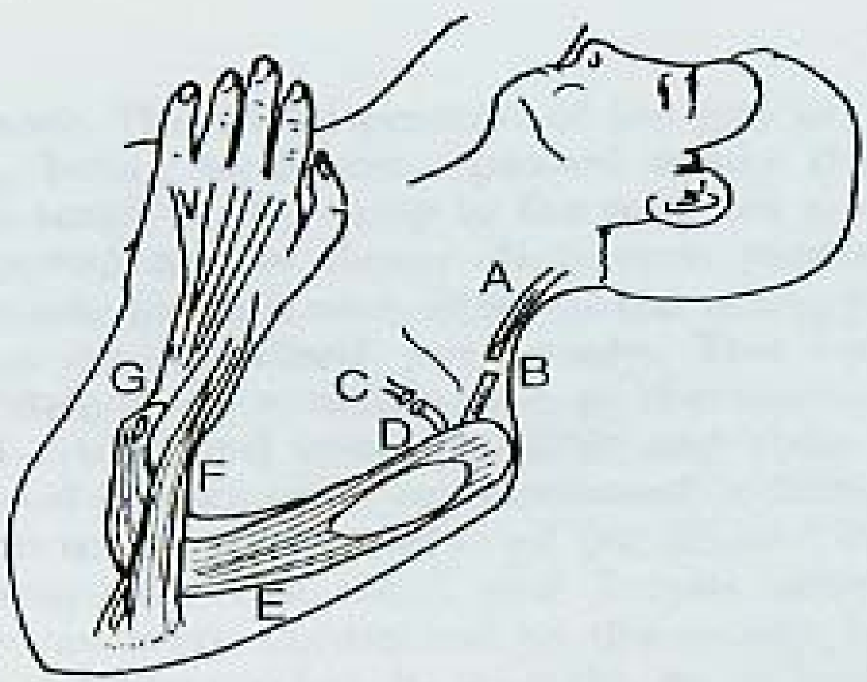


Figure 2. The initial operative procedure for reconstruction of prehension following complete brachial plexus avulsion is a free-muscle transfer to restore finger extension and elbow flexion simultaneously. Either the gracilis or latissimus dorsi is transferred and is innervated by the spinal accessory 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.)

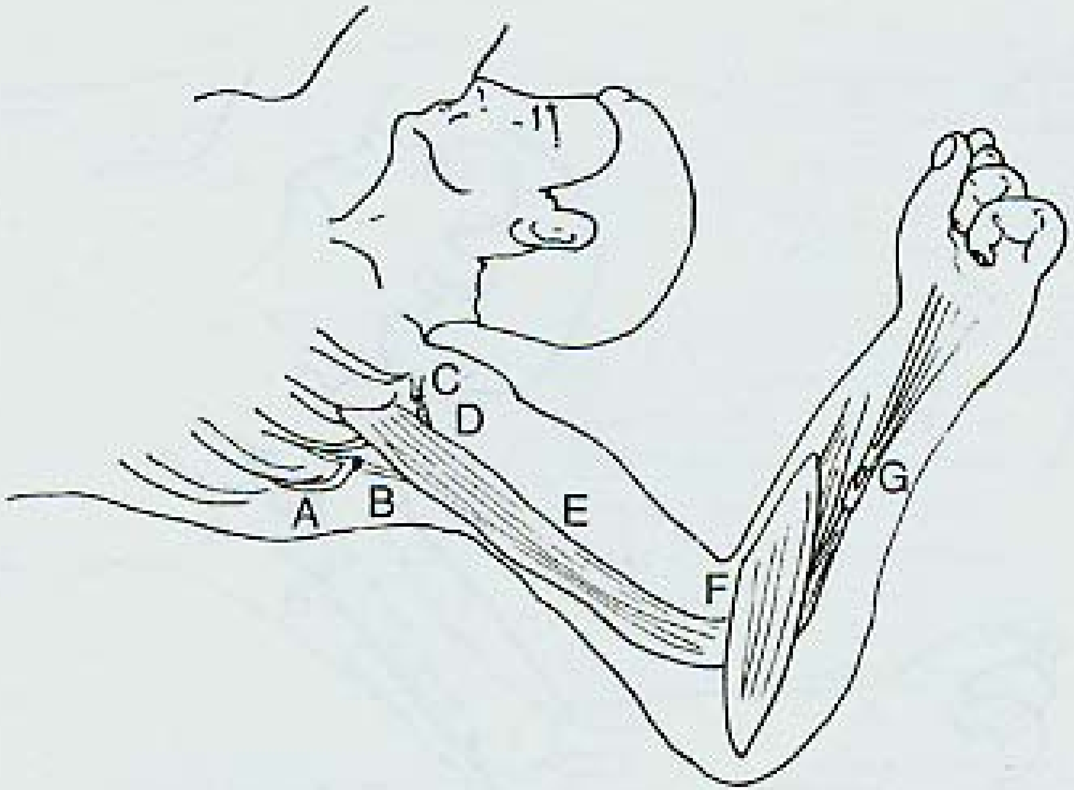


Figure 3. The second operative procedure for reconstruction of prehension following complete brachial plexus avulsion is a second free-muscle transfer to restore finger flexion. Either the gracilis or latissimus dorsi is transferred and is innervated by the fifth and sixth intercostal nerves. A, The 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.)

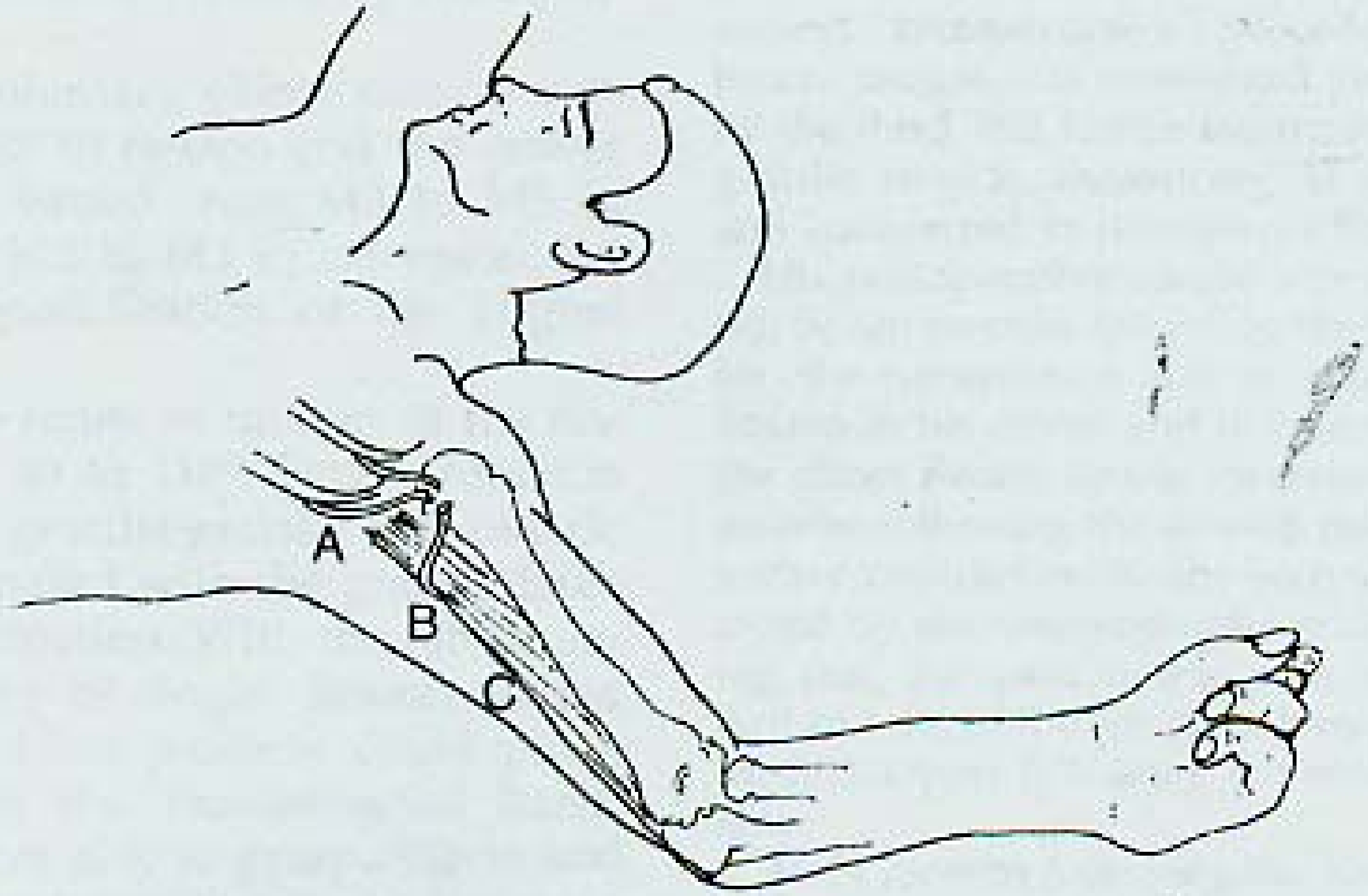
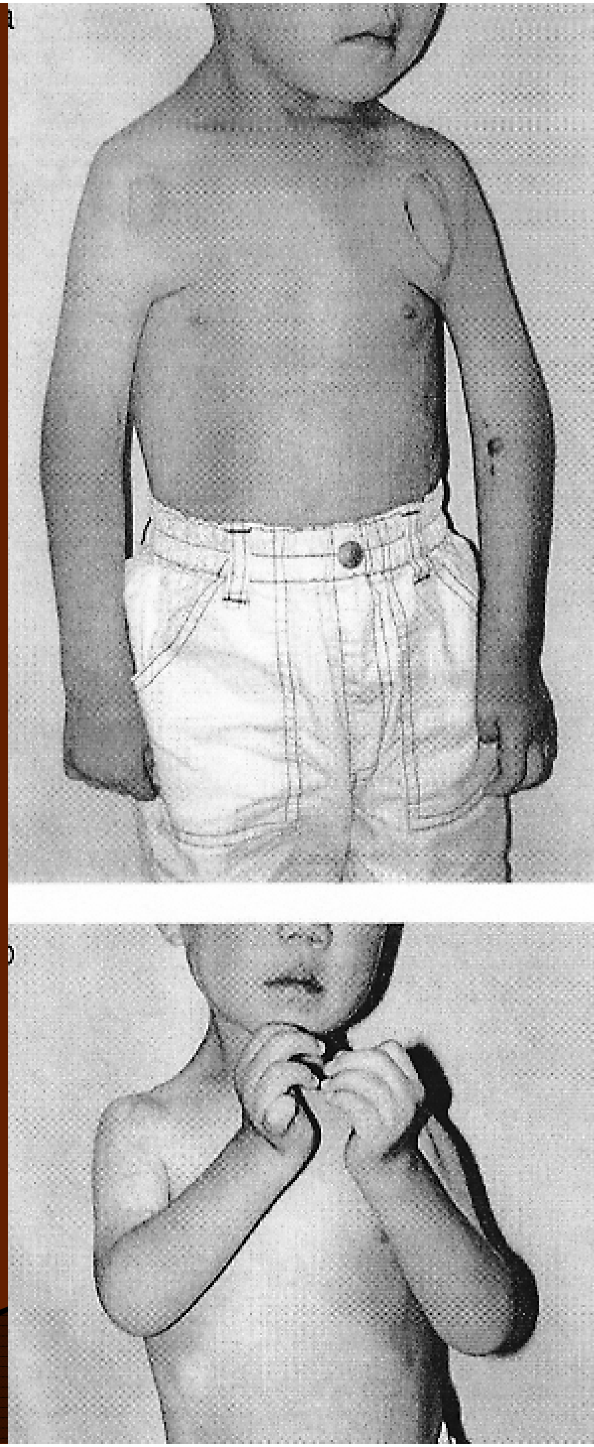


Figure 4. Nerve-crossing of the third and fourth intercostal nerves to the motor branch of the triceps brachi muscle to restore elbow extension and stabilization following complete brachial plexus avulsion. A, The third and fourth intercostal nerves; B, motor branch of the triceps brachi muscle; C, triceps 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 detatched 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 inc 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
  - Inominate a, Left Common Carotid, L & R Subclavian vv., Vagus n., Phrenic n., Trachea, Esophagus, Internal Jugular v.

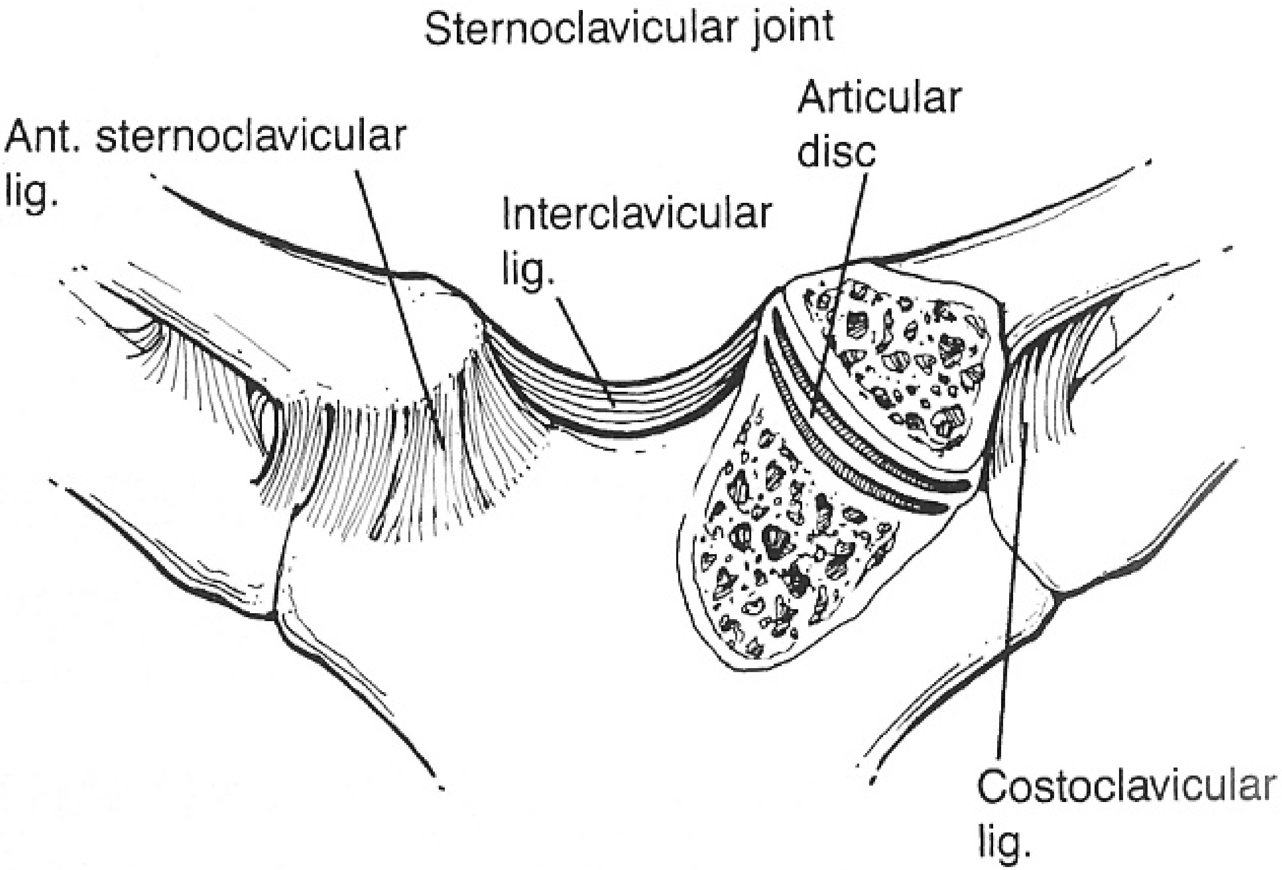
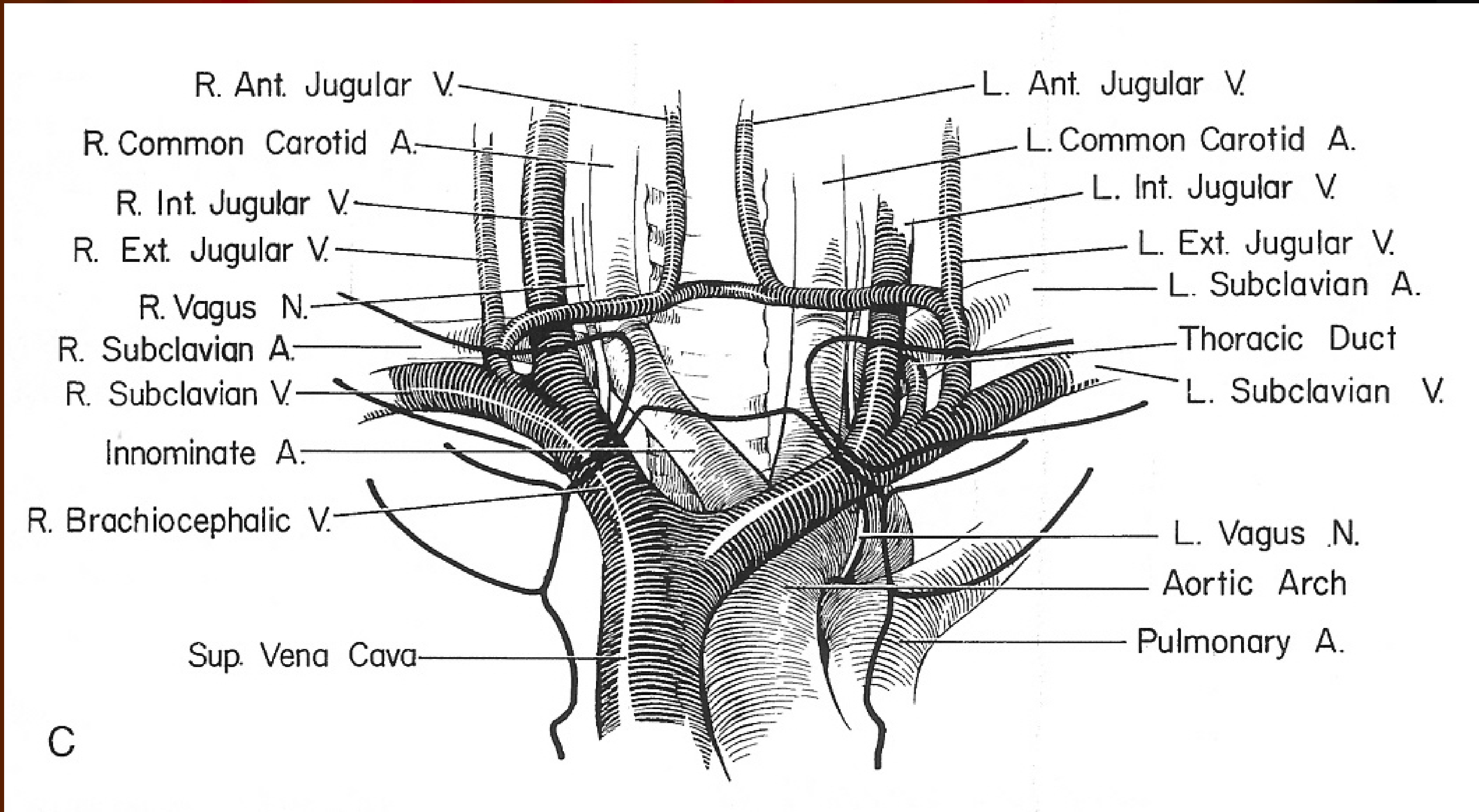


Figure 21A1–3. The sternoclavicular joint is stabilized by the interclavicular ligament, the anterior and posterior capsular structures, the costoclavicular ligaments, and the intra-articular disc. Ant., anterior; lig., ligament.



R. Ant. Jugular V.
R. Common Carotid A.
R. Int. Jugular V.
R. Ext. Jugular V.
R. Vagus N.
R. Subclavian A.
R. Subclavian V.
Innominate A.
R. Brachiocephalic V.
Sup. Vena Cava
L. Ant. Jugular V.
L. Common Carotid A.
L. Int. Jugular V.
L. Ext. Jugular V.
L. Subclavian A.
Thoracic Duct
L. Subclavian V.
L. Vagus N.
Aortic Arch
Pulmonary A.
C

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

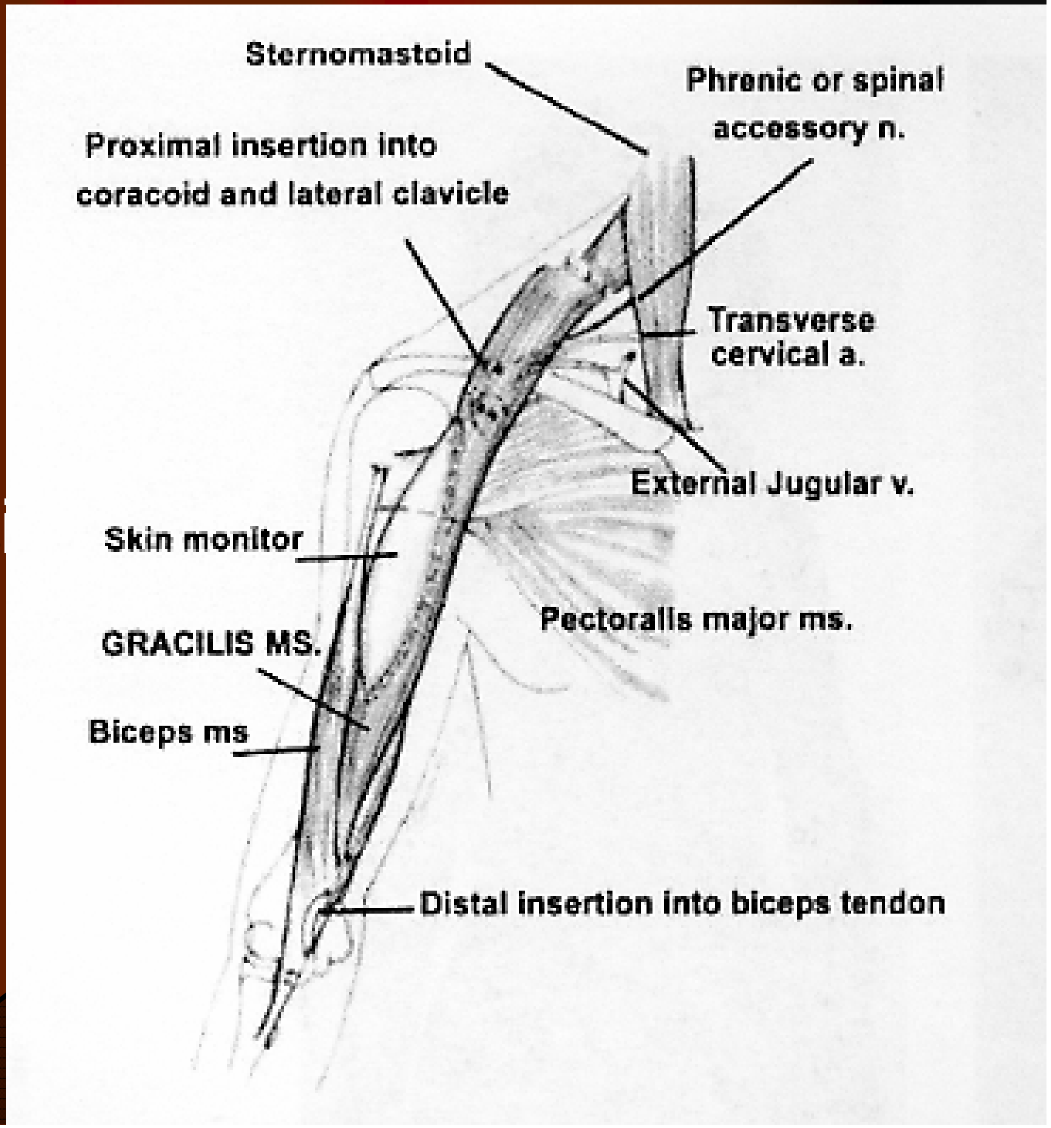
- Law of Seven Seventies (Narakas)
  - 70% traumatic lesions due to traffic accidents
  - 70% traffic accidents involve a cycle or motorcycle
  - 70% of these pts have multiple injuries
  - 70% supraclavicluar injuries
  - 70% of pts w/ supraclavicular lesions will have one or several roots avulsed from 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

El-Gammal et al, Apr 2002, Microsurgery

- Shoulder fusion and free-functioning gracilis transplantation in patients with elbow and shoulder paralysi caused by poliomyelitis



Baliarsing, Doi, & Hattori, Oct. 2002 J. Hand Surgery

- case study of a child w/ 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) 2^{nd} free muscle transfer, neurotized by 5^{th} & 6^{th} intercostal nerves, for finger flexion, 2 – 3 months after 1^{st} transfer
  - 3) nerve crossing procedure, 3^{rd} & 4^{th} 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 sugery
  - 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