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VIII. Hand, Upper Extremity

VIII.F.1. Hand: Nerve and Nerve Injuries

By Edward Luce, MD

Financed with a grant from The Hoopes Foundation.

A. Anatomy, Physiology:

1. In general, the radial nerve supplies what muscles in the upper extremity? (All of the muscles groups on the extensor side, namely, the triceps and the extensor muscles of the forearm as well as the supinator.)
    a. An exception, a flexor? (The brachoradialis – a flexor of the elbow.)

2. The median nerve innervates all of what in the forearm? (All of the extrinsic or long flexors of the hand and wrist.)
    a. Exceptions? (The ulnar two flexor dig. profundi, innervated by the ulnar nerve.)

3. In general, the ulnar and median nerves innervate what in the hand? (The intrinsics) Specifically? (The median innervates the muscles of the thenar eminence with the exception of the deep head of the short flexor of the thumb as well as the two radial lumbricals. The ulnar nerve innervates all of the interossei, the muscles of the hypothenar eminence, the adductor of the thumb, the ulnar two lumbricals, and the deep head of the flexor pollicis brevis, although considerable overlap with the median nerve exists.)

4. A patient presents with numbness of the little finger, weakness of the interossei, and paraesthesias and diminished sensation in the medial arm and forearm. Where is the lesion? (The ulnar nerve at the takeoff from the medial cord of the brachial plexus or dermatome C_8-T_1.)

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5. Peripheral nerves are both myelinated and unmyelinated. What entity is responsible for the myelin production? (Schwann cell)
    a. What is the physiologic difference between the two? (The conduction velocity is higher in myelinated nerve fibers, think insulation. Also, the diameter of myelinated fibers tend to be considerably larger than unmyelinated fibers. Think flow as a function of the radius to the fourth power.)
    b. What are the two structural factors of a nerve that determine velocity of transmission? (As above, diameter and presence of myelin; both increasing diameter and the presence of myelin increase velocity.)

6. What is the node of Ranvier including where is it and what produces it? (A node of Ranvier is a periodic intersection or break point in the myelin layer of a nerve and is produced by lack of myelination at that particular juncture by the internodal Shwann cell .)

7. Axonal transport or flow refers to what? (Fast and slow ante and retrograde flow; antegrade flow of the products of cell body synthesis; retrograde flow of scavenged axonal material.)

8. What is a significant difference, physiologically, between epineurium and perineurium? Also, discuss the anatomical differences. (Epineurium is the loose connective tissue investing the peripheral nerve, externally as well as the investing loose areolar tissue within the nerve. Perineurium, in contrast, anatomically surrounds the individual fascicles. Since the perineurium is an extension of the blood brain barrier, removal results in loss of neural function. Excision of the epineurium has no significant consequences. The amount of connective tissue, internal epineurium, varies among peripheral nerves and also within a nerve, more at an anatomic point of crossing a joint, for example.)
    a. The blood vessels, arterioles, and venules, are located where? (External and internal epineurium. The intrafascicular vessels are capillaries.)

9. Define the endoneurium. (Endoneurium is composed of collagen tissue that surrounds the axons and in the instances of myelinated axons also contains the Schwann cells and blood vessels.)

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10. Define fascicle and fascicular group. (A fascicle is the smallest unit of the nerve structure and contains a group of axons within a sheath of perineurium. Fascicular group is, as the name implies, a bundle of fascicles surrounded by *internal* epineurium.)
    a. Define interfascicular branching. (Interfascicular branching refers to the interweaving of fascicles from one bundle to another proximal to distal in a major peripheral nerve. The result is that the axonal composition of any single fascicle will vary substantially from proximal to distal.)
    b. What is the practical application? (To be discussed later-inter fascicular repair consist of suturing a single fascicle to another fascicle.)

11. What are the factors that are responsible for a declining favorable outcome as the time hiatus increases between injury and nerve repair? (Increasing fibrosis of the distal axonal tubes, increasing fibrosis of the motor endplates, muscle fiber atrophy. After three years, the probability of any functional recovery is remote.)

12. Define the nerve cell body changes that occur with nerve injury and what determines the severity of those changes. (The magnitude of intracellular changes within the nerve cell body is directly dependent on the proximity of the injury or more proximal the more severe the nerve cell damage. The hypothesis is that the degree of axonoplasma that must be regenerated to complete re-innervation to the end organs, so the more proximal the lesion the higher possibility that from injury distalward the cell body must produce greater amounts of axonoplasma and may be overwhelmed.)

13. Since denervated muscle will undergo fibrosis without re-innervation, what are the timelines to obtain muscle function? (Ideally, accomplished within three months, still functional within a year, and irretrievably functionless after three years.)

14. Define the terms neuropraxia, axontomesis, and neurotemesis. (Neuropraxia references a nerve injury that is a conduction block only, namely, the nerve remains intact although the axons may be demyelinated in the area of injury. Recovery is usually complete although the time interval may be as short as several days to as long as three months. Axontomesis may vary from that of a second-degree injury with loss of myelin and

axon, without damage to the endoneural tube to axontomesis with fifth degree injury or damage to all portions of the nerve except the epineurium. Neurotemesis refers to the gross and anatomical transection of the nerve. Recovery from axontmesis can be partial, complete, or not at all depending on the degree of injury. Neurotemesis recovery is not possible without formal repair.)

a. Explain how a Tinel sign may be of value in differentiating degree of injury. (In a conduction bloc only a Tinel sign will not be present, since what is lost is myelin at the site of injury but the axons are intact and presumably not injured to the point of production of new, sprouting axons. A Tinel sign that is present but is progressive with time more distally would indicate a second or perhaps a third degree of injury with recovery. Fourth and fifth degree injury with complete disruption of the axons and lost axonal continuity but an intact fibrous tunnel will not have a progressive Tinel sign since recovery without intervention will not occur.)

15. Describe the sequence of events after the sharp transection and repair of a median nerve in the distal forearm. (Wallerian degeneration occurs, namely death of axonal nerve tissue distal to the point of injury as well as a process of ingrowth of macrophages which remove the axoplasm and myelin from the distal nerve tube. Schwann cells proliferate and nerve growth factor promotes axonal regeneration. Wallerian degeneration usually proceeds more proximal on the nerve to the next node of Ranvier and is referred to as "antegrade" degeneration. The sprouting axons from the proximal end of the cut nerve under the physiologic influence termed "neurotropism" branch and migrate towards the distal stump. The degree of the success of the outcome is dependent on the ability of axons from the proximal stump to join with axons destined to a similar end organ in the distal stump.)

    a. What are the factors related to these events that will determine the degree of successful outcome? (As above, in addition the amount of scar blockage between proximal and distal stumps, the overall connective tissue-nerve tissue ratio at that level of the peripheral nerve and again the likelihood of the motor axon joining a nerve tube that leads to a motor end plate and the same for sensory axons. Clearly, the nature of the wound, tidy vs. untidy, and nature of the wounding mechanism, sharp or blunt crushing, is critical as well.)
    b. How does "neurotropism" act? (Under the influence of certain and yet to be more fully defined growth factors, the proximal axons are influenced to move distally.)

16. List the factors that are responsible for a less favorable outcome with proximal nerve transection vs. distal. (Proximal nerves have a higher connective/neural tissue ratio, the degree of interfasicular branching over the course of the nerve will be greater in proximal vs. distal, the progressive fibrosis of the empty neural tubes with the passage of time since nerve regeneration occurs at only a millimeter a day, and the potential for neuronal cell death that occurs with the necessity to transport the components of regenerating axons at greater distances are all variables including technique that dictate the outcome.)

B. Nerve Repair

1. Define primary and delayed nerve repair. (Primary is done within 5-7 days, delayed repair is any repair more than two weeks after injury.)
    a. How many days before the distal end of a transected motor nerve will no longer respond to stimulation with a nerve stimulator? (3 days)

2. What are the criteria for a primary repair of an injured nerve? (Sharp laceration, little or no contamination, adequate well vascularized bed and overlying coverage, the absence of a significant, greater than 1-2cm, gap, absence of associated injuries, and the presence of a surgeon capable of a skillful nerve repair.)

3. What are the prognostic clinical factors in nerve repair, assuming a clean sharp transection and prompt repair of the nerve, other than technique, that will dictate the outcome? (Age, younger better than older, proximal vs. distal, namely distal better than proximal, pure vs. mixed nerve, pure motor or sensory better than mixed. Of course, undue delay and the characteristics of the wound are influential. See below.)
    a. Discuss optimal timing, nature of wound. (Primary repair accomplished within the first day or two has the advantage of a fresh wound, the ability to identify individual fascicles or grouped fascicles, as well as the possibility to perform distal stimulation to identify motor components. Delayed primary within the first 5 to 7 days is a repair accomplished under ideal conditions as electively scheduled and the availability of an experienced surgeon. Greater than 7 days is termed delayed repair and, although some controversy may exist, probably yields a diminished return in function. The characteristics as well as the nature of the injury are important, for example, crushing wounds

impair the capability to differentiate viable from non-viable nerves. Gunshot wounds are often closed and may be an axonotmesis injury alone.

4. What do the readings describe as the primary goal of the surgeon in repair of a peripheral nerve injury to facilitate proper topographical regeneration? (Accurate alignment of the fascicles of the proximal and distal stumps)

5. Describe the difference between epineural, group fascicular, and individual fascicular repair. (The terms are self-explanatory. Epineural repair refers to the placement of sutures within the epineurium alone, grouped fascicular is a group of fascicles sutured internally within the nerve and fascicular repair is individual sutures placed in each individual fascicle.)
    a. What are the benefits and liabilities of each? (Epineural repair is less accurate, individual fascicular places a great deal of suture foreign body within the nerve, and the current enthusiasm is for grouped fascicular repair.)
    b. Briefly describe the technique for each. (Epineural repair is accomplished by placement of a small suture, characteristically 6-8° within the epineurium only to coapt the proximal distal stumps together. Group fasicular is the suture within the trunk of the nerve of groups of fascicles, placing sutures within the internal epineurium alone. Finally, individual fascicular is, as the name implies, coaptation of a single fascicle to a distal fascicle.)

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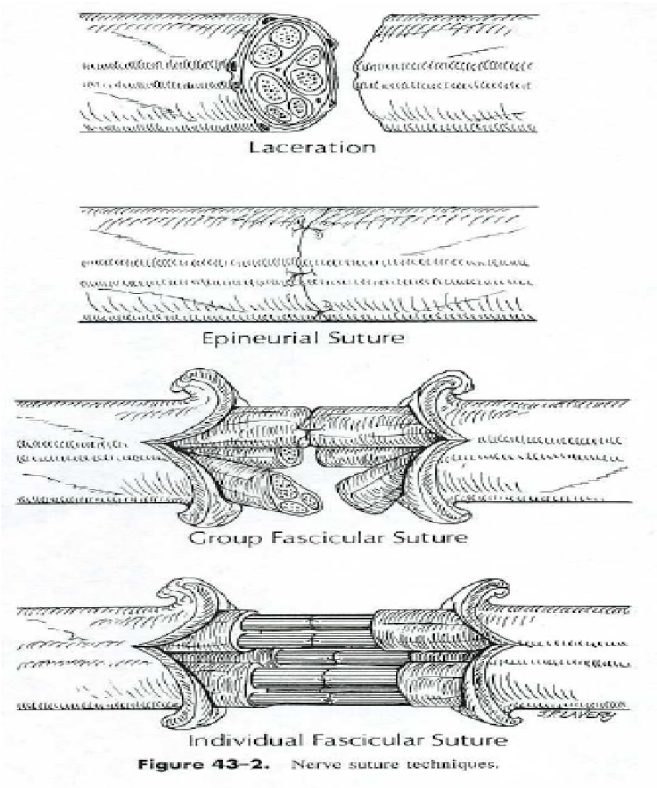

Figure 43–2. Nerve suture techniques.

Brushart TM, "Chapter 43: Nerve repair and grafting", Green, Hotchkiss, and Pederson, Churchill Livingstone, Green's Operative Hand Surgery, Fourth Edition. Vol 1, pg.1381.

6. List and explain four factors that explain why the outcome of a transection of the sciatic nerve in the proximal posterior thigh would be less favorable than the posterior tibial nerve at mid-calf. (Connective tissue-nerve tissue ratio is much greater in the sciatic nerve than the posterior tibial nerve, the degree of intraneural fascicular branching will be substantially greater since the sciatic nerve injury is much more proximal, a proximal nerve injury results in a higher percentage of proximal cell death than a more distal lesion, and finally the duration for nerve regeneration from injury point to end organ is much greater in the more proximal sciatic nerve lesion with the result of markedly increased probability with time of fibrosis of the motor end plates and the axonal tubes. The chance of success of a primary repair of a sciatic nerve is extremely low but the percentage of recovery is actually not dramatically higher for the posterior tibial nerve. These two injuries were selected for illustration only.)

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7. What are some intraoperative clues to insure a proper alignment of the proximal distal stumps and why is that crucial? (One of the most common clues is the presence of a vessel or vessels running within the epineurium, particularly with the median nerve and the presence of the median artery. Correct alignment is important for a optimal outcome since motor to motor and sensory to sensory will dictate proper re-innervation of the distal end organ.)

8. Describe intraoperative nerve mapping; critique from your perspective. (Intraoperative nerve mapping refers to the use of an extremely fine nerve stimulator in an effort to define motor fibers in the distal stump and sensory fibers in the proximal stump. With the use of anatomical landmarks on the external nerve, such as blood vessels, presumably as much of the internal topography of the nerve as possible can be determined. The obvious disadvantages are after several sensory stimulations one may have an uncooperative patient. Secondly, the ability to produce a very discrete stimulus to a single fascicle without diffusion of the stimulus to the surrounding nerve fascicles is quite difficult.)

9. List the M classification for motor recovery in nerve injuries. (M0- no evidence of contractility, M1- a flicker of muscle action is evident but no function, M2- complete range of motion but only with the aid of gravity, M3- complete range of motion against gravity, M4- range of motion against mild resistance, M5- complete range of motion with full resistance.)

C. Nerve Grafts, Conduits

1. What are the operative procedures that can be utilized to overcome a nerve gap and what are the limitation of each? (Mobilization of the proximal and distal stumps is possible but should be limited to 6-8cm proximal and less distally to avoid devascularization of the native nerve. The joints, elbow and wrist can be flexed to overcome a gap but are not recommended since joint contracture and a stretch injury of the nerve can occur with mobilization. In general, if the nerve gap cannot be coapted with two epineurial 6^{o} silk sutures then the tension will be excessive on the repair. Some have advocated the threshold as 9° suture.)
    a. In summary and in general, what is the critical gap that if greater will require a nerve graft? (3cm)

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2. Why, besides the situation circumstances that may be inherent, do nerve grafts have a poorer outcome than primary nerve suture? (The necessity for the process of Wallerian degeneration of not only the distal nerve but the nerve graft as well. In addition, the axonal sprouting must occur across two anastomoses rather than one.)

3. What is the principal factor in graft length? (As in tendon grafts the necessity of graft revascularization as well as the process of axonal regrowth vs. increasing fibrosis of the neural tubes with passage of time.)

4. Describe the harvest of the sural nerve for a nerve graft. (The sural nerve innervates the lateral and dorsal aspect of the foot and can be identified posterior to the lateral malleolus and parallels for short distance the lesser saphenous vein. The nerve is then dissected proximally through a longitudinal or stair-step incision and, dependent on the length of the nerve desired, dissected to the point of the nerve coursing deeper into the leg between the two heads of the gastrocnemius muscle. The nerve is a branch of the sciatic.)

5. What are some alternative sources for a nerve graft? (The lateral antebrachial cutaneous of the forearm as well as the terminal branch of the posterior interosseous nerve. The latter, the posterior interosseous nerve, is pure motor and has little donor site morbidity. The graft contained is by definition relatively short (2-3cm) but is a good source for reconstitution of a digital nerve.

6. Describe a technique for suturing nerve grafts into a nerve gap. (The principal technical aspect is grouped interfasicular repair of the proximal and distal ends of the nerve graft to the proximal and distal stumps of the native nerve. Cable grafts are of historical interest only.)

7. Whether primary suture or nerve graft how does one assess the recovery? (If a sequential motor innervation pattern such as the radial nerve in the forearm is available than the return of elictable segmental motor function is valuable. Regardless, a progressive Tinel sign should be utilized.)
    a. What is the approximate rate of progression? (About a mm a day or an inch a month in *optimal* conditions.)

b. What is the physiologic explanation? (The estimate of a millimeter a day or an inch a month is a clinical yardstick, but a significant physiologic explanation is that axonaplasma flow from proximal to distal through intact nerve is about a millimeter a day. Unfortunately, a lag exists at any suture anastomosis that has been performed to restore nerve continuity.)

8. What is the role, if any, of acellular allograft in management of nerve gaps? (The only demonstrable efficacy is *perhaps* in nerve gaps less than 2cm or small diameter, less than 2mm, sensory nerves, for example, a digital nerve. Contraindicated in motor or "critical" sensory nerves or nerves of larger diameter.)

9. What are the characteristics and efficacy of synthetic conduits? (Synthetic conduits are composed of absorbable materials, such as poly glycolic acid. The principal efficacy as in allografts is limited to small, less than 2.5cm, defects and most common only in small sensory nerves as again a digital nerve.)

D. Clinical Scenarios

1. A heavy metal press crushes the distal volar forearm with a fracture of the ulna and a closed ulnar nerve injury as evident by distal palsy and loss of sensation. No open repair is planned by orthopedics. (If no recovery at six weeks, perform electrodiagnostic studies, then a timeline should be developed for exploration. The results may signal a conduction block consistent with neuropraxia but more likely will be nondiagnostic. If no recovery at 3 months, repeat electrodiagnostic studies and continued observation but an alternate treatment plan is exploration and repair. If continued observation is selected and no recovery is evident at 6 weeks, patient should be explored and the fibrotic nerve excised and grafted.)

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VIII.F.1. – Hand: Nerve Injuries

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