D.1. Diagnosis and Management of Peripheral Nerve Injury and Entrapment

This review is intended to present a set of general principles which can be applied clinically to both evaluate and treat a broad spectrum of peripheral nerve problems which include traumatic injuries and associated entrapment neuropathies.

a. Peripheral nerve injuries

i. Clinical evaluation

Peripheral nerve injury or disease can cause symptoms of pain, dysesthesias, and either partial or complete loss of sensory and motor function. A thorough clinical history, physical examination, electrodiagnostic evaluation, and relevant radiographic studies should be performed to distinguish a peripheral nerve problem from one involving the spinal cord or brain, bone, or soft tissues. In addition, early neurosurgical consultation should be obtained.

The strength of individual muscles or muscle groups is graded. A sensory exam is performed which includes testing for light touch, pinprick, two-point discrimination, vibration, and proprioception accordingly. It is helpful to test sensation in the autonomous zones of a nerve where there is minimal overlap from adjacent nerves. The presence of Tinel's sign is useful to localize a nerve injury. The Tinel's sign refers to paresthesias elicited by tapping along the course of a nerve. Progressive distal advancement of a Tinel's sign over time can be useful clinically to follow the course of regenerating sensory axons. However, the presence of a Tinel’s sign does not guarantee motor recovery. Return of sweating in an autonomous zone signifies sympathetic nerve fiber regeneration. Reflex changes are also sensitive and early indicators of nerve damage.

Both electromyography (EMG) and nerve conduction studies (NCS) are useful to distinguish an upper from lower motor neuron disorder as well as diagnose a primary muscle disease. For EMG studies, a needle electrode is placed through the skin into a specific muscle and the activity at rest and electrical response to graded muscle contractions are determined. The nerve conduction study involves stimulation and recording along the course of peripheral nerves. This allows one to measure the velocity and amplitude of the propagating nerve action potential.

An understanding of the functional anatomy of the peripheral nervous system can often permit the clinician to localize nerve injuries and lesions with a high degree of accuracy:

The brachial plexus typically originates from the fifth through eighth cervical spinal nerve roots as well as the first thoracic root and innervates all of the muscles of the upper extremity. These nerve roots join to form trunks, which further subdivide into divisions, then cords, then, more distally, individual peripheral nerve branches. Severe trauma transmitted to the most proximal portions of the brachial plexus may produce a preganglionic injury with avulsion of spinal nerve roots from the spinal cord. It is important to determine whether avulsion of the ventral or dorsal roots has occurred, since direct repair of a peripheral nerve whose contributing spinal roots have been disconnected from the spinal cord will not restore function. A Horner's syndrome, characterized by ptosis, miosis, and anhidrosis indicates avulsion of the ipsilateral proximal C8 and/or T1 spinal nerve roots. Other physical signs of proximal nerve root avulsion are elevation of the

ipsilateral hemidiaphragm (phrenic nerve), scapular winging (long thoracic nerve), and weakness of the rhomboid muscles (dorsal scapular nerve). All of these nerves originate proximally along spinal nerves.

The lumbo-sacral plexus arises from the first lumbar through the fourth sacral spinal nerves. The femoral and obturator nerves arise from the anterior divisions of L2-4. The sciatic nerve is the largest nerve in the body and arises from the L4-S4 spinal nerves. This nerve passes through the sciatic notch and travels down the back of the leg where it branches into peroneal and tibial nerves usually just above the popliteal fossa.

ii. Imaging of peripheral nerve lesions

Imaging techniques such as X-rays, CT, and, most recently, MRI can be valuable diagnostic tools in evaluating peripheral nerve lesions. Cervical spine fractures are frequently associated with brachial plexus injuries, as well as injuries of the proximal spinal nerves and roots. Chest radiographs may show unilateral elevation of the diaphragm as a signature of phrenic nerve paralysis (C3-5) from injury to the proximal upper cervical spinal nerves and roots. Mid-humeral fractures are associated with radial nerve injuries while midforearm fractures of the ulna or radius are associated with median or ulnar nerve injuries, respectively. Hip and proximal femur fractures are associated with sciatic nerve injuries while more distal femur fractures are associated with peroneal or tibial nerve injuries.

Myelography in conjunction with a CT scan are useful to visualize meningeal diverticula and abnormalities of the spinal nerve roots, findings of which also indicate a spinal nerve root avulsion injury.

CT is able to delineate soft tissue mass lesions such as tumors. MRI has proven to be much more effective in resolving the fine anatomical detail of soft tissues. Using conventional and enhanced MRI techniques, it has been possible to visualize both normal and abnormal peripheral nerve structures. New techniques such as MRI "neurography" make it possible to image and reconstruct the complex peripheral nerve anatomy as well as pinpoint regions of pathology. MRI can also be used to image signal changes in denervated muscle.

iii. Grading of peripheral nerve injury

The severity or grade of a peripheral nerve injury is determined by the magnitude and duration of the applied forces of injury. Seddon defined 3 grades of nerve injury (neurapraxia, axonotmesis, and neurotmesis) based on the extent of injury to the three structural components of the peripheral nerve described above.

- Neurapraxia, the mildest grade of nerve injury, is characterized by a reduction or complete blockage of conduction across a segment of nerve. Axonal continuity is maintained and nerve conduction is preserved both proximal and distal to the lesion but not across the lesion. Neurapraxia can result from direct mechanical compression, ischemia secondary to vascular compromise, metabolic derangements, or diseases or toxins causing demyelination of the nerve. Conduction is restored once either the metabolic derangement is corrected or remyelination occurs. Neurapraxic injuries are usually reversible and a full recovery can occur within days to weeks.

 Axonotmesis represents a more severe grade of nerve injury and is characterized by interruption of the axons with preservation of the surrounding connective tissue "highway" which can support axonal regeneration. Distal Wallerian degeneration (axon and myelin degenerate distal to site of injury) of the axons occurs over a several day period after which direct electrical stimulation of the disconnected distal nerve stump will not give rise to a nerve conduction or muscle response. Recovery can occur through axonal regeneration due to the preservation of the connective tissue "highway" which consists of Schwann cells and their basal lamina. The Schwann cells proliferate and form longitudinal conduits (i.e. the bands of Bungner) through which axons regenerate. Axonotmetic injuries usually recover over a period of months. The timing and degree of recovery depends on several factors which include the extent of retrograde axonal loss, as well as the time to regenerate and reinnervate target muscles and/or sensory end organs. As a general rule, peripheral nerve fibers regenerate at a rate of approximately 1 mm per day or 1 inch per month. Therefore, more proximal injuries require longer time intervals for regenerating axons to reinnervate their targets.

 Neurotmesis is the severest grade of peripheral nerve injury. Neurotmetic injuries are characterized by disruption of the axon, myelin, and connective tissue "highway" components of the nerve. Therefore, recovery through regeneration cannot occur. This grade of injury encompasses nerve lesions where external continuity of the nerve is preserved but intraneural fibrosis occurs and blocks axonal regeneration. Neurotmetic injuries also include nerves whose continuity has been completely interrupted. Since the necessary "highways" for axonal regeneration are absent, surgery is required to remove any intervening roadblocks in the form of scar tissue as well as to re-establish continuity of the nerve.

On the basis of clinical symptoms and physical findings alone, it is often difficult to differentiate neurapraxic, axonotmetic, and neurotmetic grades of nerve injury, especially in the acute setting. Nerve conduction studies, both sensory and motor, are useful during and after the first week following an injury to distinguish neurapraxic from axonotmetic and neurotmetic grades.

iv. Treatment Strategies:

Trauma is the most frequent cause of peripheral nerve lesions. Nerve injuries are caused by traction, compression, sharp laceration, and missile injury (gun shot wounds). Traction injury is often associated with a fracture or dislocation.. An understanding of the mechanism of injury is extremely helpful in determining the severity of the lesion and to guide clinical management.

Traumatic peripheral nerve injuries can be classified into open and closed injuries. Decision making for open injuries is relatively straightforward. Immediate repair of acute sharp lacerating injuries (i.e. glass or knives) should be undertaken with the goal of performing a primary end to end suture repair. However, not all transecting injuries lead themselves to a primary repair. It the ends are ragged or contused, a delayed repair is preferable to demarcate normal from abnormal neural tissue.

The decision making process in treating closed traumatic peripheral nerve injuries is more complex. The majority of closed traumatic injuries are due to stretch and/or compressive forces. An associated expanding hematoma producing a compartment syndrome may require emergent surgery to avoid irreversible nerve injury. Because nerves are often contained in a neurovascular bundle, there is potential for combined vascular and neural trauma A delayed onset of a neural deficit due to a traumatic pseudoaneurysm may also require urgent attention. An angiogram is necessary when damage to vascular structures is suspected clinically. In the majority of closed traumatic injuries, however, nerves are not actually transected. Instead, a "lesion in continuity" representing the damaged segment of nerve may be produced which results in either a neurapraxic, axonotmetic, neurotmetic, or combination of these grades of injury.

In the case of compression or stretching, it if often not possible to immediately determine the grade of the injury. A partial nerve injury associated with muscle denervation usually indicates an axonotmetic grade of injury. Patients with such injuries should be followed with serial clinical and electrodiagnostic examinations to document recovery and confirm the diagnosis. These patients do not require immediate surgical intervention. An enlarging hematoma can convert a partial nerve injury into a complete injury. Complete nerve injuries produce severe muscle denervation and may represent either an axonotmetic or neurotmetic grade of injury. It is critical to distinguish between these two grades of injury over time, since the latter requires a surgical repair for recovery to occur. Patients are therefore followed closely over a several month period looking for clinical and electrodiagnostic evidence of nerve regeneration and muscle reinnervation.

Muscles should be reinnervated within two years following a traumatic nerve injury if recovery of useful motor function is to occur. Beyond this point, denervated muscles undergo irreversible atrophy and replacement with fat. Therefore, it is necessary to time a surgical exploration so that a successful nerve repair results in muscle reinnervation within two years of the injury. A useful rule of thumb is to follow a patient for 3 to 4 months to allow any element of neurapraxia to resolve as well as permit axonal regeneration to occur beyond the point of injury. If there is no clinical or electrodiagnostic evidence of muscle reinnervation, then a surgical exploration using intraoperative electrophysiological monitoring should be performed.

Another approach in the management of these traumatic peripheral nerve injuries is to operate "early" (i.e. as soon as medically feasible). The rationale for this approach is the following: 1) less scarring and thereby easier dissection of peripheral nerve elements; and 2) intraoperative evaluation of anatomical and electrophysiological continuity. However, it remains controversial whether an earlier surgical repair leads to a better recovery of peripheral nerve function.

b. Entrapment neuropathies

Peripheral nerve entrapment describes the mechanical irritation by which a specific peripheral nerve becomes locally injured in a vulnerable anatomic site. Peripheral nerve entrapments produce focal disturbances of nerve function. Nerve entrapment may occur at any site as a result of non-specific local lesions including fracture

callus, hematomas, and benign or malignant tumors. There are several anatomical sites where peripheral nerves run in relatively confined spaces and are therefore at increased risk of compression. The differential diagnosis of entrapment neuropathies includes any disease process that damages nerves in a focal manner: i.e. degenerative, hereditary, vascular, inflammatory, and metabolic. Predisposing factors include repetitive activities involving the affected extremity, tenosynovitis, rheumatoid arthritis, acromegaly, alcoholism, amyloidosis, mucopolysaccharidosis, gout, sarcoid, vitamin B6 deficiency, diabetes, trauma, and conditions altering fluid balance including pregnancy, oral contraceptives, and hypothyroid myxedema.

i. Carpal tunnel syndrome

Median nerve compression beneath the flexor retinaculum of the wrist is the most common entrapment neuropathy. Women>men 2:1

aa. Symptoms

- Intermittent numbness and paresthesias along flexor aspects of thumb, index, and middle fingers, as well as radial side of 4th finger with or without pain
- Pain may radiate to the forearm and upper arm
- Symptoms are worse with repetitive use of the hand.
- Pain awakens patients from sleep

bb. Exam

- Phalen's maneuver (flexion of wrist with elbow extended for 60 seconds reproducing symptoms
- Reverse Phalen's maneuver (extension of wrist for 60 seconds)
- Tinel's sign (localized pain or paresthesia in the cutaneous distribution of the nerve when it is percussed)
- Sensory loss in median nerve distribution (altered light touch and later two-point discrimination)
- Thenar muscle wasting (LOAF muscles: lumbricals I,II, opponens pollicis, abductor pollicis brevis, flexor pollicis brevis)

cc. Diagnostic studies

- Nerve conduction studies show localized slowing of nerve conduction velocity or decreased sensory amplitude in the sensory fibers across the wrist
- Signs of muscle denervation of thenar musculature on EMG (electromyogram) with advanced disease

dd. Differential Diagnosis

- C6 radiculopathy
- Proximal median nerve compression
- Anterior interosseus syndrome
- Lateral cord of brachial plexus compression
- Raynaud's disease / vascular
- Generalized peripheral neuropathy
- Amyotrophic lateral sclerosis

ee. Treatment

s. Nonsurgical

- Avoid precipitating activity
- Volar wrist splint in neutral position

- Short course of nonsteroidals or prednisone
- Local steroid injection into carpal tunnel
- Diuretic if premenstrual
- Recommended for patients with mild, intermittent, or acute symptoms

t. Surgical- Carpal Tunnel release

- Indicated for thenar muscle weakness or atrophy
- Denervation by EMG (axonotmesis)
- Failure of nonsurgical management

ii. Ulnar Nerve Entrapment

Ulnar nerve entrapment in the region of the elbow is the second most frequently seen compression neuropathy. As the ulnar nerve descends down the arm it becomes superficial behind the medial epicondyle at the elbow. At this point it travels between the heads of flexor carpi ulnaris (cubital tunnel) and finally passes through the ulnar tunnel (Guyon's canal) to enter the hand. The anatomic cubital tunnel is a fibroosseous ring formed by the medial epicondyle and the proximal part of the ulna. The ulnar nerve is vulnerable to compromise from compression, scar fixation, or traction, as it winds around the medial epicondyle. Patients subjected to immobilization (e.g. anesthesia, coma, restrained positions) are at risk for prolonged pressure on the ulnar nerve.

aa. Symptoms

- Pain at the elbow
- Paresthesias in ulnar side of 4th and 5th digits (palm and dorsum)
- Exacerbated with repetitive flexion

bb. Diagnosis

- Weakness of pinching, grip, 4th and 5th flexors
- Positive Froment's sign (Inability to adduct the thumb against the index finger without flexing the interphalangeal joint)
- Weakness of third palmar interosseous with abduction of 5th digit (Wartenberg's sign)
- Clawing posture of little and ring fingers (benediction posture)
- Point tenderness (Tinel's sign) above elbow (ligament of Struthers), at elbow (trauma), or below elbow (cubital tunnel), with radiation into the 4th and 5th fingers.
- Electrodiagnostics show motor nerve conduction slowing across the elbow, reduced sensory action potential, and denervation in ulnar innervated muscles (intrinsic hand muscles)

cc. Differential Diagnosis

- Ulnar neuropathy at Guyon's canal in the hand
- C8 radiculopathy
- Thoracic outlet syndrome (medial cord of brachial plexus C8-T1)
- Raynaud's disease

dd. Treatment

- Nonsurgical
- Avoid repetitive flexion and pressure on the nerve
- Splint elbow in extension

- Elbow pad
- Surgical
- Ulnar nerve decompression and/or anterior transposition (subcutaneous, intramuscular, or submuscular) if progressive deficits or objective weakness

iii. Thoracic outlet syndrome

The brachial neurovascular bundle goes through the thoracic outlet to enter the arm. Thoracic outlet syndrome is caused by bony, fascial, and muscular structures that interfere with the neurovascular bundle. A fibrous band within the scalenius anterior muscle, a cervical rib, or its remnant may result in angulation or compression of the lower trunk of the brachial plexus or C8/T1 roots and subclavian vessels.

aa. Diagnosis

- Paresthesias in forearm and hand commonly precede the development of pain
- Atrophy of intrinsic hand muscles
- Pain or paresthesias when arms held overhead
- Sensory loss in territories of ulnar and medial cutaneous nerves

bb. Treatment

- Nonsurgical
- Corset to prevent elevation of the arms or hands
- Mild Symptoms may respond to stretching physiotherapy
- Surgical
- Exploration for refractory symptoms

iv. Meralgia Paresthetica

Entrapment of the lateral femoral cutaneous nerve is referred to as meralgia paresthetica (meros=thigh; algo=pain). The lateral femoral cutaneous nerve is a branch of the L2 and L3 nerve roots and is purely sensory. It exits the pelvis to enter the thigh at the upper lateral end of the inguinal ligament. The most frequent location of entrapment is medial to its origin on the anterior iliac spine.

aa. Symptoms

- Numbness, burning, or tingling of lateral thigh
- Positive Tinel's at the level of the inguinal ligament
- Worse standing or extending the leg
- Better sitting
- Associated with obesity and/or pregnancy

bb. Treatment

- Nonsurgical
- Weight loss
- Remove constricting binders, corsets, tight belts, tight jeans
- Surgical
- Steroid/local anesthetic test infiltration around the nerve at the inguinal ligament
- Lateral femoral cutaneous nerve surgical decompression (high recurrence rate) or proximal transection of nerve