Electrodiagnosis of Brachial Plexopathies and Proximal Upper Extremity Neuropathies

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KEYWORDS

• Brachial plexus • Brachial plexopathy • Axillary nerve • Musculocutaneous nerve • Suprascapular nerve • Nerve conduction studies • Electromyography

KEY POINTS

- The brachial plexus provides all motor and sensory innervation of the upper extremity.
- The plexus is usually derived from the C5 through T1 anterior primary rami, which divide in various ways to form the upper, middle, and lower trunks; the lateral, posterior, and medial cords; and multiple terminal branches.
- Traction is the most common cause of brachial plexopathy, although compression, lacerations, ischemia, neoplasms, radiation, thoracic outlet syndrome, and neuralgic amyotrophy may all produce brachial plexus lesions.
- Upper extremity mononeuropathies affecting the musculocutaneous, axillary, and suprascapular motor nerves and the medial and lateral antebrachial cutaneous sensory nerves often occur in the context of more widespread brachial plexus damage, often from trauma or neuralgic amyotrophy but may occur in isolation.
- Extensive electrodiagnostic testing often is needed to properly localize lesions of the brachial plexus, frequently requiring testing of sensory nerves, which are not commonly used in the assessment of other types of lesions.

INTRODUCTION

Few anatomic structures are as daunting to medical students, residents, and practicing physicians as the brachial plexus. Yet, detailed understanding of brachial plexus anatomy is central to electrodiagnosis because of the plexus' role in supplying all motor and sensory innervation of the upper extremity and shoulder girdle. There also are several proximal upper extremity nerves, derived from the brachial plexus,

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which are not commonly tested in most electrodiagnostic evaluations but knowledge of which is important to any electromyographer involved in brachial plexus studies.

Patients commonly are referred to the electromyographer because of weakness, pain, or numbness of an upper limb, with a request to assess for brachial plexopathy. A properly trained electromyographer can combine sensory and motor nerve conduction studies with a detailed needle electromyographic examination to differentiate brachial plexopathy from radiculopathy, mononeuropathy, or mononeuropathy multiplex and then to localize the lesion within the brachial plexus. In this way, the electromyographer provides essential input, which the referring clinician can use for diagnosis, treatment, and prognosis.

ANATOMY OF THE BRACHIAL PLEXUS AND ITS MAJOR BRANCHES

The brachial plexus has 5 components: roots, trunks, divisions, cords, and terminal branches (**Fig. 1**). It runs behind the scalene muscles proximally and then behind the clavicle and pectoral muscles more distally as it courses from the neck into the shoulder girdle and arm. Proximal to the clavicle are the roots and trunks. Beneath it are the divisions. Distal to it are the cords and terminal nerve branches. In addition to providing the motor nerve supply to all muscles of the upper extremities and shoulder girdle, the brachial plexus supplies upper extremity cutaneous sensation (**Fig. 2**). The major clinically significant terminal branches of the brachial plexus and their origins from the plexus are summarized in **Table 1**. The components of the brachial plexus each have specific anatomic details with which the electromyographer should become familiar:

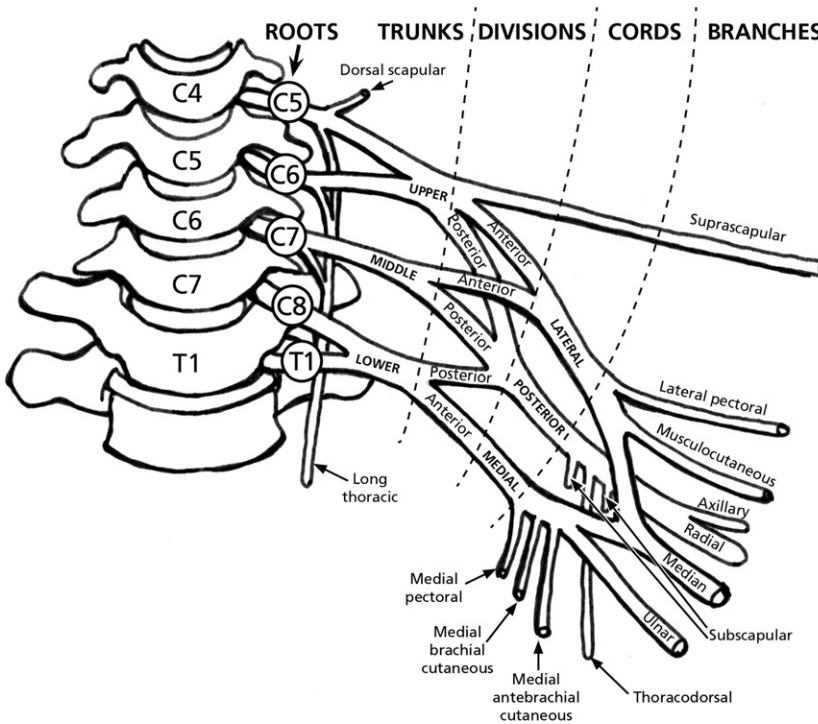

Fig. 1. Brachial plexus. The components shown are the roots, trunks, divisions, cords, and the major terminal branches.

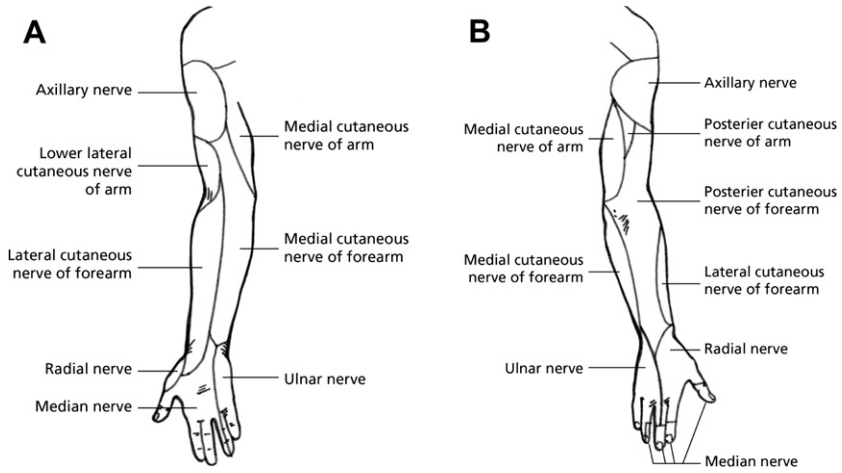

Fig. 2. Cutaneous innervation of the upper extremities. (*A*) Right upper extremity, anterior aspect; (*B*) right upper extremity, posterior aspect.

Roots

The brachial plexus arises from the spinal cord at the C5 through T1 levels. Each of these levels gives rise to dorsal (sensory) and ventral (motor) rootlets, which then merge to form a short spinal nerve. This in turn divides into anterior and posterior primary rami (**Fig. 3**). The anterior primary rami are often referred to as the roots of the brachial plexus and are located immediately external to the intervertebral foramina. There is anatomic variation. The term "prefixed plexus" is used when there is a contribution from C4 and the T1 contribution is minimal. In such cases, all the nerve contributions to the brachial plexus are shifted one level superiorly. In a postfixed

Table 1
Major upper extremity nerves

Nerve	Origin
Dorsal scapular	C5 (±C4) root
Long thoracic	C5, C6 (±C7) roots
Suprascapular	Upper trunk
Lateral pectoral	Lateral cord
Musculocutaneous/lateral antebrachial cutaneous	Lateral cord
Medial pectoral	Medial cord
Medial brachial cutaneous	Medial cord
Medial antebrachial cutaneous	Medial cord
Ulnar	Medial cord
Median	Lateral and medial cords
Upper subscapular	Posterior cord
Lower subscapular	Posterior cord
Thoracodorsal	Posterior cord
Axillary	Posterior cord
Radial	Posterior cord

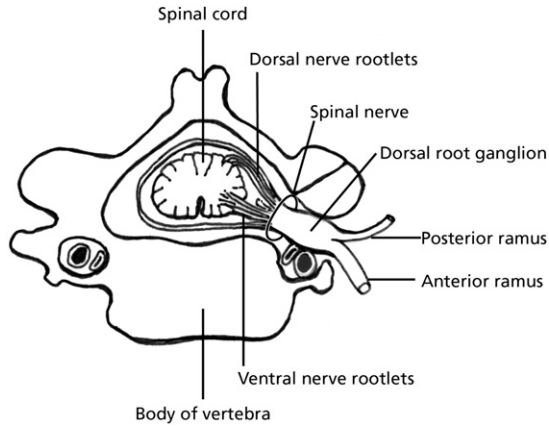

Fig. 3. Details of the anatomy at a cervical spinal cord level. The dorsal and ventral rootlets combine to form a spinal nerve, which then divides into anterior and posterior primary rami.

plexus, there is a minimal contribution from C5 and a more substantial contribution from T2, resulting in the plexus being shifted one root level inferiorly. At times, the plexus may be expanded, with contributions from C4 through T2. Two branches originate directly at the root level: (1) the dorsal scapular nerve is derived from the C5 root, sometimes with a contribution from C4, and provides innervation to the major and minor rhomboid muscles and (2) the long thoracic nerve comes directly off the C5, C6, and sometimes the C7 anterior primary rami, innervating the serratus anterior muscle. Electromyographers should bear in mind that the cervical paraspinal muscles are innervated by the posterior primary rami and, therefore, can also be considered to have their innervation arise directly at the root level.

Trunks

There are 3 trunks. The upper trunk is formed by merger of the C5 and C6 roots. The middle trunk is the continuation of the C7 root. The C8 and T1 roots merge to form the lower trunk. One major branch and one minor one arise from the upper trunk. The suprascapular nerve, derived from the C5 and C6 roots, is the major terminal branch originating at the trunk level, coming off the upper trunk to provide innervation to the supraspinatus and infraspinatus muscles. It passes through the suprascapular notch of the scapula, an area covered by the transverse scapular ligament, and supplies motor branches to the supraspinatus muscle. Then, it continues around the spinoglenoid notch of the scapular spine (bounded by the scapula spine medially and the spinoglenoid ligament [inferior transverse scapular ligament] laterally) to supply motor branches to the infraspinatus muscle. The nerve to the subclavius is the minor branch of the upper trunk, which cannot be tested easily by physical examination or electrodiagnosis. There are no significant terminal branches arising directly from the middle or lower trunk.

Divisions

Each of the 3 trunks divides into an anterior and a posterior division, situated behind the clavicle. No terminal branches arise directly from the divisions.

Cords

The 3 cords are formed from the 6 divisions. The anterior divisions of the upper and middle trunks form the lateral cord, whereas the anterior division of the lower trunk

continues as the medial cord. All 3 posterior divisions merge to form the posterior cord. Several terminal branches arise at the cord level.

Branches of the lateral cord: (1) The lateral pectoral nerve is derived from the C5-C7 spinal nerve levels and innervates the pectoralis major muscle. (2) The musculocutaneous nerve is derived from the C5-C6 spinal levels, sometimes with a contribution from C7. It innervates the coracobrachialis, biceps brachii, and brachialis muscles and gives rise to the lateral antebrachial cutaneous nerve (lateral cutaneous nerve of the forearm), which provides cutaneous sensation to the lateral forearm from wrist to elbow.

Branches of the medial cord: (1) The medial pectoral nerve is formed from C8 and T1 spinal nerves. It innervates the pectoralis minor muscle and the inferior portions of the pectoralis major muscle. (2) The medial brachial cutaneous nerve (medial cutaneous nerve of the arm) provides cutaneous sensation to the medial arm proximal to the elbow. (3) The medial antebrachial cutaneous nerve (medial cutaneous nerve of the forearm) provides cutaneous sensation to the medial forearm between the wrist and elbow. (4) The ulnar nerve arises from spinal levels C8-T1 primarily, usually with a contribution from C7. It supplies many forearm and hand muscles and provides cutaneous sensation over the medial hand, part of the ring finger, and all of the little finger.

Branch of both the lateral and medial cords: The median nerve is derived from spinal levels C6-T1. The motor fibers are derived from all these levels, whereas sensory fibers are derived primarily from C6-C7. Occasionally C5 contributes. Sensory fibers travel through the upper and middle trunks to the lateral cord. Motor fibers travel through all trunks to the lateral and medial cords. The different spinal level origins, and the different trunk and cord pathways, of the motor and sensory fibers, has meaningful clinical and electrodiagnostic implications for localization. The median nerve supplies forearm and hand muscles and cutaneous sensation over part of the hand.

Branches of the posterior cord: (1) The upper subscapular nerve is derived from the C5-C6 spinal levels and innervates the upper portion of the subscapularis muscle. (2) The lower subscapular nerve is derived from the C5-C6 spinal levels and innervates the lower portion of the subscapularis muscle and the teres major muscle. (3) The thoracodorsal nerve arises between the upper and lower subscapular nerves, derives from the C5-C7 spinal levels, and innervates the latissimus dorsi muscle. (4) The axillary nerve is derived from spinal levels C5-C7. It supplies the teres minor muscle and then terminates by innervating the deltoid muscle. It also supplies cutaneous sensation to the lateral aspect of the upper arm overlying the deltoid muscle. (5) The radial nerve arises from spinal levels C5-C8, occasionally with a T1 contribution. It supplies the triceps muscle, anconeus muscle, and muscles of the forearm and hand. It also provides cutaneous sensation to the arm, forearm, and hand as the posterior cutaneous nerve of the arm, lower lateral cutaneous nerve of the arm, posterior cutaneous nerve of the forearm, and superficial radial sensory nerve.

CAUSES OF BRACHIAL PLEXOPATHY

There are many causes of brachial plexopathy, and these may result in lesions at many levels. A listing of the most common causes is provided in **Box 1**. A few of these merit more detailed discussion.

Traction

Traction injuries are common. There are many causes, including a fall onto the shoulder from a height, traction to a limb when it is pulled severely, sports injuries (particularly in football), and closed traction during motor vehicle accidents.[1] Traction

Box 1
Common causes of brachial plexopathy

- Traction
  - Fall from a height, particularly onto shoulder
  - Trauma in which the arm is pulled down, damaging the upper plexus
  - Trauma in which the arm is pulled up, damaging the lower plexus
  - Sports injuries, especially football
  - Motor vehicle accidents and other trauma
  - Obstetric paralysis
  - Surgery, particularly during median sternotomy
- Compression
  - Supraclavicular plexopathy from pack straps
  - Infraclavicular plexopathy from crutches
  - Hematoma, aneurysm, arteriovenous malformations
- Lacerations from penetrating injuries
  - Gunshot or other missile
  - Knife or other penetrating sharp object
  - Neurovascular injury, particularly during trauma
- Ischemia
- Neoplastic infiltration
- Radiation therapy
- Thoracic outlet syndrome
- Neuralgic amyotrophy (Parsonage-Turner syndrome)
- Iatrogenic injury
  - Direct injury during surgery

during surgery may result in postoperative brachial plexopathy. This plexopathy most commonly occurs after chest surgeries due to stretch injuries to the plexus from chest wall retraction. The lower trunk or medial cord usually is involved, with the expected clinical presentation as described later in this article. Recovery depends on the severity of axonal injury. Obstetric paralysis typically has been attributed to traction on the neck by the clinician during passage in the birth canal.[2] However, it now appears that some of these injuries develop prenatally or are due to propulsive forces over which the birth attendant does not have control.[1,3] Upper or upper and middle plexus involvement are most common, although about 23% of infants sustain pan-plexus injuries.[4]

Neoplastic and Radiation-induced Brachial Plexopathy

Radiation-induced brachial plexopathy is most commonly a delayed syndrome, occurring from a few weeks to many years after radiation. The higher the radiation dose, the higher the risk of developing a radiation-induced brachial plexopathy.[5] The electromyographer is most often called on to distinguish a radiation-induced

plexopathy from one due to neoplastic infiltration. Radiation-induced plexopathy is less likely to be painful, and more likely to be characterized by progressively evolving sensory disturbances. Electrodiagnostically, myokymic discharges and fasciculation potentials are more likely to be present in radiation-induced plexopathy. In contrast, neoplastic brachial plexopathy usually is characterized by prominent pain, more rapidly developing symptoms, often accompanied by a Horner syndrome, and rarely associated with fasciculation potentials or myokymia.[1,6] Tumors at the lung apex (Pancoast tumors) most commonly invade the lower portion of the plexus, but metastases from other types of malignancies or direct infiltration of the nerves or nerve sheaths can also occur at any level of the plexus.

Thoracic Outlet Syndrome

This syndrome has been the subject of extensive review, to which the interested reader is referred.[1,7–9] True neurogenic thoracic outlet syndrome is rare. Most are caused by a fibrous band from a rudimentary cervical rib to the first thoracic rib, which entraps the lower trunk of the brachial plexus. Thus, the clinical presentation and the electrodiagnostic findings are those of a lower trunk brachial plexopathy, the exception being that the T1 fibers usually are preferentially affected, resulting in greater atrophy of the thenar than hypothenar mucles.[7] Sensory loss parallels that seen in lower trunk plexopathies.

Neuralgic Amyotrophy (Parsonage-Turner Syndrome)

Also termed immune brachial plexus neuropathy, this condition is most commonly sporadic, although it may be familial. First described in detail in the modern era by Parsonage and Turner in 1948[10] and then described in detail with respect to its natural history more than 20 years later,[11] this condition is now well recognized by most neurologists, but often unknown to nonneurologists and confused with cervical radiculopathy. Individuals of all ages may be affected, and there is a male predominance. The symptoms are widely varied, as has been well described.[12,13] Most commonly, the initial symptom is pain of abrupt onset, often severe, usually in the shoulder or periscapular region. Pain generally begins to improve in 2 to 3 weeks, in association with the development of weakness. The weakness may involve the brachial plexus in a patchy fashion, for example affecting one or more trunks or single peripheral nerves, most commonly the long thoracic, suprascapular, or axillary nerves. Bilateral involvement occurs in about one-third of patients, usually asymmetrically. It may be preceded by a flulike or other febrile illness. Reports of this syndrome following a variety of conditions (immune, infectious, neoplastic, traumatic, etc) have been reported, suggesting that a variety of events can trigger an immune-mediated attack on the brachial plexus.[14] Electrodiagnostic studies may reveal a pattern of brachial plexus involvement not readily localizable to one or more specific trunks, divisions, cords, or peripheral nerves. This patchy or multifocal involvement is common and is a hallmark of this syndrome. Pathogenetically, this condition appears to be an inflammatory, immune-mediated process.[15]

CAUSES OF PROXIMAL UPPER EXTREMITY NEUROPATHIES

Medial Antebrachial Cutaneous (MAC) Nerve

Lesions generally arise from lesions that affect the lower trunk or medial cord of the brachial plexus. Several causes of brachial plexopathy are particularly likely to affect the lower trunk or medial cord and thus the MAC nerve: (1) trauma in which the arm and shoulder are pulled up; (2) invasion of the plexus by a Pancoast tumor at the

lung apex; (3) stretch injuries of the lower plexus during chest surgery such as coronary artery bypass surgery; and (4) thoracic outlet syndrome entrapping the lower trunk of the plexus.

Musculocutaneous Nerve

Lesions are most commonly caused by trauma to the shoulder and upper arm, especially factures of the proximal humerus from falls or sports injuries. In such cases, other nerves usually are damaged as well. For example, primary shoulder dislocations or fractures of the humeral neck may result in injuries to several nerves, including the axillary, suprascapular, radial, and musculocutaneous nerves.[16] Other forms of trauma, including gunshot wounds and lacerations, also may produce musculocutaneous nerve lesions. Isolated nontraumatic lesions of the musculocutaneous nerve are rare, usually occurring as it passes through the coracobrachialis muscle. Causes include weightlifting or other vigorous physical exercises,[17,18] as well as surgery, pressure during sleep, and malpositioning during anesthesia.[19,20] Rare cases of musculocutaneous nerve compression have included repeated carrying of items on the shoulder with the arm curled around the item, or osteochondroma of the humerus compressing the musculocutaneous nerve.[21] The musculocutaneous nerve may also be involved in neuralgic amyotrophy.

Lateral Antebrachial Cutaneous (LAC) Nerve

Injuries can occur in isolation without involvement of the main portion of the musculocutaneous nerves. The LAC nerve may be entrapped, usually at the elbow, where it is compressed by the biceps aponeurosis and tendon against the brachialis muscle.[19,22] Other causes of isolated LAC injury include hyperextension injury of the elbow, such as during sports, and antecubital phlebotomy.[23]

Axillary Nerve

This is most commonly damaged by trauma, including shoulder dislocations, fractures of the humeral neck,[16] blunt trauma to the shoulder in contact sports,[24] gunshot wounds, and injections. Compression may produce an axillary neuropathy during general anesthesia or by sleeping with the arms above the head. The nerve may be entrapped within the quadrilateral space (formed by the humerus, teres minor muscle, teres major muscle, and long head of the triceps muscle) by muscular hypertrophy and repetitive trauma in athletes such as tennis players and baseball pitchers.[25–27] As for other upper extremity neuropathies, neuralgic amyotrophy may be a cause.

Suprascapular Nerve

This may be entrapped as it passes through the suprascapular notch, or, less commonly, as it passes through the spinoglenoid notch.[28,29] Causes of suprascapular nerve entrapment also include mass lesions such as ganglion cysts, sarcomas, and metastatic carcinomas.[30–33] Traumatic causes of suprascapular neuropathy include shoulder dislocation or protraction or scapular fracture,[34,35] as well as injuries that generally produce more widespread damage to the brachial plexus such as stretch, gunshot, and penetrating injuries. Weightlifters may suffer suprascapular neuropathies, probably due to repetitive movement of the scapula. Other athletic activities involving overhand activities can predispose individuals to suprascapular entrapment, particularly at the spinoglenoid notch. Such injuries are particularly common in professional volleyball players[36,37] but also are seen in baseball pitchers and dancers.[38,39] As with many other upper extremity neuropathies, the suprascapular nerve also may be affected in neuralgic amyotrophy.

CLINICAL PRESENTATIONS OF BRACHIAL PLEXOPATHY

Familiarity with the clinical features of brachial plexopathies at the trunk and cord levels facilitates more targeted and clinically useful electrodiagnostic evaluations.

Upper Trunk Plexopathy

Weakness will be seen in muscles innervated at the C5-C6 levels such as the spinati (arm external rotation), deltoid (arm abduction), biceps, and brachioradialis (elbow flexion). Some muscles are partially innervated from the upper trunk, and may be partially affected, such as the pronator teres (forearm pronation), flexor carpi radialis (wrist flexion), and triceps (elbow extension). The biceps and brachioradialis reflexes are decreased or absent. Sensory loss is expected to be over the lateral upper arm in the distribution of the axillary nerve, in the lateral hand and digits 1 to 3 (median and radial sensory branches), and in the distribution of the lateral antebrachial cutaneous nerve over the lateral forearm.

Middle Trunk Plexopathy

Isolated lesions of the middle trunk are rare and usually occur in conjunction with more widespread brachial plexus lesions. The middle trunk is formed from the C7 anterior primary ramus, and so has the same clinical features as a C7 radiculopathy, with weakness of elbow, wrist, and finger extension, as well as weakness of the flexor carpi radialis (wrist flexion) and pronator teres (forearm pronation) muscles. The triceps reflex is decreased or absent. Sensory loss is over the distribution of the posterior cutaneous nerve of the forearm and in the hand over the middle finger and to a lesser degree index and ring fingers.

Lower Trunk Plexopathy

The lower trunk is formed from the C8-T1 spinal levels. Lesions involve all ulnar-innervated muscles and also C8-T1 median-innervated muscles, such as the flexor pollicis longus, pronator quadratus, and intrinsic hand muscles, and C8-innervated radial muscles, such as the extensor indicis, extensor digitorum, and extensor carpi ulnaris, resulting in weakness of grip due to weakness of hand muscles, inability to fully flex the fingers and thumb, and partial weakness of finger and wrist extension. No upper extremity reflex abnormalities are present. Sensory abnormalities occur in the medial arm, medial forearm, medial hand, and digits 4 to 5.

Lateral Cord Plexopathy

Lesions at this level result in weakness of C6-C7 innervated median muscles such as the pronator teres and flexor carpi radialis (wrist flexion) and in weakness of elbow flexion due to involvement of the biceps brachii muscle. The biceps reflex is decreased or absent, but the brachioradialis and triceps reflexes are normal. Sensory loss occurs over the lateral forearm and hand and digits 1 to 3.

Posterior Cord Plexopathy

Weakness occurs in all muscles innervated by the radial nerve, resulting in finger extension weakness, wrist drop, and arm extension weakness at the elbow. There is weakness of shoulder abduction (deltoid) and adduction (latissimus dorsi). The triceps and brachioradialis reflexes are decreased or absent, although the biceps reflexes is preserved. There is sensory loss in the distributions of the axillary nerve, posterior cutaneous nerve of the arm, and superficial radial nerve.

Medial Cord Plexopathy

This lesion results in the same clinical deficits as a lower trunk lesion, except for preservation of radial-innervated C8 fibers. Patients demonstrate weakness of all ulnar-innervated muscles and C8-T1-innervated median muscles, leading to weakness of grip due to weakness of hand muscles and to inability to fully flex the fingers and thumb. However, finger and wrist extensors are spared. There is sensory loss in the same distribution as for lower trunk lesions: medial arm, medial forearm, medial hand, and digits 4 to 5. There are no reflex abnormalities.

Panplexopathy

Widespread lesions of this type cause weakness of the upper extremity except for remaining function of the rhomboids and serratus anterior muscles. Reflexes are all decreased or absent. There is widespread sensory loss.

CLINICAL PRESENTATIONS OF PROXIMAL UPPER EXTREMITY NEUROPATHIES

The *MAC nerve* is exclusively a sensory nerve, supplying cutaneous sensation over the medial portion of the forearm. Lesions of this nerve result in sensory loss in this distribution, without weakness and without reflex changes. As noted earlier, lesions of this nerve often occur in association with lesions of the lower trunk or medial cord of the brachial plexus.

Patients with *musculocutaneous neuropathies* present with weakness of elbow flexion, an absent biceps reflex, and sensory alteration in the distribution of the *LAC nerve* (lateral forearm), whereas those with an isolated LAC neuropathy demonstrate the sensory alteration, but with normal muscle strength and reflexes. Patients in whom the *LAC nerve* is entrapped at the elbow present with pain in the anterolateral aspect of the elbow region, which is worsened by pronation of the arm and extension at the elbow.[19,22,40]

Axillary nerve lesions result in partial weakness of shoulder abduction and external rotation, motions that are partially maintained by the supraspinatus and infraspinatus muscles, respectively. Atrophy of the deltoid region of the upper arm may result. There is sensory loss over the lateral aspect of the upper arm.

Entrapment of the *suprascapular nerve* at the suprascapular notch usually is accompanied by pain, most prominently along the superior aspect of the scapula and radiating to the posterior and lateral shoulder. The pain may be referred to arm, neck, or upper anterior chest wall[21,29] and may be exacerbated by shoulder movements. The suprascapular notch may be tender to palpation. When suprascapular nerve is injured or when it is entrapped at the suprascapular notch, the clinical manifestation is primarily weakness of shoulder external rotation (infraspinatus muscle weakness). Shoulder abduction (supraspinatus muscle) is weakened only slightly because of preservation of the deltoid muscle. Atrophy may be noted, particularly of the infraspinatus muscle, which is only partly covered by the overlying trapezius muscle. If entrapment occurs at the spinoglenoid ligament, then only infraspinatus weakness results, resulting in weakness of shoulder external rotation but no weakness of shoulder abduction. There is no cutaneous sensory alteration.

ELECTRODIAGNOSIS OF BRACHIAL PLEXOPATHIES

As is generally the case with electrodiagnosis, the electromyographer's role is one of localization and assessment of severity, than determination of causes. It is important for the electromyographer to have a good understanding of the history and

examination findings of the patient being studied, of course, because this information, in conjunction with information about localization and severity, is the key in narrowing down the range of possible causes and in permitting the electromyographer to use his or her knowledge to function as a true electrodiagnostic consultant and partner in the diagnosis and care of the patient, than simply as a technical proceduralist. There are few types of disorders in which electrodiagnosis is more important than in brachial plexopathies, which can be due to a wide variety of causes and present and evolve in many different ways. Electrodiagnostic evaluations of brachial plexopathies are generally complex, involving the study of multiple nerves and muscles to permit accurate localization. General principles that guide the performance of the electrodiagnostic evaluation of brachial plexopathies, are provided in **Boxes 2–4** and **Table 2**.

Upper Trunk Plexopathy

Sensory studies will reveal abnormalities in the following nerves: LAC, median sensory (particularly to the thumb), and radial sensory (particularly to the thumb) nerves. Routine studies of the median and ulnar motor nerves are normal, but studies of the suprascapular, axillary, and musculocutaneous nerves, if performed, may be abnormal. Needle examination is expected to demonstrate abnormalities in the supraspinatus, infraspinatus, deltoid, biceps brachii, and brachioradialis muscles. The pronator teres, flexor carpi radialis, triceps, and extensor carpi radialis muscles may show abnormalities. C5-C6 muscles innervated at the root level will be spared, including the cervical paraspinal, serratus anterior, and rhomboid muscles.

Middle Trunk Plexopathy

The median sensory response is expected to be abnormal when recording from the middle finger. Routine studies of the median and ulnar motor nerves are normal.

Box 2
Guidelines for sensory nerve studies in brachial plexopathy

- Sensory nerve studies are a key feature in distinguishing brachial plexopathies from radiculopathies. In radiculopathy, because the lesion occurs proximal to the dorsal root ganglion, sensory nerve conduction studies are NORMAL, even in the distribution of the numbness, because the sensory nerve is intact from the level of its cell body (the dorsal root ganglion) to the level of the skin. In plexopathies (or in peripheral neuropathies), the lesion occurs at or distal to the dorsal root ganglion so that the sensory nerve conduction studies are ABNORMAL because of axon loss from the level of the cell body to the skin.
- Beginning with standard median, ulnar, and radial sensory studies usually is most helpful.
- It is often helpful to perform extensive sensory nerve studies, including some uncommonly studied nerves, to distinguish a brachial plexopathy from radiculopathy or from multiple mononeuropathies and to more precisely localize the plexopathy. Medial and lateral antebrachial cutaneous nerve studies are particularly useful for distinguishing plexopathy from radiculopathy.
- Side-to-side comparisons of sensory amplitudes are helpful, particularly when assessing uncommonly studied nerves, for which normal values may be less well established. A sensory nerve action potential amplitude on the symptomatic side that is less than half of that on the asymptomatic side is considered to be abnormal, even if the absolute value of the amplitude falls within the normal range.
- Careful selection of the digit used when recording a median or radial sensory response can improve sensitivity and specificity. **Table 2** lists some sensory studies, which are particularly useful in the electrodiagnostic assessment of brachial plexopathies.

Box 3
Guidelines for motor nerve studies in brachial plexopathy

- Beginning with standard median, ulnar, and (in selected instances) radial motor studies usually is most helpful.
- Suprascapular, axillary, and musculocutaneous nerve studies should be considered in selected cases. These studies are not commonly performed because the needed information often is obtained through needle examination of the muscles supplied by these motor nerves. However, nerve conduction studies should be considered if the needle examination cannot be performed or is limited. These nerve studies can provide useful information regarding upper trunk, posterior cord, and lateral cord plexopathies.

Needle examination generally reveals abnormalities in C7-innervated muscles, such as the pronator teres, flexor carpi radialis, triceps, extensor carpi radialis, and extensor digitorum communis muscles. C7 muscles innervated at the root level will be spared, such as the cervical paraspinal and serratus anterior muscles.

Lower Trunk Plexopathy

Several sensory studies will be abnormal, including the studies of MAC nerve, the median sensory to the ring finger, the ulnar sensory to the little finger, and the dorsal ulnar cutaneous sensory nerve. In testing of motor nerves, if there is sufficient axon loss, then the median and ulnar motor studies may be abnormal, with the degree of abnormality being determined by the severity of the axon loss. Partial axon loss may reveal low compound muscle action potential (CMAP) amplitudes, mildly to moderately prolonged distal motor latencies, and mildly to moderately slowed conduction velocities. Severe axon loss could result in absent responses. On needle examination, abnormalities are expected in C8-T1-innervated muscles, including all ulnar-innervated muscles and selected median and radial muscles. Of the radial-innervated muscles, the extensor indicis is a particularly useful muscle to test. Median-innervated muscles, which are likely to be abnormal, are the flexor pollicis longus, pronator quadratus, and intrinsic hand muscles. Of course, cervical paraspinal muscles will be spared.

Lateral Cord Plexopathy

Abnormalities are expected in the LAC nerve and the median sensory nerve, recording from the thumb, index, or middle finger. Routine studies of the median and ulnar motor

Box 4
Guidelines for the needle examination in brachial plexopathy

- The needle examination in brachial plexopathies often will need to be extensive if it is to result in accurate localization.
- The presence or absence of axonal continuity often is of great value to the surgeon. So it is important to search carefully for voluntary motor unit action potential firing in weak muscles. If axonal continuity is present, surgical exploration may be postponed.
- Keep in mind those muscles that are innervated at the root level, proximal to the brachial plexus. Those muscles will be abnormal in some radiculopathies but normal in brachial plexopathies.
- There are variations in the spinal levels supplying the various portions of the plexus. Denervation in unexpected muscles or the absence of denervation in muscles expected to be affected may represent not only the patchy nature of some brachial plexopathies, but also the anatomic variations that may occur.

Table 2
Median and radial sensory studies of importance in assessment of brachial plexopathy

Clinical Finding	Clinical Considerations	Sensory Nerve to Study	Localization When Abnormal
Sensory loss lateral forearm and hand	• Upper trunk plexopathy • Lateral cord plexopathy • C6 radiculopathy	Median sensory to the thumb	Upper trunk or lateral cord plexopathy or median neuropathy
		Radial sensory to the thumb	Upper trunk or posterior cord plexopathy or radial neuropathy
		Lateral antebrachial cutaneous nerve	Upper trunk or lateral cord plexopathy
Sensory loss medial forearm and hand	• Lower trunk plexopathy • Medial cord plexopathy • C8-T1 radiculopathy	Ulnar sensory to the little finger	Lower trunk or medial cord plexopathy or ulnar neuropathy
		Dorsal cutaneous ulnar sensory nerve	Lower trunk or medial cord plexopathy or ulnar neuropathy proximal to the wrist
		Medial antebrachial cutaneous nerve	Lower trunk or medial cord plexopathy

nerves are normal. Needle examination reveals abnormalities in the biceps brachii and median-innervated forearm muscles (pronator teres, flexor carpi radialis), with sparing of the more distal median-innervated muscles such as the flexor pollicis longus and median-innervated hand muscles. Cervical paraspinal muscles and other muscles innervated at the root level are spared.

Posterior Cord Plexopathy

The radial sensory study is abnormal. Routine studies of the median and ulnar motor nerves are normal. When studying the radial motor nerve, if there is sufficient axon loss, then the radial motor studies may be abnormal, with the degree of abnormality being determined by the severity of the axon loss. Partial axon loss may reveal low CMAP amplitudes, mildly to moderately prolonged distal motor latencies, and mildly to moderately slowed conduction velocities. Severe axon loss could result in absent responses. Needle examination is expected to show abnormalities in all radial-innervated muscles and in the deltoid, teres minor, and latissimus dorsi muscles.

Medial Cord Plexopathy

Electrodiagnostic testing is expected to produce the same findings as for a lower trunk lesion, but with sparing of C8 muscles innervated by the radial nerve. Abnormalities are expected on testing of the MAC nerve, the median sensory to the ring finger, the ulnar sensory to the little finger, and the dorsal ulnar cutaneous sensory nerve. On motor nerve testing, if there is sufficient axon loss, then the median and ulnar motor studies may be abnormal, with the degree of abnormality being determined by the severity of the axon loss. Partial axon loss may reveal low CMAP amplitudes, mildly to moderately prolonged distal motor latencies, and mildly to moderately slowed conduction velocities. Severe axon loss could result in absent responses. Needle examination should reveal abnormalities in C8-T1-innervated muscles supplied by the ulnar and median nerves, including all ulnar-innervated muscles and selected median-innervated muscles such as the flexor pollicis longus, pronator quadratus,

and intrinsic hand muscles. As noted earlier, radial-innervated C8 muscles are spared. The extensor indicis is a particularly useful muscle to test. Once again, cervical paraspinal muscles are spared, as with all plexus lesions.

Panplexopathy

As expected, the abnormalities here are widespread. Median, ulnar, and radial sensory responses are abnormal, as are the MAC and LAC nerve studies. If there is sufficient axon loss, then the median, ulnar, and radial motor studies may be abnormal, as may the suprascapular, axillary, and musculocutaneous nerve studies, with the degree of abnormality being determined by the severity of the axon loss. Partial axon loss may reveal low CMAP amplitudes, mildly to moderately prolonged distal motor latencies, and mildly to moderately slowed conduction velocities. Severe axon loss could result in absent responses. On needle examination, abnormalities are expected in all muscles of the upper extremity and shoulder girdle except for those innervated directly at the root level, specifically the cervical paraspinal, rhomboid, and serratus anterior muscles.

ELECTRODIAGNOSIS OF PROXIMAL UPPER EXTREMITY NEUROPATHIES

Medial Antebrachial Cutaneous Nerve

Recording electrodes (**Fig. 4**)

- Active electrode (E1): On the medial forearm, 12 cm distal to the stimulation site, on a line between the stimulation site and the ulnar aspect of the wrist.
- Reference electrode (E2): 3 to 4 cm distal to E1.

Stimulator

- In the medial portion of the antecubital fossa, midway between the tendon of the biceps brachii muscle and medial epicondyle.

Normal values[21]

- Amplitude greater than or equal to 5 μV
- Conduction velocity greater than or equal to 50 m/s
- Distal peak latency less than or equal to 3.2 ms

Alternative normal values[41]

- Amplitude greater than or equal to 10 μV
- Conduction velocity greater than or equal to 41.7 m/s

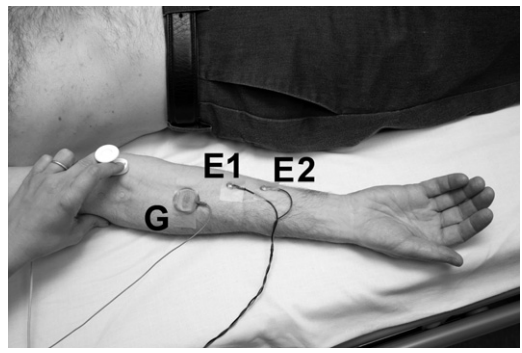

Fig. 4. Nerve conduction study of the medial antebrachial cutaneous nerve. Stimulation is at the medial portion of the antecubital fossa. Recording is from the medial forearm. E1, active electrode; E2, reference electrode; G, ground.

- Distal peak latency mean 2.1 ms

Notes

- The nerve is superficial, and maximal responses usually are obtained at low levels of stimulation.
- Side-to-side comparisons of the symptomatic and asymptomatic side are more useful than absolute values.

Musculocutaneous Nerve

Recording electrodes (**Fig. 5**)

- Active electrode (E1): Over the biceps, just distal to the midpoint of the muscle.
- Reference electrode (E2): Distally to E1 in the antecubital fossa, over the biceps tendon.

Stimulator

- Erb point

Normal values[21]

- Latency less than or equal to 5.7 ms at distance 23 to 29 cm, using calipers

Alternative normal values[42,43]

- Latency less than or equal to 5.7 ms at distance of 23.5 to 29 cm (calipers), 28 to 41.5 cm (tape, arm at side), or 26 to 35.5 cm (tape, arm abducted 90°)
- Latency 5.5 ms to 6.7 ms at distance of 25 to 33 cm, using calipers

Notes

- Supramaximal stimulation is difficult to achieve. Best to compare symptomatic to asymptomatic side.

Lateral Antebrachial Cutaneous Nerve

Recording electrodes (**Fig. 6**)

- Active electrode (E1): On the lateral forearm, 12 cm distal to the stimulation site, on a line between the stimulation site and the radial pulse.
- Reference electrode (E2): 3 to 4 cm distal to E1

Stimulator

- Lateral portion of the antecubital fossa, just lateral to the tendon of the biceps brachii muscle.

Normal values[21]

- Amplitude greater than or equal to 10 μV
- Conduction velocity greater than or equal to 55 m/s

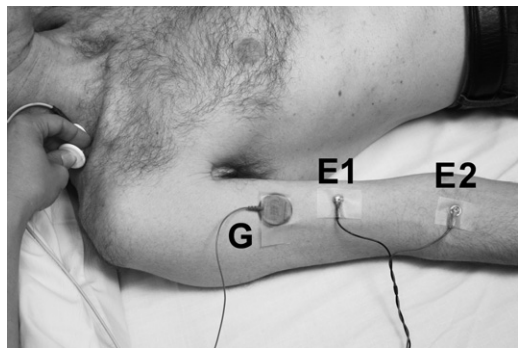

Fig. 5. Nerve conduction study of the musculocutaneous nerve. Stimulation is at Erb point. Recording is from the biceps, just distal to the midpoint. E1, active electrode; E2, reference electrode; G, ground.

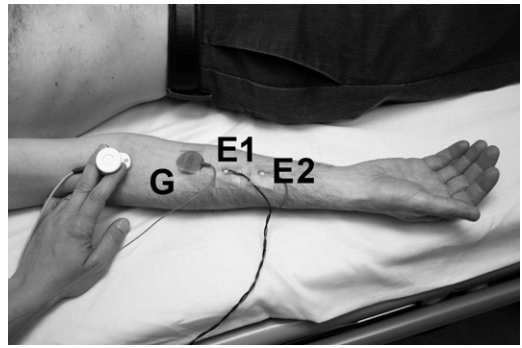

Fig. 6. Nerve conduction study of the lateral antebrachial cutaneous nerve. Stimulation is at the lateral portion of the antecubital fossa. Recording is from the lateral forearm. E1, active electrode; E2, reference electrode; G, ground.

- Peak latency less than or equal to 3.0 ms

Alternative normal values[44]

- Amplitude greater than or equal to 12 μV
- Conduction velocity greater than or equal to 57.8 m/s
- Distal peak latency less than or equal to 2.5 ms

Notes

- The nerve is superficial, and maximal responses usually are obtained at low levels of stimulation.
- Side-to-side comparisons of the symptomatic and asymptomatic side are more useful than absolute values.

Axillary Nerve

Recording electrodes (**Fig. 7**)

- Active electrode (E1): Middle deltoid
- Reference electrode (E2): Distally to E1, over the deltoid tendon.

Stimulator

- Erb point

Normal values[42]

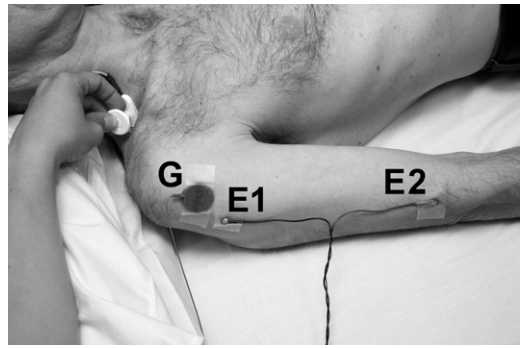

Fig. 7. Nerve conduction study of the axillary nerve. Stimulation is at Erb point. Recording is from the middle deltoid. E1, active electrode; E2, reference electrode; G, ground.

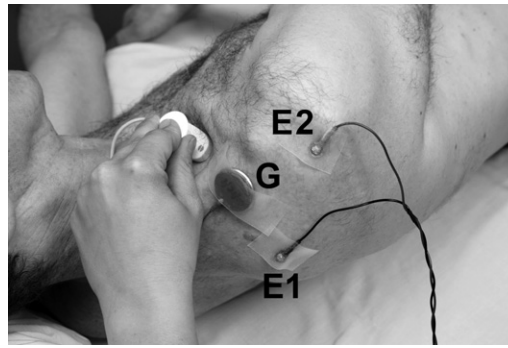

Fig. 8. Nerve conduction study of the suprascapular nerve, recording from the supraspinatus muscle. A needle than a surface-recording electrode would be used. Stimulation is at Erb point. E1, active electrode; E2, reference electrode; G, ground.

- Latency less than or equal to 5.0 ms at a distance of 14.8 to 21 cm (calipers), 20 to 26.5 cm (tape, arm at side), or 17.5 to 25.3 cm (tape, arm abducted 90°).

Notes

- Compare symptomatic to asymptomatic side.
- May be technically difficult to obtain supramaximal stimulation.

Suprascapular Nerve

Recording electrodes (**Figs. 8** and **9**)

- Active electrode (E1): A monopolar needle in the supraspinatus or infraspinatus muscle. Do NOT use a surface electrode because the trapezius muscle is more superficial and covers the intended muscles.
- Reference electrode (E2): Distally over shoulder joint.

Stimulator

- Erb point.

Normal values[42]

- Recording from supraspinatus muscle: Latency less than or equal to 3.7 ms at a distance of 7.4 to 12 cm (calipers) or 9 to 13.8 cm (tape, arm at side or abducted 90°)

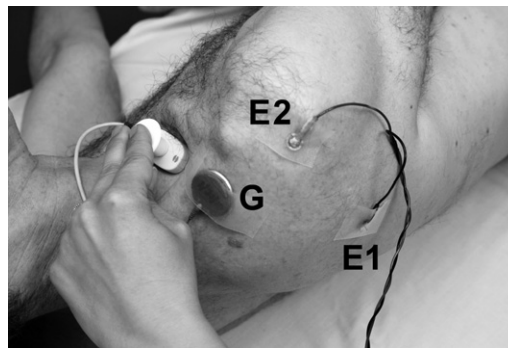

Fig. 9. Nerve conduction study of the suprascapular nerve, recording from the infraspinatus muscle. A needle than a surface-recording electrode would be used. Stimulation is at Erb point. E1, active electrode; E2, reference electrode; G, ground.

- Recording from infraspinatus muscle: Latency less than or equal to 4.2 ms at a distance of 10 to 15 cm (calipers) or 15 to 19.5 cm (tape, arm at side or abducted 90°).

Notes

- Compare symptomatic to asymptomatic side.
- May be technically difficult to obtain supramaximal stimulation.

SUMMARY

Although initially intimidating to many electromyographers, the brachial plexus is a highly organized structure, knowledge of which will, in conjunction with familiarity with proximal upper extremity nerves, permit logical clinical and electrodiagnostic evaluations that result in useful conclusions regarding localization and severity of abnormalities. A willingness to take the time to perform some additional electrodiagnostic evaluation beyond the "standard" studies generally will be rewarded with information that is helpful to the referring clinician. When combined with knowledge of possible causes of brachial plexus lesions, the electrodiagnostic evaluation will truly function as an extension of the clinical examination.

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