Neurological Injuries Associated With Regional Anesthesia

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A peripheral nerve or spinal cord injury is a rare but significant complication of regional anesthesia. Evaluation of acute nerve injury includes a focused history and examination to localize the lesion. Confirmatory testing should include electromyography and appropriate imaging. In most cases magnetic resonance imaging (MRI) is preferred to computed tomography (CT) or ultrasound given the better resolution of the nerves and soft tissue. Most cases of peripheral nerve injury will improve and resolve without deficit. In mild cases reassurance and observation is all that is necessary. In more severe cases, if the deficit is progressive or complete, surgical exploration should be considered. If there is no recovery by 2 to 5 months then referral to a peripheral nerve surgeon should be considered. The prognosis for cauda equina or spinal cord lesions is more guarded. Recovery from these is commonly incomplete. Early diagnosis and intervention is the key to preventing catastrophic neurological outcomes. *Reg Anesth Pain Med 2008;33:442-448.*

Peripheral nerve injury is a rare complication of regional anesthesia. Retrospective studies have suggested an incidence rate of around 0.5% to 1.0% of cases using peripheral nerve blocks. Prospective studies have suggested a higher incidence rate of between 10% to 15%.[1] The discrepancy between these is likely from the inclusion of mild and subclinical mononeuropathies in the prospective studies which are absent from the retrospective chart reviews. Fortunately most nerve injuries related to regional anesthesia are transient. Approximately 95% resolve within 4 to 6 weeks, and over 99% resolve within 1 year.[2,3] Despite their infrequent occurrence and their usually benign outcome, peripheral nerve injury remains a significant medicolegal issue associated with regional anesthesia.

Lesions of the cauda equina and spinal cord are more uncommon, but often have a poorer prognosis. A large Scandinavian series identified an incidence rate of about 1 per 14,000 procedures involving spinal or epidural anesthesia.[4] The majority represented compressive lesions, secondary to either a spinal hematoma or pre-existing structural lesion. Less commonly these complications are attributed to infectious causes, either meningitis or localized abscess.

Mechanisms of Injury

Injury to the nerve typically results in either axonal loss or neurapraxia. Neuropraxic lesions will typically have a better prognosis and faster resolution than those with axonal loss. Neuropraxic lesions result in damage to the myelin sheath which disrupt the nerve action potential. Neuropraxic lesions, however, will preserve the axon. Because the axon remains functional, once the myelin sheath is repaired the nerve will once again function normally. If the axon is lost, recovery is dependent upon collateral reinnervation from surviving axons or from axonal regrowth. This latter process is slow and often incomplete.

The mechanisms of peripheral nerve or cauda equina injury can usually be classified as: (1) blunt trauma; (2) toxic injury; (3) compressive injury; (4) stretch injury; and (5) ischemic injury. Blunt trauma occurs during needle placement or by surgical transection of the nerve. Blunt trauma injuries tend to result in axonal loss and thus a poorer prognosis. Direct toxic injury from the anesthetic agent continues to be a controversial topic.

Compressive injury occurs commonly from a hematoma at the site of the injection or prolonged tourniquet use. Less common compressive injuries may occur as a result of postoperative edema or from large-volume injections into the region. Stretch injuries typically occur via prolonged traction or improper limb positioning. Both compressive and stretch inju-

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ries are more commonly associated with neuropraxic lesions and less axonal damage as a result.

The final mechanism of injury is ischemic. Nerve ischemia may occur after vascular injury, prolonged tourniquet use, or as a result of vasoconstrictors used in the nerve block. Ischemic injuries are primarily associated with axonal injury and have a poorer prognosis.

Besides pathology, the severity of the lesion is relevant to the prognosis. An incomplete lesion with preserved nerve continuity will result in a much better long-term outcome than complete or transection lesions. This is due to the greater efficiency of reinnervation via collateral sprouting. A complete nerve lesion or a transection must depend entirely upon axonal regrowth for reinnervation. This process is slow, inefficient, and usually incomplete. Lesions this severe are typically associated with long-term deficits and poorer functional outcomes.

It is generally believed that subjects with an underlying peripheral neuropathy are at greater risk for peripheral nerve complications. The reasons for this are unclear. It has been hypothesized that sick nerves are more susceptible to injury. Alternatively it is possible that those with pre-existing nerve lesions are more likely to be aware of a superimposed deficit than someone without a pre-existing lesion. Regardless of the reason, studies have shown that a high proportion of postprocedure nerve lesions occur within nerves with pre-existing pathology.[3]

Rarely, peripheral nerve injuries after regional anesthesia or other procedures are due to an inflammatory neuritis also known by the eponym "Parsonage-Turner Syndrome."[5] The mechanism of postoperative inflammatory neuritis is poorly understood. It is commonly believed that the procedure induces an immunological response that results in an autoimmune reaction against antigenic elements of the axons, peripheral myelin, or Schwann cells.

Evaluation

The first step when encountering a patient with a suspected postprocedure neuropathy is to take a careful history and to carefully examine the area of interest. In eliciting the history, one is principally interested in any symptoms suggestive of a pre-existing peripheral nerve problem. Of particular importance is a history of diabetes or glucose metabolism impairment. The objective of the neurological examination is to localize the lesion to the appropriate structure(s) and region. This requires a comprehensive knowledge of peripheral nerve anatomy as well as the ability to perform and interpret the neurological examination reliably. The goal of the examination is to identify if the process is affecting a single peripheral nerve, multiple peripheral nerves, the plexus, or the nerve root(s). The examination will also determine the severity of the deficits, a factor in the long-term prognosis. An overview of the diagnostic workup and management algorithm is outlined in Figure 1.

At this stage if no deficit is apparent and the symptoms are mild or resolving, reassurance and observation may be all that is indicated. The long-term prognosis for these patients is excellent and may be counseled as such. If a deficit is identified then additional investigations are suggested. There are 2 principal ancillary tests to consider: neurophysiology (nerve conduction studies and electromyography), and imaging of the nerves. These tests are complementary, each providing unique information not available otherwise. A compressive lesion of the cauda equina or spinal cord, such as a spinal hematoma, after epidural or spinal anesthesia is a true neurologic emergency and urgent imaging of the spine is necessary. If confirmed, neurosurgical consultation and intervention is imperative to minimize long-term residual deficits.

Neurophysiology

Nerve conduction studies and electromyography (commonly referred to in combination as EMG) can provide a quantitative or semiquantitative assessment of nerve injury. It will provide information on the pre-existing status of the nerves, prognosis of the new lesion, and may often suggest the underlying pathology. Imaging studies on the other hand are principally used to identify or confirm the location of the lesion and define the anatomy of the region.

Well performed electrophysiology studies are essential for the correct diagnosis and localization of these lesions. Success of the electrophysiology studies depends upon proper planning and a focused differential diagnosis. This differential diagnosis is the result of an accurate history and detailed clinical examination of the affected area. One needs to accurately assess which muscles are clinically weak, which reflexes are diminished, and what is the distribution of any apparent sensory loss. Using this information the clinician can usually form a short list of plausible localizations. The electrophysiology studies need to be directed at differentiating this short list.

The timing of the EMG needs to be carefully considered. EMG testing done within the first few days of the onset will not be as informative as testing done 14 to 21 days later. Figure 2 is an example of a motor nerve conduction study in an

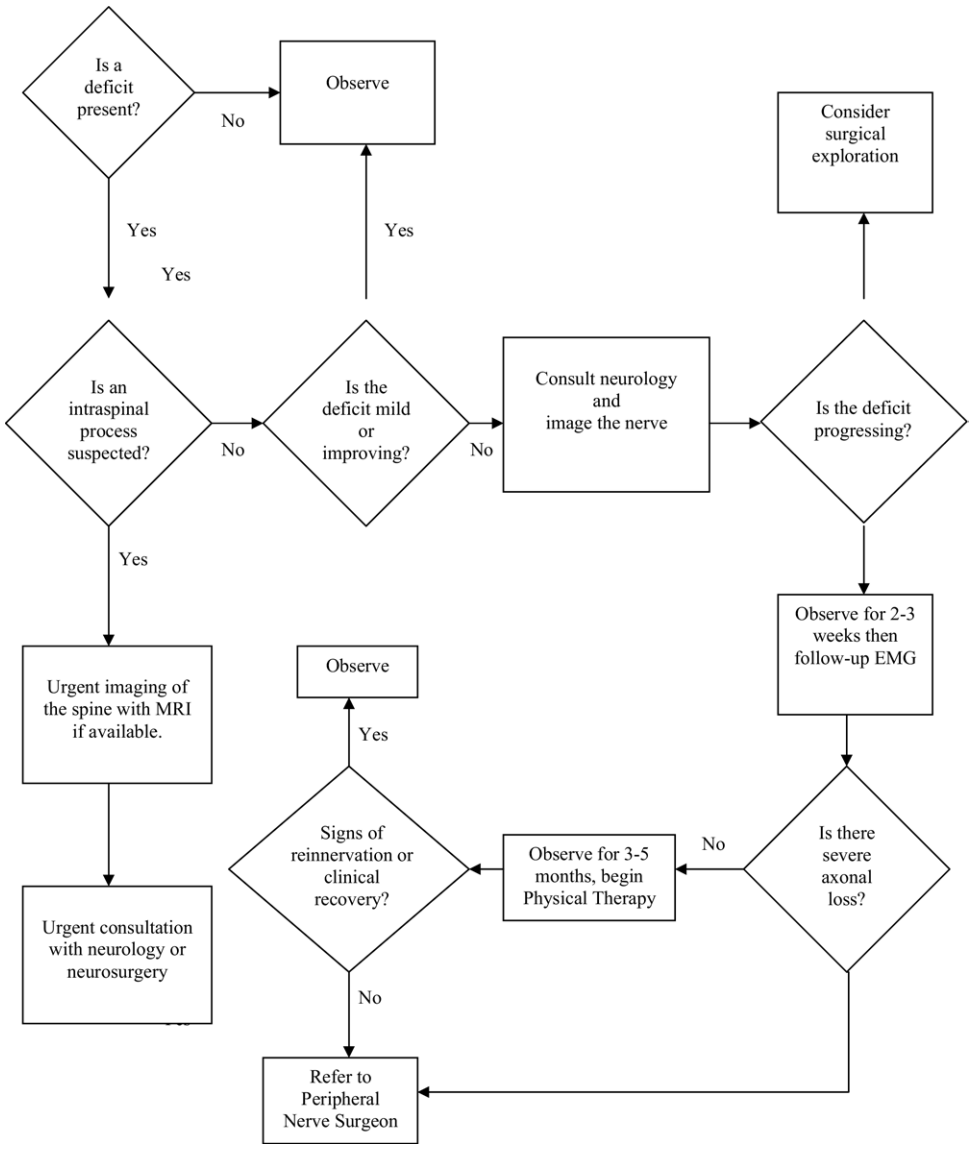

Fig 1. Flowchart outlining a diagnostic and management approach.

acute, complete radial neuropathy occurring at the spiral groove. Within the first few days, the preserved response with stimulation distal to the transection will falsely imply nerve preservation.

Within the first few days only motor unit recruitment on needle EMG will be affected by the acute lesion. Other changes identified will be indicative of the pre-existing status of the nerve. This may be used to the advantage of the EMG physician as this represents an opportunity to establish whether or not a pre-existing lesion was present prior to the procedure. When combined with follow-up testing, EMG may accurately identify the magnitude and timing of the nerve injury, an issue that has significant medicolegal implications.

Nerve conduction studies and needle EMG are complementary in the information they provide. Together, they are used to derive the localization of any nerve lesion. The gold standard of localization is identification of conduction block or focal slowing. Only with a reliable, reproducible focal area of conduction block can a lesion be localized with the utmost confidence. By definition, conduction block occurs where the conduction of a nerve action potential is blocked along the path of an intact axon. Conduction block is the electrophysiologic equivalent of neurapraxia. This can be identified by electrical stimulation of the nerve proximal to the lesion and then again distal to the lesion. Typically conduction block can only be reliably identified in the compound muscle action potentials. Conduction block results in a significant drop in the compound muscle action potential amplitude when stimulating proximally, compared with the distal stimulation sites. Sensory nerve action potentials normally drop in amplitude as the distance increases be-

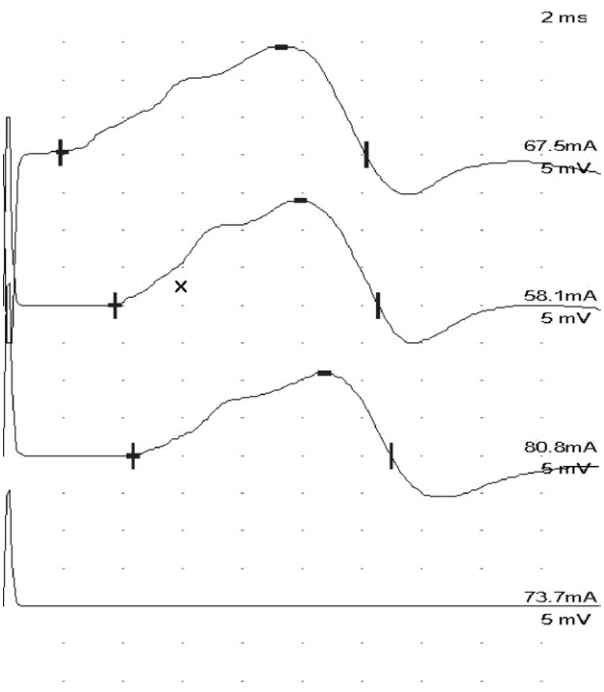

Fig 2. Motor nerve conduction study of the radial motor nerve showing a complete conduction block at the spiral groove as evident by the absent response in the fourth tracing.

tween the stimulation site and recording site, making identification of conduction block by the sensory studies unreliable.

There are no generally agreed upon criteria for the diagnosis of conduction block.[6-8] One practical rule of thumb is the 10-20-30 rule. Conduction block is present if there is a drop in amplitude or area of greater than 10% over a short segment (e.g., inching techniques), 20% over intermediate segments (e.g., above elbow-below elbow, or above fibular head-below fibular head) or 30% over any length of nerve *without* dispersion of the response. Dispersion is defined as a change in the duration of the proximal response of greater than 15% the distal response. If dispersion is present then one can only conclude probable or possible conduction block. Alternatively, a drop in amplitude or area of greater than 50% irrespective of nerve length or dispersion is consistent with conduction block.

The importance of conduction block cannot be overstated. First, if identified carefully, it will definitively localize the lesion to the site of block. Second, conduction block typically offers a good prognosis for recovery as it suggests neurapraxia. Lesions resulting in conduction block typically have the best overall recovery in the shortest period of time. In making this prognosis, however, one has to be careful to avoid confusing a pseudo conduction block secondary to an acute transection (Fig 2) with classical conduction block of neurapraxia and compression.

Pseudo conduction block occurs immediately after axonal disruption and before wallerian degeneration has occurred. In the few days after a nerve transection the distal segment will continue to be electrically excitable and will generate and propagate a nerve action potential to electrical stimulation. In this setting, stimulation above the transection will fail to elicit a compound muscle action potential, but stimulation distal to the transection will elicit a normal compound muscle action potential. These findings will exactly mimic conduction block. In the setting of a nerve transection, however, the axons distal to the transection will become electrically inexcitable over the next 7 to 10 days as the axons begin to undergo degeneration and the pseudo conduction block will disappear. Therefore it is recommended that any apparent conduction block identified within the first week after a nerve injury be confirmed with repeat testing in 1 to 2 weeks time.

Most traumatic lesions will result in axonal disruption which will not result in conduction block or focal slowing. With axonal loss, stimulation above and below the lesion will not generate any apparent distinction to the compound muscle action potential amplitudes. To localize an axonal lesion the 2 most helpful examinations are the sensory nerve action potential studies and needle EMG.

Sensory nerve action potentials, when abnormal, are very helpful in mapping the distribution of the sensory deficits and identifying the peripheral nerves affected. These studies, however, cannot confirm the exact site of the lesion; they merely confirm which particular nerve or nerves are affected. Needle EMG provides complementary information to the nerve conduction studies. The goal of needle EMG is to examine muscles along the course of the nerve to identify where the denervation begins and ends. By doing so, the clinician can conclude that the lesion is proximal to the branch point to the most proximally affected muscle. Unfortunately precise localization cannot be made.

While it is tempting to conclude that the lesion is between the branches to the last unaffected muscle and the first affected muscle, experience dictates that this may not be valid. In partial lesions, some fascicles may remain unaffected. Therefore if a muscle is spared, one cannot conclude with certainty that the lesion is distal to that muscle's innervation. If localization remains indeterminate after neurophysiology testing, imaging of the nerve with high strength (3 tesla [3T]) MRI now provides adequate resolution to identify many peripheral nerve injuries/lesions.

Imaging

MRI has become the imaging modality of choice when visualizing the peripheral nerves directly. CT imaging may be appropriate in some situations where an acute hematoma is suspected (i.e., subject with a coagulopathy or retroperitoneal hemorrhage) or if bony structures are implicated. High-resolution 3T MRI is preferable where available given the enhanced resolution to visualize the nerves and surrounding soft tissue structures (Fig 3). Ultrasound is a newer imaging modality that may have a role in imaging of the nerve but has not yet proven its value. Ultrasound provides dynamic imaging of the nerve and soft tissues in varying positions which is a theoretical advantage over MRI and CT. Ultrasound, however, does not provide the image resolution that either CT or MRI attains (Fig 4).

MRI of the peripheral nerves is more complicated given the size of the structures involved. The smaller the nerve the more difficult it is to obtain high-quality imaging. The principal advantage of the 3 tesla magnet is the improved resolution the higher strength magnet allows. Standard spin-echo sequences to generate traditional T1-weighted imaging are useful in demonstrating normal anatomy. The muscles, blood vessels, and nerves are nicely outlined by fat tissue planes. While the size of the nerve may be appreciated on T1-weighted images, intrinsic pathology of the nerve cannot. Routine fast spin-echo sequences to generate T2-weighted images will be limited due to the fat artifact from the surrounding tissue planes obscuring the signal from the nerve. Because of these reasons fat suppression techniques are required on T2-weighted imaging to eliminate this fat effect. It is generally recommended to perform imaging in at least 2 separate planes.[9] Typically imaging is done in the cross-sectional plane and then 1 of the longitudinal planes. Comparisons across planes make artifact identification easier.

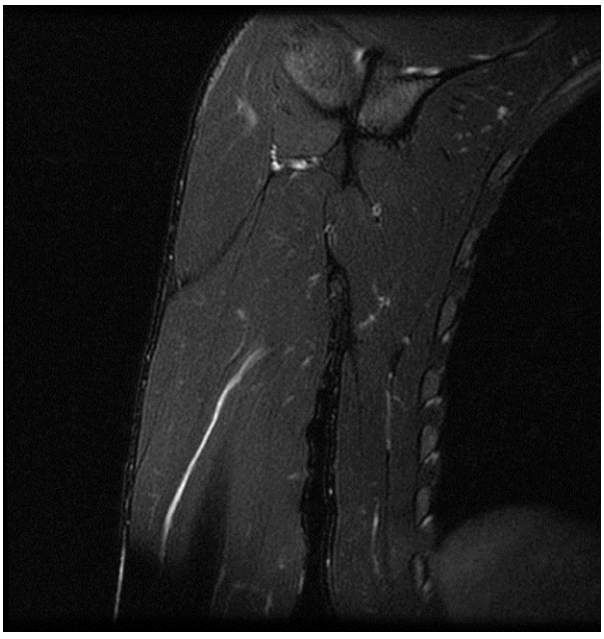

Fig 3. Imaging of the peripheral nerves via a high tesla magnet will significantly increase the resolution of the neural structures. Note this example, of the radial nerve as it passes through the spiral groove, completed on a 3 tesla magnet.

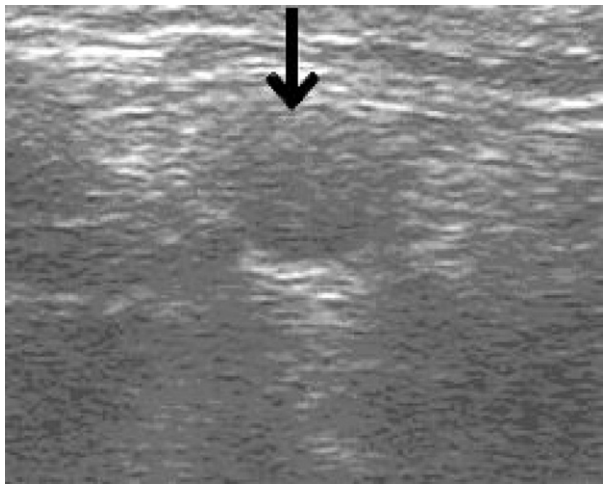

Fig 4. An example of ultrasound imaging of the brachial plexus. The subclavian artery is identified as the large circular hypoechoic structure denoted by the black arrow. The hyperechoic regions surrounding the artery represent the 3 cords of the brachial plexus.

Infiltrating or compressive lesions are frequently easy to identify with MRI. More subtle changes in the size of the nerve or signal characteristics of the nerve should also be examined. Examination of the contralateral nerve in the same region may be helpful in assessing for asymmetry. Unfortunately, the angle of the tissue plane relative to the magnet will affect the signaling characteristics of the nerve. Small changes in the magnet angle may create artifactually increased or decreased signal with the nerve of interest.[10] Finally, it is frequently possible in chronic lesions to identify signal change within the muscles that are innervated by the lesioned nerve.[11-13]

MRI has replaced CT and myelography as the imaging modalities of choice for the spinal canal. The ability of MRI to noninvasively image the spine in multiple planes with better resolution of the soft tissues offers significant advantages over CT and myelography (Fig 5). CT with myelography is indicated in subjects with a contraindication to MRI. Such contraindications include implantable devices (such as a pacemaker or implantable pump), pres-

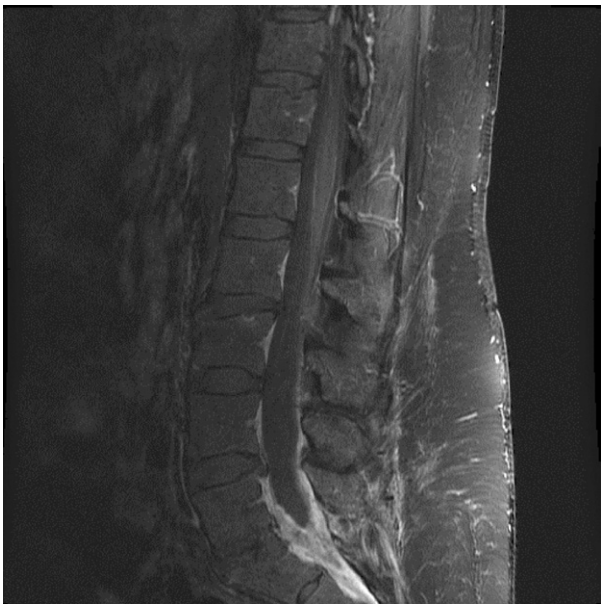

Fig 5. An example of an epidural abscess identified in the sacral region by contrast-enhanced magnetic resonance imaging scan.

ence of MRI-incompatible hardware, or hardware placement adjacent to the area of interest (such as metallic spinal rod placement). In some institutions MRI may not be available on an emergent basis. In these cases CT should be pursued, as waiting for elective MRI images will unwisely delay intervention.

An epidural hematoma or abscess are among the most feared complications of spinal or epidural anesthesia. On MRI images these abnormalities are easily identified. The signal characteristics of an epidural hematoma will depend on its stage of evolution (Table 1). After only a few hours the hematoma will usually have isointense to hypointense signal on T1-weighted imaging. On T2-weighted imaging there is usually prominent hypointense signal due to clot formation and retraction. Over the next 2 to 4 days, the hemoglobin will be oxidized to methemoglobin resulting in a strong paramagnetic effect. This will cause T1-weighted shortening and increases the signal of the now subacute hematoma on T1-weighted imaging. Within this subacute hematoma the red cells remain intact restricting the T2-weighted shortening and the signal remains hypointense on T2-weighted images. After this time period, the red cells begin to lyse releasing the methemoglobin into the hematoma. At this time T1-weighted images remain hyperintense and now that the methemoglobin is no longer compartmentalized, the T2-weighted images also become hyperintense.

The imaging characteristics of an abscess are more straightforward. The center of an abscess will typically be hypointense on T1-weighted images and hyperintense on T2-weighted images. The rim of the abscess is often isointense on T1-weighted images and hyperintense on T2-weighted images. Characteristically the rim will enhance intensely after gadolinium administration (Fig 5).

Management

Fortunately most peripheral nerve deficits are transient and resolve completely. Cases without deficit or with minimal deficit can be observed with reassurance. The management of cases with moderate or severe deficits, however, is more controversial. There is no consensus as to when exploration of the nerve is warranted.

In the acute setting (first day or two) there is no marker to establish a firm prognosis. If in the acute setting the deficit is severe (identified by clinical examination and confirmed by EMG) and progressive (suggestive of an expanding lesion), or there is a reasonable suspicion of a complete nerve transection then surgical exploration may be indicated.[14] In a majority of cases, however, awaiting confirmatory EMG testing in 2 to 3 weeks time will be helpful in delineating the prognosis and the degree of axonal damage. If at follow-up testing the lesion is complete and accompanied by prominent axonal loss, it is unlikely that recovery will occur with a good functional outcome. Referral to a peripheral nerve surgeon should be considered at this time. If the lesion is incomplete then clinical follow-up for an additional 2 to 5 months with repeat EMG, assessing for reinnervation and clinical improvement, should be completed.[14] If reinnervation and clinical improvement become apparent then conservative management is recommended. If no reinnervation occurs or there is no clinical improvement then referral to a peripheral nerve surgeon should again be considered.

For intraspinal lesions, the intervention must be directed at the underlying cause and mechanism. If a compressive lesion is identified, usually a spinal hematoma or abscess, urgent decompression is necessary. In cases of infection (meningitis or abscess), broad-spectrum antibiotics should be initiated while

Table 1. Magnetic Resonance Imaging Characteristics of a Hematoma

	Acute	Subacute	Chronic
Temporal profile	First day	2 to 4 days	More than 4 days
T1 characteristics	Isointense or hypointense	Hyperintense	Hyperintense
T2 characteristics	Hypointense	Hypointense	Hyperintense

waiting for culture confirmation. In these cases long-term outcome depends largely on the magnitude of the deficit at the time of intervention. The residual deficits may be severe and disabling. The introduction of rehabilitative efforts should begin as soon as medically able.

Summary

Peripheral nerve and spinal cord injuries are a rare but significant complication of regional anesthesia. These injuries can be caused by a variety of mechanisms including blunt trauma, drug neurotoxicity, compressive injury, stretch injury, and nerve ischemia. It is generally believed that subjects with a preexisting neuropathy are at greatest risk.

Evaluation of acute nerve injury begins with a focused history and neurological examination to localize the problem to specific peripheral nerves, plexus, nerve roots, or spinal cord. If no deficits exist or if the deficits are minimal and improving observation may be all that is necessary. Ancillary testing should include electromyography and appropriate imaging. EMG in the first few days will establish benchmarks to compare at 14 to 21 days. This will quantitate the magnitude of the acute injury and provide long-term prognostic information. Imaging of the nerve should be considered. In most cases MRI is preferred given the better resolution of the nerves and soft tissue. The role of ultrasonography is not yet established. When imaging the spine, MRI is preferable to CT or myelography. CT should be completed when there is a contraindication to MRI or MRI cannot be completed in a timely manner.

Most cases of peripheral nerve injury will improve and resolve without deficit. In mild cases reassurance and observation is all that is necessary. In more severe cases, unless the deficit is progressive or complete, conservative management is usually indicated. If there is no clinical recovery or evidence of reinnervation by EMG by 2 to 5 months then referral to a peripheral nerve surgeon should be considered.

The prognosis for cauda equina or spinal cord lesions is more guarded. Recovery from these is typically less complete and early diagnosis and intervention is the key to preventing catastrophic neurological outcomes.

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