

**American College of Radiology
ACR Appropriateness Criteria®**

Clinical Condition: Plexopathy

Variant 1: Brachial — acute onset or chronic plexopathy without trauma.

Radiologic Procedure	Rating	Comments	RRL*
MRI neck and/or chest and/or upper extremity without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI neck and/or chest and/or upper extremity without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
CT neck and/or chest and/or upper extremity with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	☼ ☼ ☼ ☼
CT neck and/or chest and/or upper extremity without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	☼ ☼ ☼
X-ray chest	3		☼
X-ray cervical spine	3		☼ ☼
FDG-PET whole body	1		☼ ☼ ☼ ☼
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 2: Brachial — plexopathy due to traumatic injury.

Radiologic Procedure	Rating	Comments	RRL*
MRI neck and/or chest and/or upper extremity without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI neck and/or chest and/or upper extremity without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
Myelography and post myelography CT cervical and/or thoracic spine	6		☼ ☼ ☼ ☼
CT neck and/or chest and/or upper extremity with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	☼ ☼ ☼ ☼
X-ray myelography cervical and/or thoracic spine	5		☼ ☼ ☼
CT neck and/or chest and/or upper extremity without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	☼ ☼ ☼
X-ray chest	3		☼
X-ray cervical spine	3		☼ ☼
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Clinical Condition:**Plexopathy****Variant 3:****Brachial — entrapment syndromes.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI neck and/or chest and/or upper extremity without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI neck and/or chest and/or upper extremity without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
CT neck and/or chest and/or upper extremity with contrast	6	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	⊕ ⊕ ⊕ ⊕
CT neck and/or chest and/or upper extremity without contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	⊕ ⊕ ⊕
X-ray chest	3		⊕
X-ray cervical spine	3		⊕ ⊕
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 4:**Brachial — post-treatment syndrome.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI neck and/or chest and/or upper extremity without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI neck and/or chest and/or upper extremity without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
FDG-PET whole body	7		⊕ ⊕ ⊕ ⊕
CT neck and/or chest and/or upper extremity with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	⊕ ⊕ ⊕ ⊕
CT neck and/or chest and/or upper extremity without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	⊕ ⊕ ⊕
X-ray chest	3		⊕
X-ray cervical spine	3		⊕ ⊕
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Clinical Condition:**Plexopathy****Variant 5:****Lumbosacral — acute onset or chronic plexopathy without trauma.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI abdomen and/or pelvis without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI abdomen and/or pelvis without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
CT abdomen and/or pelvis with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	⊕ ⊕ ⊕ ⊕
CT abdomen and/or pelvis without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	⊕ ⊕ ⊕ ⊕
X-ray lumbosacral spine	3		⊕ ⊕ ⊕
FDG-PET whole body	1		⊕ ⊕ ⊕ ⊕
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 6:**Lumbosacral — plexopathy due to traumatic injury.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI abdomen and/or pelvis without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI abdomen and/or pelvis without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
CT abdomen and/or pelvis with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	⊕ ⊕ ⊕ ⊕
CT abdomen and/or pelvis without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	⊕ ⊕ ⊕ ⊕
X-ray lumbosacral spine	3		⊕ ⊕ ⊕
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Clinical Condition:**Plexopathy****Variant 7:****Lumbosacral — entrapment syndromes.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI abdomen and/or pelvis without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI abdomen and/or pelvis without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
CT abdomen and/or pelvis with contrast	6	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	☼☼☼☼
CT abdomen and/or pelvis without contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	☼☼☼☼
X-ray lumbosacral spine	3		☼☼☼
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 8:**Lumbosacral — post-treatment syndrome.**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
MRI abdomen and/or pelvis without and with contrast	8	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRI abdomen and/or pelvis without contrast	7	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances.	O
FDG-PET whole body	7		☼☼☼☼
CT abdomen and/or pelvis with contrast	5	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	☼☼☼☼
CT abdomen and/or pelvis without contrast	4	One or more anatomically contiguous studies may be appropriate depending on clinical circumstances. Oral contrast often employed.	☼☼☼☼
X-ray lumbosacral spine	3		☼☼☼
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

PLEXOPATHY

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Summary of Literature Review

Plexopathy is the term used to describe abnormal neurological symptoms and signs localized to an anatomically defined network of nerves called a nerve plexus. Nerve plexuses are derived from the ventral rami of a set of spinal nerves. Commonly recognized nerve plexuses include the brachial plexus and the lumbosacral plexus. The brachial plexus is formed from C5-T1 ventral rami. The roots pass between the anterior and middle scalene muscles with the subclavian artery to form the trunks in the supraclavicular region. Trunks then split into anterior and posterior divisions, form cords, and travel with the subclavian artery and vein within the infraclavicular region. Finally, the cords form terminal branches at the lateral margin of the pectoralis minor muscle and continue through the axilla. Individual nerve branches then continue into the arm and forearm [1].

The lumbosacral plexus comprises two distinct plexuses, the lumbar and the sacral, with a bridging lumbosacral trunk. The lumbar plexus is formed from the L1-L3 ventral rami with contributions from T12 and L4. The roots emerge from the psoas major muscle, form anterior

and posterior divisions, and finally form anterior and posterior branches. The lumbar plexus innervates the muscles of the anterior and medial thigh. The sacral plexus is formed from the L4-L5 ventral rami (the lumbosacral trunk) and S1-S4. Anterior and posterior divisions arise from the roots, course over the sacral promontory posterolateral to the internal iliac vessels, and terminate in branches innervating the muscles of the gluteal region, lateral and posterior thigh, and lower leg. The largest terminal branch, the sciatic nerve, exits the pelvis with the piriformis muscle and gluteal vessels through the greater sciatic foramen [1]. Mastery of anatomy and availability of anatomical references are useful in interpreting studies of the brachial and lumbosacral plexus.

Plexopathy may manifest as pain (shoulder and arm, or back and leg) with a neuropathic character, dysethesias, and burning or electric sensation, occurring in more than one peripheral nerve distribution. In contradistinction, pain that radiates in a dermatomal distribution with or without accompanying sensory loss or motor loss in a spinal nerve root distribution would be considered evidence of radiculopathy.

Complete brachial plexopathy causes weakness, sensory loss, and loss of tendon reflexes in body regions innervated by nerves in the C5-T1 segmental distribution. The clinical diagnosis is confirmed by electrodiagnostic studies (EMG) showing evidence of a neurogenic lesion in muscles innervated by at least two cervical segments involving at least two different peripheral nerves. Lumbar plexopathy produces weakness, sensory loss, and reflex changes in the distribution of spinal segments L2-L4, resulting in weakness and sensory loss in obturator- and femoral-innervated territories. Sacral plexopathy causes the same abnormalities in segments L5-S3, causing weakness and sensory loss in the gluteal (motor only), peroneal, and tibial nerve territories [1].

Imaging Modalities

Imaging is aimed at visualizing the plexus and surrounding structures. For brachial plexopathy, anatomic territories are targeted based on clinical findings and electrodiagnostic data, but may include the cervical spine, chest, or shoulder. Generally, one side or the other is chosen for imaging, but imaging may be repeated for both sides as indicated by clinical findings [1]. For lumbosacral plexopathy, imaging focuses on including both left and right sides of the lumbosacral plexus in a single field of view while maintaining a diagnostically appropriate spatial resolution [1].

Magnetic resonance imaging (MRI) at 1.5 Tesla is the mainstay of plexus imaging. It has been shown to detect features of intraneural anatomy not previously seen with earlier diagnostic imaging studies and to localize pathologic lesions in conditions where electrophysiologic and physical findings are nonspecific or nonlocalizing [1].

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The use of phased arrays and integrated arrays of radiofrequency (RF) coils for dedicated brachial plexus imaging has made it possible to directly evaluate the plexus components — roots, trunks, divisions, and cords — and frequently to distinguish between intrinsic and extrinsic pathological changes. A 1994 study by Bilbey et al [2] found conventional spin-echo MRI without gadolinium to be 63% sensitive, 100% specific, and 77% accurate compared to clinicopathologic results in the evaluation of 43 patients with suspected brachial plexopathy. Accuracy increased to 88% when evaluation involved only the subset of patients (n=34) with neoplastic or traumatic disorders. With current high-resolution MRI and the use of gadolinium contrast agents, accuracy is likely to be increased further [1].

T1-weighted images display regional anatomy, including muscles, blood vessels, and nerves, outlined by fat planes. Conventional two-dimensional (2D) fast spin-echo (FSE) sequences are used to generate the T1-weighted images, although some investigators prefer T1-weighted 3D gradient-echo images [3,4]. The 2D T2-weighted images are generated with FSE sequences and are useful to detect pathologic changes within components of the plexus. Because abnormal intraneural signal from one component of the plexus, such as a root or a cord, may be obscured by adjacent fat signal, fat suppression is used. The two most common methods are short-tau inversion recovery (STIR) and frequency-selective saturation of the fat resonance.

Contrast-enhanced images of the plexus are obtained routinely in patients being evaluated for suspected neoplasm, radiation injury, inflammation, or abscess formation, and following peripheral nerve surgery. In addition to these indications, contrast-enhanced images have also proven useful in some cases of nerve entrapment and stretch injury. In cases of acute severe traumatic nerve injury and simple compressive neuropathy, a noncontrast examination can be sufficient. High-resolution coronal and sagittal images of the symptomatic brachial plexus are especially beneficial. Axial images may be acquired in patients with a concomitant Horner's syndrome to demonstrate paraspinous extension of tumor. Three planes of images of the cervical spine are acquired when the clinical findings suggest an abnormality at the level of the cervical roots. For lumbosacral imaging, high-resolution coronal and axial images of the bilateral lumbar plexus or sacral plexus are typically obtained.

Optimization of MRI protocols for imaging the plexus has improved our ability to visualize the anatomy and detect pathology [5,6]. Research continues to evaluate new techniques, such as diffusion-weighted imaging [7]. As radiologists gain more experience with plexus imaging, imaging phenomena such as magic angle effect in plexus components oriented at 55 degrees to the magnetic field are being described [8].

Abnormal plexus findings include the following: loss of fat planes around all or part of a plexus component, diffuse or focal enlargement of a component (especially, the presence of an eccentric or nodular mass), marked

hyperintensity on T2-weighted images, and/or enhancement on T1-weighted images with fat suppression. An altered fascicular pattern is also abnormal, although it may not always be apparent. Demonstration of a fascicular pattern may be more difficult for plexus components than for individual peripheral nerves, like the sciatic and tibial nerves, because of the lower spatial resolution of plexus images and because of the difficulty in obtaining true cross-sectional views of most plexus components [1].

Computed tomography (CT) imaging of the spine, chest, and body complements MRI of the plexus, especially in cancer patients. In patients unable to undergo MRI due to implanted devices, CT offers the next highest level of anatomic visualization possible for these patients.

Myelography and CT myelography outline the contours of the spinal cord and nerve roots with myelographic contrast injected either via a lumbar approach or a cervical approach. These techniques are complementary to MRI in the setting of trauma to evaluate the integrity of nerve roots and to localize secondary signs of nerve injury such as pseudomeningoceles [9,10].

Positron emission tomography (PET)/CT imaging performed with F18-fluorodeoxyglucose (FDG) is beneficial in imaging patients with suspected malignancies directly invading or metastatic to the region of the plexus. As a problem-solving tool, it can be used to differentiate radiation plexitis from tumor recurrence in patients who have received radiation therapy to the region of the plexus [11,12].

Ultrasound (US) imaging of the brachial plexus is a new area of research both for diagnosis of plexopathies and for image-guided therapy. US is able to define the anatomy of the brachial plexus and demonstrate signs of trauma and tumor involvement [13-16]. US of the brachial plexus is dependent on the skills of the technologist and is not yet in widespread use.

Indications for MR Imaging of the Brachial Plexus

Acute Onset or Chronic Plexopathy without Trauma

Acute onset or chronic plexopathies may be caused by diverse etiologies such as intrinsic or extrinsic masses, radiation treatment, entrapment syndromes, and miscellaneous causes such as infectious, autoimmune, hereditary, and idiopathic neuropathies. MRI of the plexus, aided by CT, CT myelography, and PET/CT as indicated, augment clinical findings and EMG studies in reaching a diagnosis and guiding treatment.

MRI can often determine whether a mass is intrinsic or extrinsic to a component nerve of the plexus and, for extrinsic masses, determine the site of the displaced and compressed nerve fibers prior to surgical intervention. Such information is valuable in the diagnosis and management of patients with plexopathy due to neoplastic or non-neoplastic processes [17,18]. The information from MRI aids in preoperative planning and may help to shorten the surgical procedure [18-20]. Primary tumors in organs adjacent to the plexus, such as lung, colon, and genitourinary tumors, may directly invade the plexus. Lymphatic or hematogenous metastases to the structures

surrounding the plexus have been reported with a wide variety of primary malignancies [21,22]. Lymphoma can involve the plexus in two ways. First, enlarged lymph nodes can compress and/or infiltrate the plexus. Second, neurolymphomatosis, which is a rare manifestation of lymphoma primarily involving the peripheral nerves, can affect the plexus. Infiltrative lesions of the plexus include soft-tissue tumors such as sarcomas and fibromatosis [21]. The most common neurogenic tumors of the plexus are the benign nerve sheath tumors such as neurofibroma and schwannoma. Malignant peripheral nerve sheath tumors account for 14% of the neurogenic tumors and occur more frequently in patients with neurofibromatosis or a history of previous radiation therapy [23,24]. When the clinical examination does not reveal an etiology for the patient's neuropathy, MRI may identify a focal or diffuse peripheral nerve or plexus structural abnormality, such as occurs in chronic inflammatory demyelinating polyneuropathy (CIDP) [25,26], multifocal motor neuropathy (MMN) [27], hereditary hypertrophic motor and sensory neuropathies (HMSN) [28,29], and inflammatory pseudotumor [30]. Idiopathic brachial plexitis presents with sudden onset of severe, constant pain in the lateral neck, shoulder, scapula, or upper arm. It may demonstrate increased signal intensity in the plexus on T2-weighted images, or the plexus may appear normal [13,22,31].

Plexopathy Due to Traumatic Injury

Injury to a peripheral nerve due to trauma can range from disruption of axonal conduction with preservation of anatomical continuity of the connective tissue sheaths (neurapraxic injury) to avulsed or severed nerve with complete loss of continuity of the nerve (neurotmesis injury) [32,33]. By demonstrating the location and severity of injury and the morphology of the injured nerve, high-resolution MRI complements the electrophysiologic studies in determining the exact site and type of nerve injury, and the potential for surgical treatment versus spontaneous recovery. Additionally, MRI can show the relationship of the intact nerve to post-traumatic lesions such as spindle, lateral, and stump neuromas, as well as focal or diffuse perineural fibrosis.

Intraspinous nerve root avulsion (preganglionic lesion) should be distinguished from brachial plexus interruption (postganglionic lesion) because the surgical treatment differs [34]. Somatosensory-evoked potentials have been routinely used to diagnose nerve root avulsion; however, because these do not enable one to discriminate between incomplete avulsion and intact roots, or between intraforaminal root avulsion and rootlet avulsion from the spinal cord, the inclusion of imaging studies (myelography, CT myelography, high-resolution MRI, and MR myelography) in the diagnostic evaluation has been recommended [9,35-38].

In the detection of nerve root avulsion, some studies [37] found that myelography/CT myelography was the most accurate approach (>90%), confirming separate reports of the reliable demonstration of root avulsion with CT myelography [10] and a 92% accuracy of MR myelography compared to CT myelography [39]. Other studies, however, found that myelography/CT

myelography and MRI achieved similar accuracy [40]. In the detection of traumatic pseudomeningoceles, conventional spin-echo MRI is equivalent to CT myelography, which is more accurate than myelography. For overall characterization of traumatic brachial plexopathy, MRI has an advantage over CT and myelography, because it is better able to show plexus lesions (postganglionic), in addition to detecting pseudomeningoceles. Examples of post-traumatic lesions of the plexus that have been demonstrated on spin-echo images include neuromas (tangles of regenerating nerve fibers), focal or diffuse fibrosis, and masses that compress or stretch the plexus, such as hematoma, clavicular fracture, and humeral dislocation [2,3,22,41].

Entrapment Syndromes

Guided to the location of entrapment/compression by the clinical and neurological examination, the MRI study is used to detect objective findings of nerve compression [42]. There is some disagreement regarding the value of MRI in diagnosing neurologic or combined neurovascular thoracic outlet syndrome (TOS) [43,44].

Post-treatment Evaluation

Patients with a history of cancer and clinical evidence of plexopathy following radiation therapy may have, predominantly or exclusively, recurrent tumor or radiation-induced plexopathy. Imaging features that favor recurrent tumor are nonuniform, diffuse, or focal enlargement of the plexus components and the presence of an eccentric mass with postcontrast enhancement [45,46]. Imaging features that suggest postradiation injury of the brachial plexus are diffuse, uniform swelling and T2 hyperintensity of the plexus nerves within the radiation field. Diffuse, uniform postcontrast enhancement for months to years after treatment may also result from radiation injury [1,46]. Radiation fibrosis often has low signal intensity on T1-weighted and T2-weighted images, [47], and this may represent the more common appearance for chronic radiation injury, although a correlation between the time interval following radiation therapy and T2 signal intensity has not been reported.

Differentiation between radiation injury and local or regional recurrent cancer with axillary/supraclavicular metastases may not be possible. Preliminary results suggest that FDG-PET helps to confirm metastases in patients with indeterminate MRI findings and is useful for depicting metastases outside the axilla [11].

Summary

- The purpose of imaging of the plexus is to complement and supplement the clinical and electrophysiologic data in order to establish a diagnosis and assist treatment planning.
- MRI is the mainstay of imaging the brachial and lumbosacral plexus.
- MRI protocols should optimize visualization of the anatomy of the affected plexus and detection of pathologic conditions.
- CT, CT myelography, and PET/CT complement MRI in certain clinical settings.

Anticipated Exceptions

Nephrogenic systemic fibrosis (NSF) is a disorder with a scleroderma-like presentation and a spectrum of manifestations that can range from limited clinical sequelae to fatality. It appears to be related to both underlying severe renal dysfunction and the administration of gadolinium-based contrast agents. It has occurred primarily in patients on dialysis, rarely in patients with very limited glomerular filtration rate (GFR) (ie, <30 mL/min/1.73m²), and almost never in other patients. There is growing literature regarding NSF. Although some controversy and lack of clarity remain, there is a consensus that it is advisable to avoid all gadolinium-based contrast agents in dialysis-dependent patients unless the possible benefits clearly outweigh the risk, and to limit the type and amount in patients with estimated GFR rates <30 mL/min/1.73m². For more information, please see the [ACR Manual on Contrast Media](#) [48].

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, both because of organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria[®] [Radiation Dose Assessment Introduction](#) document.

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
0	0 mSv	0 mSv
☼	<0.1 mSv	<0.03 mSv
☼☼	0.1-1 mSv	0.03-0.3 mSv
☼☼☼	1-10 mSv	0.3-3 mSv
☼☼☼☼	10-30 mSv	3-10 mSv
☼☼☼☼☼	30-100 mSv	10-30 mSv
*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as NS (not specified).		

Supporting Document(s)

- [ACR Appropriateness Criteria[®] Overview](#)
- [Procedure Information](#)
- [Evidence Table](#)

References

1. Maravilla KR, Bowen BC. Imaging of the peripheral nervous system: evaluation of peripheral neuropathy and plexopathy. *AJNR Am J Neuroradiol* 1998; 19(6):1011-1023.
2. Bilbey JH, Lamond RG, Mattrey RF. MR imaging of disorders of the brachial plexus. *J Magn Reson Imaging* 1994; 4(1):13-18.
3. Collins JD, Shaver ML, Disher AC, Miller TQ. Compromising abnormalities of the brachial plexus as displayed by magnetic resonance imaging. *Clin Anat* 1995; 8(1):1-16.
4. Van Es HW, Witkamp TD, Ramos LM, et al. MR imaging of the brachial plexus using aT1-weighted three-dimensional volume acquisition. *Int J Neuroradiol* 1996; 2:264-273.
5. Reeder SB, Yu H, Johnson JW, et al. T1- and T2-weighted fast spin-echo imaging of the brachial plexus and cervical spine with IDEAL water-fat separation. *J Magn Reson Imaging* 2006; 24(4):825-832.
6. Zhang ZW, Song LJ, Meng QF, et al. High-resolution diffusion-weighted MR imaging of the human lumbosacral plexus and its branches based on a steady-state free precession imaging technique at 3T. *AJNR Am J Neuroradiol* 2008; 29(6):1092-1094.
7. Tsuchiya K, Fujikawa A, Tateishi H, Nitatori T. Visualization of cervical nerve roots and their distal nerve fibers by diffusion-weighted scanning using parallel imaging. *Acta Radiol* 2006; 47(6):599-602.
8. Chappell KE, Robson MD, Stonebridge-Foster A, et al. Magic angle effects in MR neurography. *AJNR Am J Neuroradiol* 2004; 25(3):431-440.
9. Bertelli JA, Ghizoni MF. Use of clinical signs and computed tomography myelography findings in detecting and excluding nerve root avulsion in complete brachial plexus palsy. *J Neurosurg* 2006; 105(6):835-842.
10. Walker AT, Chaloupka JC, de Lotbiniere AC, Wolfe SW, Goldman R, Kier EL. Detection of nerve rootlet avulsion on CT myelography in patients with birth palsy and brachial plexus injury after trauma. *AJR* 1996; 167(5):1283-1287.
11. Hathaway PB, Mankoff DA, Maravilla KR, et al. Value of combined FDG PET and MR imaging in the evaluation of suspected recurrent local-regional breast cancer: preliminary experience. *Radiology* 1999; 210(3):807-814.
12. Planner AC, Donaghy M, Moore NR. Causes of lumbosacral plexopathy. *Clin Radiol* 2006; 61(12):987-995.
13. Beekman R, van den Berg LH, Franssen H, Visser LH, van Asseldonk JT, Wokke JH. Ultrasonography shows extensive nerve enlargements in multifocal motor neuropathy. *Neurology* 2005; 65(2):305-307.
14. Cash CJ, Sardesai AM, Berman LH, et al. Spatial mapping of the brachial plexus using three-dimensional ultrasound. *Br J Radiol* 2005; 78(936):1086-1094.
15. Graif M, Martinoli C, Rochkind S, et al. Sonographic evaluation of brachial plexus pathology. *Eur Radiol* 2004; 14(2):193-200.
16. Gruber H, Glodny B, Galiano K, et al. High-resolution ultrasound of the supraclavicular brachial plexus--can it improve therapeutic decisions in patients with plexus trauma? *Eur Radiol* 2007; 17(6):1611-1620.
17. Binder DK, Smith JS, Barbaro NM. Primary brachial plexus tumors: imaging, surgical, and pathological findings in 25 patients. *Neurosurg Focus* 2004; 16(5):E11.
18. Saifuddin A. Imaging tumours of the brachial plexus. *Skeletal Radiol* 2003; 32(7):375-387.
19. Aagaard BD, Maravilla KR, Kliot M. MR neurography. MR imaging of peripheral nerves. *Magn Reson Imaging Clin N Am* 1998; 6(1):179-194.
20. Britz G, West G, Daily A, et al. Magnetic resonance imaging in evaluation and treating peripheral nerve problems. *Perspect Neuro* 1995; 6:53-66.
21. de Verdier HJ, Colletti PM, Terk MR. MRI of the brachial plexus: a review of 51 cases. *Comput Med Imaging Graph* 1993; 17(1):45-50.
22. Posniak HV, Olson MC, Dudiak CM, Wisniewski R, O'Malley C. MR imaging of the brachial plexus. *AJR* 1993; 161(2):373-379.

23. Pierce SM, Recht A, Lingos TI, et al. Long-term radiation complications following conservative surgery (CS) and radiation therapy (RT) in patients with early stage breast cancer. *Int J Radiat Oncol Biol Phys* 1992; 23(5):915-923.
24. Varma DG, Mouloupoulos A, Sara AS, et al. MR imaging of extracranial nerve sheath tumors. *J Comput Assist Tomogr* 1992; 16(3):448-453.
25. Duggins AJ, McLeod JG, Pollard JD, et al. Spinal root and plexus hypertrophy in chronic inflammatory demyelinating polyneuropathy. *Brain* 1999; 122 (Pt 7):1383-1390.
26. Van den Bergh PY, Thonnard JL, Duprez T, Laterre EC. Chronic demyelinating hypertrophic brachial plexus neuropathy. *Muscle Nerve* 2000; 23(2):283-288.
27. Van Es HW, Van den Berg LH, Franssen H, et al. Magnetic resonance imaging of the brachial plexus in patients with multifocal motor neuropathy. *Neurology* 1997; 48(5):1218-1224.
28. Masuda N, Hayashi H, Tanabe H. Nerve root and sciatic trunk enlargement in Dejerine-Sottas disease: MRI appearances. *Neuroradiology* 1992; 35(1):36-37.
29. Tachi N, Kozuka N, Ohya K, Chiba S, Naganuma M. MRI of peripheral nerves and pathology of sural nerves in hereditary motor and sensory neuropathy type III. *Neuroradiology* 1995; 37(6):496-499.
30. Weiland TL, Scheithauer BW, Rock MG, Sargent JM. Inflammatory pseudotumor of nerve. *Am J Surg Pathol* 1996; 20(10):1212-1218.
31. van Alfen N, van Engelen BG. The clinical spectrum of neuralgic amyotrophy in 246 cases. *Brain* 2006; 129(Pt 2):438-450.
32. Seddon HJ. Three types of nerve injuries. *Brain* 1943; 66:238-283.
33. Sunderland S. A classification of peripheral nerve injuries producing loss of function. *Brain* 1951; 74(4):491-516.
34. Millesi H. Brachial plexus injuries: management and results. In: Terzis JK, ed. *Microreconstruction of nerve injuries*. Philadelphia, Pa: WB Saunders; 1987:347-359.
35. Rankine JJ. Adult traumatic brachial plexus injury. *Clin Radiol* 2004; 59(9):767-774.
36. Tsai PY, Chuang TY, Cheng H, Wu HM, Chang YC, Wang CP. Concordance and discrepancy between electrodiagnosis and magnetic resonance imaging in cervical root avulsion injuries. *J Neurotrauma* 2006; 23(8):1274-1281.
37. Carvalho GA, Nikkiah G, Matthias C, Penkert G, Samii M. Diagnosis of root avulsions in traumatic brachial plexus injuries: value of computerized tomography myelography and magnetic resonance imaging. *J Neurosurg* 1997; 86(1):69-76.
38. Doi K, Otsuka K, Okamoto Y, Fujii H, Hattori Y, Baliarsing AS. Cervical nerve root avulsion in brachial plexus injuries: magnetic resonance imaging classification and comparison with myelography and computerized tomography myelography. *J Neurosurg* 2002; 96(3 Suppl):277-284.
39. Gasparotti R, Ferraresi S, Pinelli L, et al. Three-dimensional MR myelography of traumatic injuries of the brachial plexus. *AJNR Am J Neuroradiol* 1997; 18(9):1733-1742.
40. Ochi M, Ikuta Y, Watanabe M, Kimori K, Itoh K. The diagnostic value of MRI in traumatic brachial plexus injury. *J Hand Surg [Br]* 1994; 19(1):55-59.
41. Sherrier RH, Sostman HD. Magnetic resonance imaging of the brachial plexus. *J Thorac Imaging* 1993; 8(1):27-33.
42. Beltran J, Rosenberg ZS. Diagnosis of compressive and entrapment neuropathies of the upper extremity: value of MR imaging. *AJR* 1994; 163(3):525-531.
43. Cherington M, Wilbourn AJ, Schils J, Whitaker J. Thoracic outlet syndromes and MRI. *Brain* 1995; 118 (Pt 3):819-821.
44. Panegyres PK, Moore N, Gibson R, Rushworth G, Donaghy M. Thoracic outlet syndromes and magnetic resonance imaging. *Brain* 1993; 116 (Pt 4):823-841.
45. Thyagarajan D, Cascino T, Harms G. Magnetic resonance imaging in brachial plexopathy of cancer. *Neurology* 1995; 45(3 Pt 1):421-427.
46. Wittenberg KH, Adkins MC. MR imaging of nontraumatic brachial plexopathies: frequency and spectrum of findings. *Radiographics* 2000; 20(4):1023-1032.
47. Wouter van Es H, Engelen AM, Witkamp TD, Ramos LM, Feldberg MA. Radiation-induced brachial plexopathy: MR imaging. *Skeletal Radiol* 1997; 26(5):284-288.
48. American College of Radiology. *Manual on Contrast Media*. Available at: http://www.acr.org/SecondaryMainMenuCategories/quality_safety/contrast_manual.aspx.

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

Appendix 1. Approximate Boundaries for Imaging of Neural Plexuses—Brachial, Lumbar, and Sacral

Brachial plexus, right or left individually, is imaged. Each extends obliquely from paraspinal region (neural foramina) in the neck to the lateral axilla. Superiorly, include the level of the C4 vertebra. Inferiorly, include the level of aortic arch (with spatial presaturation pulses covering arch on MRI). Medially, include spinal canal. Laterally, include axilla lateral to pectoralis minor muscle. Cover from posterior neck (including spinous processes) to anterior neck and axilla (including anterior aspect of first rib).

Lumbar plexus, right and left together are imaged. Each plexus follows an oblique course from the lumbar paraspinal region (neural foramina) to and within the ipsilateral psoas muscles. Superiorly, include the level of the T12 vertebra. Inferiorly, include the level of the S2 vertebra. Cover from the posterior surface of the lower back to the anterior borders of the psoas muscles.

Sacral plexus, right and left together are imaged. Each plexus is primarily located anterior to the piriformis muscle and follows an infero-anterolateral course from the lumbosacral foramina to the ipsilateral greater sciatic foramen. Superiorly, include the level of the L4 vertebra. Inferiorly, include the level of the greater sciatic foramen (approximately S4-5 in the transverse plane). Cover from posterior surface of sacrum and the gluteal muscles to the anterior aspect of the pelvis.