ABSTRACT

Ultrasound (US) and MR imaging have been shown able to detect in-depth features of brachial plexus anatomy and to localize pathological lesions in disorders where electrophysiology and physical findings are nonspecific or nonlocalizing. High-end gradient technology, phased array coils, and selection of an appropriate protocol of pulse sequences are the main requirements to evaluate the brachial plexus nerves with MR imaging and to distinguish between intrinsic and extrinsic pathological changes. A careful scanning technique based on anatomical landmarks is required to image the brachial plexus nerves with US. In traumatic injuries, MR imaging and myelographic techniques can exclude nerve lesions at the level of neural foramina and at intradural location. Outside the spinal canal, US is an excellent alternative to MR imaging to determine the presence of a lesion, to establish the site and the level of nerve involvement, as well as to confirm or exclude major nerve injuries.

In addition to brachial plexus injuries, MR imaging and US can be contributory in a variety of nontraumatic brachial plexopathies of a compressive, neoplastic, and inflammatory nature. In the thoracic outlet syndrome, imaging performed in association with postural maneuvers can help diagnose dynamic compressions. MR imaging and US are also effective to recognize neuropathies about the shoulder girdle involving the suprascapular, axillary, long thoracic, and spinal accessory nerves that may mimic brachial plexopathy. In this article, the clinical entities just listed are discussed independently, providing an overview of the current status of knowledge regarding imaging assessment.

KEYWORDS: Brachial plexus, Parsonage-Turner syndrome, brachial plexopathies, thoracic outlet syndrome, magnetic resonance imaging, ultrasound, MR myelography

Evaluation of the brachial plexus represents a great challenge to the clinician and the radiologist, posing difficulties in patient management, the timing and range of investigation, as well as the indication for surgery. In the diagnostic workup for brachial plexus pathology, a preliminary meticulous physical examination is essential to understand which part or parts of the plexus are involved. Electrophysiology, including nerve conduction studies and electromyography (EMG), may serve to confirm and extend clinical information, to assess whether a lesion is pre- or post-ganglionic based on the pattern of involvement.
However, functional studies are often nonspecific or nonlocalizing, especially at the early stage of some brachial plexopathies or in cases of mild abnormalities. Imaging modalities, therefore, are a necessary complement to conclude the diagnostic assessment of most brachial plexus disorders. Imaging is currently based on magnetic resonance (MR) imaging, computed tomography (CT), ultrasound (US), myelographic techniques, and radiography. Although MR imaging is widely regarded as the method of choice in the workup of many brachial plexus disorders, this technique has inherent limitations in specific clinical settings and can be variably supported by other modalities depending on the underlying clinical problem but also on the equipment used and the management policy of peripheral nerve surgeons.

In the last decade, the diagnostic workup for evaluation of brachial plexus pathology has been continually reviewed with technological refinements in progress and the introduction of novel cutting-edge imaging algorithms. Light must be shed, therefore, on where imaging is going to draw the current optimal imaging strategy for any indication, thereby avoiding underutilization or inappropriate use of the available imaging techniques. In this article, we discuss and illustrate the imaging appearance of a wide spectrum of brachial plexus pathologies, including traumatic injuries, entrapment syndrome at the thoracic outlet, Parsonage-Turner syndrome, secondary and primary tumors, and radiation therapy. In addition to the plexus, some frequently missed uncommon neuropathies about the shoulder girdle affecting the suprascapular, the axillary, the long thoracic and the spinal accessory nerves are discussed.

NORMAL ANATOMY

The brachial plexus has a complex anatomy with many nerves involved that interconnect. At each vertebral level, anterior (motor) and posterior (sensory) nerve rootlets exit the spinal cord and merge at the dorsal root ganglion at the level of the neural foramina. Thereafter, each ganglion gives off a large ventral and a small dorsal branch, each including motor and sensory fibers. The dorsal branch provides nerve supply to the paraspinal muscles but does not take part in the brachial plexus (Fig. 1A). Instead, the plexus is formed by the contribution of the ventral branches coming from the four cervical (C5, C6, C7, and C8) and the first thoracic (T1) level (Fig. 1B). These branches are referred to as the proper “nerve roots” and extend from the neural foramina to the interscalene triangle.

Figure 1  Brachial plexus anatomy. (A) Schematic drawing of a cross-sectional view of the fifth cervical vertebra showing the spinal cord (black arrow). The spinal nerve arises from the spinal cord by dorsal (outlined arrowhead) and ventral (black arrowhead) rootlets. The spinal ganglion (G) is located on the dorsal root within the intervertebral foramen. The dorsal and ventral rootlets join at about the level of the intervertebral foramen to form a spinal nerve. Just outside the foramen, the spinal nerve divides into ventral (1) and dorsal (2) branches. The ventral branches participate in the brachial plexus, the dorsal ones direct posteriorly to supply the paraspinal muscles, including the multifidus (MF), the semispinalis cervicis (SS), the semispinalis capitis (SC), and the longus colli (LC). The spinal cord, the rootlets, the ganglion, and the spinal nerve are invested by the arachnoid and dura mater (white arrow). a, vertebral artery. Note that the sixth cervical nerve leaves the intervertebral foramen superior to the transverse process of C6. (B) Schematic drawing of the general structure of the brachial plexus. C5, fifth nerve root; C6, sixth nerve root; C7, seventh nerve root; C8, eighth nerve root; T1, first thoracic nerve root. Moving away from the spine, C5 and C6 join to form the upper trunk, C7 continues as the middle trunk, and C8 and T1 constitute the lower trunk. Each of the trunks splits into anterior and posterior divisions that further anastomose to give origin to the lateral, medial, and posterior cords. The level of origin of the long thoracic, suprascapular, musculocutaneous, axillary, radial, ulnar, and median nerves is shown.
At the external border of the interscalene triangle, the roots unite to form three trunks: The roots of C5 and C6 join together to form the upper trunk, the root of C7 continues as the middle trunk, and, in the lower neck, the roots of C8 and T1 form the lower trunk of the brachial plexus. More distally, in the supraclavicular region, each trunk gives off two divisional branches, named anterior and posterior divisions, which innervate the flexor and extensor muscles of the upper extremity, respectively. In the axilla, these divisions join in various combinations to form the cords of the brachial plexus. The lateral cord is formed by the anterior division of the upper and middle trunks, the medial cord by the anterior division of the lower trunk, and the posterior cord by the posterior divisions of all the trunks. Distal to the pectoralis minor muscle, the cords continue as the five peripheral nerves of the upper limb. The axillary and radial nerves originate from the posterior cord, the musculocutaneous and part of the median nerve arise from the lateral cord, whereas the other contributions of fibers to the median nerve and the ulnar nerve originate from the medial cord.

Clinically relevant spaces along the course of brachial plexus nerves are (1) the interscalene triangle, (2) the costoclavicular space, and (3) the retropectoralis minor space (subcoracoid tunnel). The interscalene triangle is bordered by the anterior and middle scalene muscles on each side and the first rib inferiorly (Figs. 2A, B). The subclavian artery travels through the lower part of this space, and the lower trunk of the

![Figure 2](image_url)

**Figure 2** Brachial plexus anatomy: interscalene triangle. (A) Schematic drawing illustrates the trunks as they exit the interscalene space, a passageway delimited by the anterior scalene (AS), the middle scalene (MS), and the first rib. The trunks are located superior to the subclavian artery (white arrow). Note the phrenic nerve (arrowhead) as it winds through the anterior scalene muscle. The posterior scalene muscle (PS) is also demonstrated in close proximity to the middle scalene. Black arrow, subclavian vein. (B) Cadaveric view shows the brachial plexus trunks passing through the interscalene triangle. The phrenic (arrowheads) and the suprascapular nerves are demonstrated in relationship to the nerve trunks. (C) Sagittal turbo spin-echo T1-weighted image of the interscalene space reveals the roots from C5 through T1 as aligned hypoechoic dots passing deep to the anterior scalene muscle and posterior to the subclavian artery (SA). (D) Oblique transverse ultrasound image demonstrates the brachial plexus nerves as hypoechoic dots embedded in the hyperechoic fatty space lying between the scalene muscles. The more external the nerve bundles, the higher the level of the plexus. SCM, sternocleidomastoid muscle.
plexus crosses the inferior part of the triangle behind
the subclavian artery. This space may be responsible for
upper extremity neurovascular compression. A narrow
triangle may often be due to anatomical variants of
size, shape, and attachment of the scalene muscles on
the first rib, and they can cause a scissoring effect on
the plexus nerves and the vessels. Distal to the
interscalene triangle, the costoclavicular space is a
triangular space bounded anteriorly by the inner half
of the clavicle, underlying the subclavius muscle and
the costoclavicular ligament, and posteromedially by
the first rib and insertion of the anterior and the
middle scalene muscles (Figs. 3A, B). In this space,
neurovascular compression may occur as a result of
congenital or acquired changes in the clavicle and first
rib, structural changes in the subclavius muscle, change
in shoulder position, and trauma. Crossing down
the clavicle, the nerve cords enter the retropectoralis
minor space (Figs. 4A, B). During upper limb eleva-
tion, the cords may lean tightly against the posterior
side of the pectoralis minor, which may be predispos-
ing to compression, especially in short, stocky muscular
young men, leading to numbness and tingling in the
hands and weakness in the arms during hyperabduc-
tion. The most common anatomical variants of bra-
chial plexus nerves are the passage of the C5 root
completely in front of (3%) or piercing (13%) the
anterior scalene muscle and the course of the C8 and
T1 roots behind the middle scalene muscle rather than
passing anterior to it.

Figure 3  Brachial plexus anatomy: costoclavicular space. (A) Schematic drawing illustrates the relevant anatomical structures
of the costoclavicular space, a rectangular passageway delimited by the clavicle (1) and the first rib (2). Note the insertion of the
anterior (4) and middle (3) scalene muscles on the first rib, the transversely oriented subclavius muscle (5), and, in a more medial
position, the costoclavicular ligament (6), also known as the rhomboid ligament. The fascicles of the different nerve cords
(arrow) and the subclavian artery (A) cross this space passing between the scalene muscles and underneath the subclavius. The
subclavian vein (V) runs more anteriorly. (B) Cadaveric slice in the short axis of the costoclavicular space with (C), corresponding
T1-weighted turbo spin-echo magnetic resonance image demonstrates the nerve cords (arrows), the subclavian artery (A) and
vein (V) between the clavicle and the first rib. Note the subclavius (5) and the pectoralis major (PMj).
MAGNETIC RESONANCE IMAGING TECHNIQUE

MR imaging of the brachial plexus is best performed by using a multielement phased-array radiofrequency receiver coil to span the neck-to-shoulder area with the aim of imaging either the right or the left plexus at high spatial resolution, rather than a bilateral examination with lower resolution. For imaging the preganglionic segment of brachial plexus nerves, gadolinium (Gd)-enhanced MR imaging and three-dimensional (3D) heavily T2-weighted MR imaging with fat- and flow suppression (MR myelography) are the most valuable techniques for identifying root avulsions and pseudomeningoceles. Concerning the rootlets, the ganglionic area and initial segment of the roots, MR myelography has become the reference modality in the last few years, limiting the use of CT myelography to patients with contraindications to MR imaging or whenever MR imaging provides insufficient preoperative data.

Compared with CT myelography, MR myelography is noninvasive, does not use ionizing radiation, and is superior to depict pseudomeningoceles because some of them do not communicate with the dural sac and cannot be filled in with contrast medium. For the examination of the postganglionic plexus, a comprehensive MR imaging examination should extend from the cervical spine to the cords in the axilla, just distal to the pectoralis minor muscle (Fig. 5). At field strengths from 1T to 3T, the brachial plexus can be evaluated based on its appearance on T1- and T2-weighted images with flow compensation.

Concerning sequence protocols, standard 2D turbo spin-echo (TSE) sequences are valuable to generate images with T1 contrast. These images display

Figure 4  Brachial plexus anatomy: retropectoralis minor space and axillary region. (A) Schematic drawing with (B), anatomic correlation, illustrates the arrangement of the lateral (LC), medial (MC), and posterior (PC) cords of the plexus relative to the axillary artery (A), the coracobrachialis (CoB), and the pectoralis minor (Pmin) muscle. Note the origin of the axillary, musculocutaneous, radial, medial (MN), and ulnar (UN) nerves. (C) Oblique sagittal T1-weighted turbo spin-echo magnetic resonance image of the retropectoralis minor space. Deep to the pectoralis major (PMj) and minor (Pmin) muscles, the position of the LC, MC, and PC cords of the plexus relative to the axillary artery (A) and vein (V) is shown. (D) Corresponding ultrasound image depicts the hypoechoic fascicles of the different nerve cords distributed around the axillary artery.
nerves as linear low signal intensity structures outlined by surrounding fat and allow assessment of their relationship with relevant regional structures, including bones, muscles, and blood vessels. Fluid-sensitive sequences with T2 contrast including fat-suppressed T2-weighted TSE or short tau inversion recovery (STIR) sequences are then obtained to detect pathological changes within plexus components. Although STIR sequences are able to give more uniform and consistent suppression of fat signal across the field of view (FOV), they have lower signal-to-noise ratio, are more sensitive to blood flow artifacts, and allow acquisition of a lower number of slices rather than TSE T2-weighted sequences. On fat-suppressed TSE T2-weighted images, shimming of the magnetic field over the volume encompassing the region of interest may be helpful to reduce areas of incomplete suppression of fat signal or with water saturation rather than fat saturation. Placing a bag containing clay suspensions against the ipsilateral neck and suprascapular region has also been proposed to reduce magnetic susceptibility effects. MR imaging typically includes true coronal planes over the neck-to-shoulder area using a wide FOV and double oblique (oblique-sagittal oblique-coronal) planes oriented in the true short-axis of brachial plexus nerves. These latter planes are acquired with a smaller FOV. Instead of true sagittal images, double oblique planes can better approximate the real cross-section of brachial plexus fascicles, offering a better display of subtle nerve abnormalities.

On T2-weighted images, obliquely oriented saturation bands over the heart and thoracic aorta may contribute to further improve MR image quality by arterial flow saturation. 3D acquisitions have recently been implemented to image the plexus, including CISS 3D, true fast imaging with steady-state precession 3D, and 3D STIR sequences.

As technology advances, these sequences and new ones in progress are increasingly gaining ground to provide a more flexible delineation of the out-of-plane course of brachial plexus nerves. The image data set of these sequences, with $<1$ mm isotropic resolution, can be reformatted in any plane, regardless of the prescribed plane during the image acquisition, thus allowing visualization of long nerve segments in a single image and giving better depiction of diffuse pathological processes affecting them. In specific clinical settings (e.g., suspected tumors, radiation injury, neuritis, or after regional surgery), Gd-enhanced fat-suppressed TSE T1-weighted sequences can be used.

Diffusion tensor imaging (DTI) with tractography has recently been proven to provide indirect 3D images of nerves. However, the application of DTI to get reproducible tracking of brachial plexus fibers appears to be technically challenging due to the small size of nerves, the changing orientation of the fibers, the peculiar location of the plexus between the neck and the shoulder, where relevant geometric distortion and artifact may occur, as well as the intrinsic low signal-to-noise ratio of echo-planar imaging technique. In addition, current reconstruction algorithms are time consuming and have poor reproducibility.

Concerning image parameters, an in-plane resolution of 2 mm with 3-mm slice thickness provides sufficient signal-to-noise ratio for brachial plexus tractography. In perspective, DTI is the only method that can offer an indirect view of the nerve microstructure in addition to the information on fibers trajectory. With DTI, nerves are depicted because water diffusion preferentially follows the long axis of the fibers and is restricted transversely (inherent anisotropic diffusion). Similar to other nerves, the representation of brachial plexus nerves with this technique reflects lines of fast water diffusion that probably give a representation of the axonal architecture and transport (Fig. 6). Tractography is a promising method to visualize the 3D course of brachial plexus nerves and provide important information about the site of swelling and loss of water due to nerve abnormalities or entrapment. Further experience is needed, however, to solve technical challenges and evaluate the ultimate role of this technique for brachial plexus imaging.

**ULTRASOUND SCANNING TECHNIQUE**

US has recently proved to be an effective means to depict normal brachial plexus anatomy at several levels,
including the paravertebral area, the interscalene triangle, the supraclavicular region, and the retropectoralis minor space.\textsuperscript{11,27–32} The US examination of brachial plexus nerves is based on detection of some anatomical landmarks in the neck, including bones (roots), muscles (trunks), and vessels (divisions and cords). As the roots exit the neural foramina, they slide between two apophyses of the transverse processes of the cervical vertebrae, the anterior and posterior tubercles (Fig. 7). Each root emerges from the foramen as a monocellular hypoechoic structure, an appearance quite different from that of nerves in the extremities that is made of clusters of hypoechoic fascicles.\textsuperscript{27,31}

Imaging based on scanning planes is ideal to depict the relationship of the roots with the transverse processes at any given level. Based on the peculiar appearance of the transverse process of C7, in which the posterior tubercle is absent, US is able to establish the level of nerve roots.\textsuperscript{31} The scanning technique must be systematic and should reveal the C7 vertebra as the first landmark. The C7 root is detected on the same plane of the C7 vertebra because it is bordered by the posterior tubercle only. Given that, the probe may move either up or down on axial planes depending on the root the examiner wants to image.\textsuperscript{31} Shifting the probe upward, the C6 vertebra is recognized due to the presence of prominent anterior and posterior tubercles: The C6 root appears as a hypoechoic structure held in between them. The transverse processes of C5 have basically the same shape of C6 and can be identified as the successive step cranial to the C6 level by taking into account the number of transverse processes encountered while sweeping the transducer cranially from C7. As a rule, the higher the level, the closer the space intervening between the tubercles. Shifting the probe downward from C7, the lateral aspect of the T1 vertebra appears flat without any tubercle; at this level, the C8 root can be appreciated while exiting the foramen. More caudally, visualization of the T1 root is unfeasible with US due to a problem of access related to a too deep location of the intervertebral foramen between the T1 and T2 vertebra and the interposition of the first rib. In the paravertebral area, coronal planes are able to depict the nerve roots using the same scanning planes for the study of vertebral vessels. On these planes, the picture of vertebral vessels is obscured at regular intervals by the acoustic shadowing from the anterior tubercles of the transverse process of the transverse processes. Moving the transducer slightly on the back, the vessels disappear and the roots appear as curved elongated hypoechoic images exiting the neural foramina and descending the lateral neck spaces. At the level of the interscalene triangle, the roots appear as aligned hypoechoic dots passing between the anterior and middle scalene muscles (Fig. 2D). In this space, the most superficial fascicles belong to C5 and the deepest to C8.

The ability of US to recognize the exact level of the roots in the paravertebral area also leads to a confident identification of the trunks by simply following the nerve bundles from where they arise. Between the interscalene triangle and the costoclavicular space, the divisions and the initial part of the cords are visualized as a cluster of hypoechoic rounded images, most of which running alongside the posterior aspect of the subclavian artery, just over the first rib and the apical pleura. The dorsal scapular artery, a small vessel arising from the subclavian artery, may be seen encroaching the nerve divisions and cords in the supraclavicular region. This vessel may pass posterior to or among the fascicles, in this latter case forming a cleavage plane that is frequently located between the middle and the lower plexus components. More distally, the costoclavicular space is blind to US examination due to the interposition of the clavicle and the lack of an acoustic window. The inability to image this important space represents one of the main limitations of a US approach. Crossing down the...
clavicle, in the retropectoralis minor space, the nerve cords continue their course around the axillary artery. The fascicles belonging to the posterior cord course behind the artery; the lateral cord runs external and the medial cord internal to it (Fig. 4D). On short-axis planes, the axillary artery is the main landmark to identify the nerves in this area. This arrangement is maintained across these spaces like a “three-point” star with the artery centered in the middle.

Finally, the examination of the most distal part of brachial plexus nerves is completed using an axillary approach as these nerves assume a deeper course. Especially in overweight people or patients with hypertrophied regional musculature, the nerves in the axillary area may be too deep and undefined using an anterior approach. With an axillary approach, nerves appear more superficial in this area and can be accurately evaluated. US scanning should first start at the proximal arm to identify the median, ulnar, and radial nerves as they surround the brachial artery. Then the probe is swept up along the short axis of the nerves to reach the distal part of the cords.

TRAUMATIC PLEXOPATHIES
Closed brachial plexus injuries are relatively infrequent, affecting ~1% of all multitrauma patients and approaching 5% in high-velocity motor vehicle accidents, primarily motorcycle accidents, but result in debilitating consequences in a patient group that is relatively young. After traffic accidents, the second most common cause is obstetric trauma that may occur from mechanical injury involving shoulder dystocia during difficult childbirth. Brachial plexus injuries are typically related to a violent excessive nerve stretching as it occurs during simultaneous traction of the arm and throwing of the head to the opposite shoulder. Depending on trauma characteristics, brachial plexus lesions can be divided into complete (when C5 through T1 components are involved) and incomplete injuries. Incomplete injuries can be further subdivided into two types: upper and lower brachial plexus lesions. Upper lesions involve damage of C5 and C6 roots and lead to Erb’s palsy, producing the so-called waiter’s tip deformity, due to loss of the external rotators of the shoulder (suprascapular, axillary), arm flexors (musculocutaneous), and hand extensors (radial); lower lesions involve C8 and T1 either before or after they have joined to form the lower trunk. This latter condition, known as Klumpke’s palsy, is less frequent and mainly affects the intrinsic muscles of the hand and the flexors of the wrist and fingers (ulnar, median). An early assessment of the extent and severity of the injury is essential for deciding treatment strategies.

Several types of injury may occur at the brachial plexus level, including nerve stretching (neurapraxia), the most common and least severe form, rootlets avulsion (preganglionic separation from the spinal cord), pseudomeningocele (tear in the meningeal sheath around the nerve roots with leakage of cerebrospinal fluid).
fluid), and postganglionic injury (discontinuity of the brachial plexus nerves distal to the ganglion). Differentiation between intraspinal nerve root avulsion, the so-called preganglionic injuries, from extraforaminal lesions, or postganglionic injuries is aided by electrophysiological studies based on detection of abnormalities in the paraspinal muscles, and especially the multifidus, in injuries located proximal to the brachial plexus.35 A substantial number of root avulsions occur, however, without denervation signs in the paraspinal muscles due to the multisegmental level of innervation of these muscles. Somatosensory evoked potentials can be used to diagnose intraforaminal nerve injuries, but because these do not enable physicians to discriminate between incomplete avulsions and intact roots or between intraforaminal root avulsion and rootlet avulsion from the spinal cord, conventional MR imaging and myelographic techniques based on CT/MR imaging play an important role in the diagnostic workup.3,4

The first task of imaging is distinguishing intraspinal nerve root avulsion, the so-called preganglionic injuries, from extraforaminal lesions, or postganglionic injuries because the surgical treatment differs in each case.4,36 In preganglionic injuries, the lesion is intradural and located proximal to the dorsal root ganglion. Despite some attempts to subdivide these lesions into central and peripheral, in most cases they are not considered amenable to direct repair and the prognosis is unfavorable.37 Nerve transfers are usually performed to restore function, using intercostal transfer to the musculocutaneous to regain elbow function or spinal accessory to suprascapular to reestablish flexion. In cervical nerve root avulsion, the finding of a traumatic pseudomeningocele indicates an extradural collection of cerebrospinal fluid due to laceration of the dural sleeve17 (Fig. 8). This is the main landmark that indicates a preganglionic injury is present, although pseudomeningocele may occur without nerve root injury.

Figure 8 Pseudomeningocele. (A, B) Twenty-six-year-old man with a traumatic pseudomeningocele after a motorcycle accident. (A) Axial turbo spin-echo (TSE) T2-weighted magnetic resonance (MR) image shows the retracted right C7 nerve root (outlined arrow) and the leakage of cerebral spinal fluid (arrowheads). Note mild denervation signs (white arrow) in the right multifidus and semispinalis capitis muscles. (B) Coronal short tau inversion recovery MR image of the distal plexus reveals a wavy appearance of the retracted nerve cords (outlined arrows). (C) Transverse TSE T1-weighted MR image and (D) corresponding three-dimensional MR myelogram in a 17-year-old young man with chronic root avulsion demonstrate a prominent pseudomeningocele (outlined arrowheads) extending laterally to form a sac (asterisk) in the postscalenic area. Observe the normal contralateral root (black arrowhead, C) at the same vertebral level.
avulsion (~15% of cases) and, conversely, avulsion may occur without meningocele (20% of cases).38–40 Other signs of preganglionic injury include Gd enhancement of intradural roots, intramedullary edema (T2-weighted sequences), lateral displacement of the spinal cord, intracanal hematoma, and secondary denervation signs.4,41,42 These signs are found in ~20% of cases.38 Comparing the results of CT myelography and MR myelography, current literature reports that both imaging modalities have similar sensitivity for detecting intraspinal nerve injuries.17

After excluding preganglionic injuries, an early assessment of the extent and severity of the injury outside the spine is essential for determining treatment. In contrast to preganglionic injuries, postganglionic lesions with defects in nerve continuity can be repaired with nerve grafting that involves excision of the damaged segment and autograft between two nerve ends, or neurolysis to remove perineural scar and adhesions.4 If nerve fascicles are intact, spontaneous recovery is usually expected. In postganglionic injuries, lesions must be further subdivided in supraclavicular and infraclavicular based on their location.4 Preoperative electrophysiological studies are routinely performed to assess the status of brachial plexus nerves outside the spine but often yield ambiguous findings.2,43

Because patients suffering from major postganglionic nerve injuries are known to recover better if operated on early (within 3 months after injury), diagnostic imaging with US and MR imaging has critical value for assessing the status of nerves outside the neural foramina.1,4,17,43 In patients with severe extraspinal injuries, signs of nerve discontinuity are most often observed (1) at the interscalene triangle, as a result of the tethering effect exerted by the scalene muscles on the stretched nerves; and, more distally, (2) at the costoclavicular space, especially in patients with clavicular fracture when bony fragments directly impinge the underlying cords. Diagnostic imaging may provide an early categorization of extraspinal plexus pathology and define surgical candidates by identifying the exact site of the injury, how many and which are the nerves involved, the severity of involvement, and the position of the retracted wavy nerve ends in cases of neurotmesis.

In the acute phase, the information provided by US seems even more detailed than the one provided by MR imaging to distinguish the interrupted nerves from the adjacent deranged soft tissue with hemorrhage and edema.43–45 However, the interpretation of imaging findings becomes more accurate and informative after a few weeks when hematomas or areas of subcutaneous emphysema are reabsorbed and stump neuromas are developing at the nerve ends (Fig. 9). In chronic injuries, fibrous scar arising from damaged fascicles may also be seen encasing normal fascicles and causing late worsening of symptoms (Fig. 10). At the different levels, US and MR imaging can assess the relationship of fibrotic areas with brachial plexus nerves. When the traction injury is not strong enough to determine complete interruption of nerve bundles, segmental fusiform thickening of the involved nerves reflecting a spindle neuroma may occur as a result of traction trauma (Fig. 11). Spindle traction neuromas usually

Figure 9 Acute brachial plexus injury in a 25-year-old motorcyclist with total plexus palsy following a traffic accident. The examination was performed 1 week after trauma. (A) Long-axis ultrasound (US) image over the C5 (white arrowheads) and C6 (outlined arrowheads) components of the upper trunk of the right brachial plexus. Both nerves are transected and exhibit a wavy course. At their end, bulbous neuromas (asterisks) are starting to develop. (B) Three-dimensional gradient-recalled echo MR imaging acquisition with multiplanar reconstruction obtained along the axis of the right roots demonstrates discontinuity (outlined arrows) of C5 through C8 roots. Distal to the transection level, heterogeneous signal in the soft tissues (asterisk) of the supraclavicular area is seen. When compared with the left side, note the swollen appearance and more vertical course of the affected right roots.
NEUROGENIC THORACIC OUTLET SYNDROME

Thoracic outlet syndrome is a range of disorders arising from the passage of the subclavian artery and vein and brachial plexus nerves through the three anatomical spaces of the thoracic outlet: the interscalene triangle, the costoclavicular space, and the retropectoralis minor space, the narrowing of which can variably lead to arterial, venous, or nervous compression. A pure neurogenic syndrome is disputed in the literature.

For the diagnostic workup, a combined approach with MR imaging and US can be used to evaluate the traumatized patient, the first technique to evaluate the spine and the foraminal region, the second to assess the nerves outside the spine. Detection of extraspinal nerve abnormalities with US may have important clinical implications. It may give an early assessment of the status of the plexus in the immediate phases after the trauma when clinical findings are not yet conclusive on whether a brachial plexus damage will require surgery. US seems to be particularly effective in patients with supraclavicular postganglionic injuries, a difficult-to-explore area with MR imaging.

Figure 10 Chronic brachial plexus injury in a 47-year-old man with median nerve palsy following a closed trauma 1 year before. In the last 3 months, the patient presented progressive worsening of pain and neurogenic symptoms in the territory of ulnar nerve distribution. (A) Oblique sagittal turbo spin-echo T2-weighted magnetic resonance image of the supravaculocar space demonstrates swollen hyperintense cords of the plexus (white arrowhead) grouped together and encased by a peripheral fibrous scar (arrows). Outlined arrowhead, subclavian vessels. (B) Corresponding short-axis ultrasound image confirms the presence of scar tissue (arrows) derived from a previous nerve injury. Within the scar, intact hyperechoic fascicles (arrowheads) with preserved fascicular echotexture are seen. Cl, clavicle; sa, subclavian artery.

Figure 11 Brachial plexus injury in a 25-year-old man following a motorcycle accident. (A) Long-axis ultrasound image of the C5 (outlined arrowheads) and C6 (white arrowheads) roots in the paravertebral region reveals nerve abnormalities related to a stretching injury (axonotmesis). Both nerve roots are continuous but have wavy and irregular contours and less defined fascicular echotexture. (B) Normal contralateral side for comparison.
and seems to occur more frequently at the interscalene triangle and the costoclavicular space rather than at the level of the retropectoralis minor space. In many cases, the nerve involvement is not isolated but associated with arterial disease, as a possible result of common neurovascular compression and/or arterial disease causing secondary disturbances in the intraneuronal microvasculature. The clinical diagnosis is difficult because symptoms are vague and nonspecific. In upper plexus involvement, pain typically radiates in the ipsilateral neck up to the occipital region, and it may involve the rhomboid area, the upper pectoralis area, and the deltoid and trapezius down to the external aspect of the arm. Lower plexus pain distributes around the shoulder and radiates down the medial arm and the medial forearm, with an ulnar nerve distribution. Detection of nerve compression is very difficult to detect with imaging modalities both in its isolated form or in association with vascular disease. In fact, US is unable to evaluate nerve changes about the costoclavicular space due to problems of access of the US beam. Similarly, direct visualization of focal swelling and signal intensity changes in the affected nerves at the costoclavicular space is exceptional with MR imaging.

Some authors found good correlation between distortion of brachial plexus nerves seen on MR imaging and clinical symptoms. Using multiplanar reformatting of 3D gradient-recalled echo MR acquisitions or volumetric CT scan with planes reconstructed in the short axis of the interscalene and costoclavicular spaces, imaging is able to directly measure the size of these spaces with the arm alongside the body or during a postural maneuver, such as holding the arm 130 degrees abducted and rotated externally (Wright’s test). Patients with thoracic outlet syndrome showed a significantly smaller costoclavicular distance and a wider retropectoralis minor space after arm abduction (Fig. 13A). In addition, they exhibited a thicker subclavius muscle at rest and during postural maneuver than did normal volunteers. MR imaging may occasionally depict fibrous bands causing nerve distortion. A hypertrophied anterior scalene muscle, possibly accompanied by or fused with a hypertrophied middle scalene compressing the plexus against the first rib (scalenus anticus syndrome), can also be depicted on MR imaging and multislice CT.
some instances, compression may be related to the anomalous insertion of the middle scalene into almost the entire length of the first rib, thus overlapping the anterior scalene and creating a very narrow window for the neurovascular bundle. In this compression, the Adson’s test is positive when the patient’s head is turned outward. Finally, care should be taken not to miss a cervical rib or an elongated transverse process of the C7 vertebra. Both structures are often associated with fibrous bands. For this purpose, a plain film should be always obtained before other imaging studies.

Supernumerary cervical ribs account for ~0.5 to 0.6% of normal people, and in more than half of the cases they are bilateral. Conventionally, cervical ribs can be grouped into four types: type I, <2.5 cm in length; type II, >2.5 cm with free tip; type III, full-size cervical rib with fibrous connection to the first rib; and type IV, full-size cervical rib with a chondral attachment to the first rib. Depending on the rib size, symptoms are present along the C7-T1 distribution with a positive Adson’s test when the patient’s head is turned inward. Finally, care should be taken not to miss a cervical rib or an elongated transverse process of the C7 vertebra. Both structures are often associated with fibrous bands. For this purpose, a plain film should be always obtained before other imaging studies.

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PARSONAGE-TURNER SYNDROME
Parsonage-Turner syndrome, also known as “acute brachial plexus neuritis” or “neuralgic amyotrophy,” is a self-limiting clinical entity consisting of a sudden onset of severe shoulder burning pain followed shortly by profound muscle weakness and flaccid paralysis of at least one of the shoulder girdle muscles. Typically, there is no loss of sensation associated with the weakness. This uncommon but not rare disorder (incidence rate: $1.64 \times 10^5$ people) has a peak incidence between the 3rd and the 5th decades and male predominance (male-to-female ratio ranges from 2:1 to 11.5:1), is often bilateral (a third of cases), and may mimic other more common pathological conditions (e.g., cervical radiculopathy, shoulder impingement syndrome, nerve entrapment due to local mass effect, and rotator cuff tear).

Although different factors, including viral infection, trauma, surgery, and autoimmunity have been implicated to play a causative role, the precise etiology of Parsonage-Turner syndrome still remains controversial. Electrodiagnostic studies may demonstrate changes related to acute denervation in the brachial plexus distribution, especially in the C5 and C6 territory. The suprascapular nerve (supplying the supraspinatus and the infraspinatus) is the most commonly involved. Among other nerves of the shoulder girdle, the axillary (deltoid and teres minor), long thoracic (serratus anterior), and musculocutaneous (coracobrachialis, biceps brachii and brachialis) may be affected individually or in combination. Imaging studies may help confirm the diagnosis.

Although US is able to suggest denervation by showing loss in bulk and hyperechoic appearance of the affected muscles in the absence of tendon tears, MR imaging seems more reliable and gives a comprehensive view of the complex pattern of muscle involvement that characterizes the Parsonage-Turner syndrome. It may
also rule out cervical radiculopathy. Early MR imaging studies demonstrate intramuscular increased T2 signal intensity as a possible result of the increased extracellular water content and/or increased intramuscular capillary blood volume that occur during partial denervation\(^{60,61}\).

Later on, intramuscular fatty infiltration and decrease in muscle bulk can be observed. In most instances, brachial plexus nerves retain normal size, appearance, and signal intensity. Focal areas of increased Gd enhancement and higher T2 signal intensity may seldom be seen in the nerves supplying denervated muscles as a nonspecific sign of inflammation (neuritis). Prognosis is generally benign, with \(\sim 75\%\) recovery within 2 years, and treatment is symptomatic (analgesic drug and physical therapy).

**TUMORS AND POSTRADIATION IMAGING**

Brachial plexus tumors include two main classes of disorder: metastatic disease and neurogenic primary tumors.\(^{47}\) Concerning metastatic disease, a wide variety of histotypes have been reported to involve the brachial plexus secondarily. Among them, breast cancer is more common by far, accounting for approximately \(\sim 1\) to \(\sim 1.8\%\) of patients because one of the most relevant lymphatic drainage paths of the breast passes through the axillary region.\(^{62}\) The onset of metastatic plexus disease varies widely with a mean of 5.5 years. MR imaging demonstrates metastases as definite space-occupying lesions along the course of brachial plexus nerves, characterized by low intensity signal on T1-weighted images, increased signal intensity (higher than that of muscle) on T2-weighted images and Gd enhancement; however, the signal intensity may vary\(^{54}\) (Fig. 16). Pleural and vertebral involvement can be also assessed with this technique. US may reveal a well-defined solid mass with irregular margins and hypoechoic echotexture encasing nerves with an abrupt nerve-to-tumor interface.\(^{63}\) Alternatively, the neoplasm may cause segmental thickening and hypoechoic appearance.
of the involved nerves without causing a clear mass effect. Satellite lymph nodes are often associated.

Distinguishing between metastatic plexopathy and radiation injury is critical to determine both prognosis and treatment, but the distinction is not easy to make, and both electrophysiology and imaging studies have met with limited success. The incidence of radiation-induced brachial plexopathy is significantly higher when the axillary dose of radiation therapy is $>60$ Gy. However, alone, does not determine whether a given patient will develop radiation damage: the treatment technique and the concomitant use of chemotherapy seem also to play a role. Sensory symptoms, such as numbness and paresthesias (55%) along with swelling and weakness of the arm (45%), are the initial symptoms in patients with radiation plexopathy. In contrast, pain is the presenting symptom in 98% of patients with metastatic plexopathy. Based on location, the upper plexus (C5-C6) seems more frequently involved in radiation injury, the lower trunk (C8-T1) in metastatic disease. Horner’s syndrome is also more likely found in metastatic plexopathy rather than in radiation disease. In radiation plexopathy, MR imaging reveals diffuse thickening of the involved nerves without a focal mass and soft tissue changes with low signal intensity on both T1- and T2-weighted sequences. Gd does not help differentiate between tumor and radiation fibrosis because both conditions show some degree of enhancement. US demonstrates diffuse thickening of nerve fascicles in the absence of a focal mass. Different from neoplastic infiltration, the nerve thickening is more uniform, and some faint fascicular pattern is preserved in radiation fibrosis. However,
this finding is far from being specific to the diagnosis, and such a differentiation remains problematic with both modalities. \(^{18}\)F-fluorodeoxyglucose positron emission tomography (FDG-PET) and \(^{18}\)FDG-CT-PET have been used for this purpose.\(^{65,66}\) The results seem promising, particularly if other imaging studies are indeterminate despite clear clinical evidence of brachial plexopathy and for depicting metastases outside the axilla.\(^{16,65,66}\)

Among other malignant histotypes, Pancoast’s tumor (superior sulcus tumor) characteristically presents with a syndrome of pain around the shoulder and in the arm derived from involvement of the C8, T1, and T2 root distribution.\(^{54}\) The main features associated with this syndrome are Horner’s syndrome (i.e., ptosis of the upper eyelid, miosis, anhydrosis, enophthalmos, and loss of ciliospinal reflex), muscle atrophy in the territory of ulnar nerve distribution, radiographic detection of an opacity at the lung apex with first rib destruction, and, often, vertebral body involvement. 3D MR imaging and multislice CT have markedly improved the visualization of this tumor and its relationship with brachial plexus nerves and the subclavian vessels. Primary neurogenic tumors of the brachial plexus, including neurofibromas and schwannomas, are far less common than metastatic disorders. The MR imaging and US characteristics of these tumors are equal to those already described in other locations\(^{47}\) (Fig. 17). The feature of value in distinguishing these tumors from other soft tissue masses—and especially from enlarged supraclavicular lymph nodes—is demonstration of the continuity between the tumor and the nerve of origin.

**NERVES AROUND THE SHOULDER**

In some clinical settings, other neuropathies around the shoulder may be added to the differential diagnosis list.
for a suspected brachial plexus disorder. A brief focus on these frequently missed conditions affecting the suprascapular, axillary, long thoracic, and spinal accessory nerves is therefore needed to remind the radiologist of these problems when evaluating patients with suspected brachial plexus pathology that does not fit typical diagnoses.

Suprascapular Neuropathy

From an anatomical point of view, the suprascapular is a purely motor nerve that takes its origin from the upper trunk (C5 and C6) of the plexus. It descends the neck with an oblique lateral course passing beneath the trapezius and the omohyoideus and enters the supraspinous fossa through the suprascapular notch (Fig. 18A). This notch has variable shape and is roofed by the transverse scapular ligament. After crossing this ligament, the suprascapular nerve gives off motor branches to the supraspinatus muscle. The nerve then travels obliquely along the floor of the supraspinous fossa, deep to the supraspinatus, until it crosses the glenoid rim, and curves around the lateral margin of the base of the scapular spine, an area also referred to as the spinoglenoid notch, to enter the infraspinous fossa (Fig. 18A). At the spinoglenoid notch, the nerve may be roofed by the inferior transverse scapular ligament. Along its course, the suprascapular nerve is accompanied by the suprascapular vessels.

Due to its relatively fixed position combined with its lying under the rotator cuff muscles, the suprascapular nerve is particularly susceptible to compression. The suprascapular notch and the spinoglenoid notch are the most frequent sites of nerve entrapment. A narrow suprascapular notch, an abnormal transverse scapular ligament, mechanical stretching of the nerve by repeated overhead activities, spinoglenoid varicosities, even relatively small space-occupying lesions like paralabral ganglion cysts, and brachial plexus disorders (Parsonage-Turner syndrome) have been reported as potential causes of suprascapular neuropathy. Regardless of the cause, if the nerve is entrapped at the supraspinous notch, the supraspinatus and the infraspinatus muscles undergo denervation changes. By contrast, if the nerve is compressed more distally, at the spinoglenoid notch, denervation is limited to the infraspinatus or part of it, whereas the supraspinatus remains spared. Symptoms are insidious at onset unless there is a history of acute trauma and may mimic glenohumeral instability. Late in the process, wasting or atrophy of the involved muscles become more easily manifest. In many instances, however, the patient does not complain of weakness because of compensation of the posterior deltoid and teres minor.

The diagnosis of suprascapular neuropathy is essentially based on a careful and thorough history and physical examination. Neurophysiology, including EMG and nerve conduction studies, may help confirm the diagnosis, but there are false negatives and it may not always define the nature of the abnormal findings and localize the site of compression. Imaging may be useful to evaluate patients with suprascapular neuropathy, especially to determine the presence of paralabral cysts compressing the nerve and to assess the rotator cuff muscles for atrophy. Paralabral cysts are usually associated with tears of the superior and posterior glenoid labrum (from 8- to 11-o’clock positions), related to the passage of joint fluid into the cyst through a thin pedicle. During their growth, paralabral cysts may spread into the spinoglenoid notch, the suprascapular notch, or both, possibly causing nerve entrapment and muscle denervation. US and MR imaging can identify the cyst and recognize secondary changes of nerve damage, including loss in bulk and echotextural/
signal intensity changes in the innervated muscles due to edema and fatty replacement (Fig. 18B). The continuity of the cyst with a defect in the labrum can be revealed with these techniques as well. A direct correlation has been found between the size of paralabral cysts and the onset of denervation symptoms, with an average volume of the cysts causing muscle denervation significantly greater (6.0 cm³ versus 2.2 cm³ of all other paralabral cysts). Due to their deep location, depiction of paralabral cysts requires a careful scanning technique with US. Varicose veins in the spinoglenoid notch is the main differential diagnosis. Although enlarged spinoglenoid notch veins look like a cyst because they appear as fluid-filled images, they change their shape, collapsing in internal rotation of the arm and dilating maximally in external rotation.

Some relationship between spinoglenoid varicosities and suprascapular neuropathy has been suggested. It is unclear, however, if these two entities are separate expression of a narrow suprascapular tunnel or if the varicosities may actually lead to nerve impingement. Percutaneous needle aspiration of the cyst content can be attempted under US guidance to treat suprascapular nerve compression. For this purpose, repeated “to-and-fro” passage movements of the needle tip are helpful to avoid recurrence. This procedure has reported to lead to marked relief of symptoms in >86% of patients.

Axillary Neuropathy
The axillary nerve arises from the posterior cord of the brachial plexus receiving fibers from C5 and C6 levels. It travels below the coracoid process and then along the inferolateral border of the subscapularis to curve inferior to the glenohumeral joint and pass through the quadrilateral space, a squared passageway bounded by the long head of the triceps medially, the surgical neck of the humerus laterally, the teres minor cranially and the teres major and latissimus dorsi caudally. After crossing this space, the axillary nerve enters the posterior aspect of the shoulder and divides into two terminal branches: anterior and posterior. The anterior branch supplies the anterior and middle deltoid muscle and overlying skin; the posterior branch innervates the teres minor and the posterior deltoid muscle and distributes to the skin overlying the distal deltoid and the proximal triceps (Figs. 19A, B). Along its course, the nerve is accompanied by the posterior circumflex artery. The axillary neuropathy may be secondary to stretching injuries or extrinsic compression in the quadrilateral space caused by humeral fractures, improper use of crutches, casts, fibrous bands, space-occupying masses, and inferior paraglenoid cysts (from the 9- to 7-o’clock positions). Iatrogenic nerve damage during arthroscopic procedures around the coracoid or by posterior surgical arthroscopic portals has been reported. When entrapment of the axillary nerve occurs in the quadrilateral space, there is selective denervation of the teres minor muscle because the anterior branch of the nerve (supplying the deltoid) is spared.
The axillary neuropathy may be discovered incidentally during routine examination of the shoulder because the action of the teres minor cannot be clearly separated from the contribution of the infraspinatus. This would suggest that the disease may exist in a subclinical form. When symptomatic, the axillary neuropathy presents with vague, often nonspecific, posterior shoulder pain, sensory disturbances over the external aspect of the shoulder, and weakness exacerbated by overhead activity and heavy lifting. Even without any detectable soft tissue abnormality along the nerve course, the imaging diagnosis of axillary neuropathy is based on the evidence of volume loss and echotextural/signal changes of the involved muscles in the absence of a tendon tear (Figs. 19C, D). MR imaging is superior to US to depict any space-occupying lesion in the quadrilateral space, such as paralabral cysts extending off the inferior aspect of the glenoid in association with a tear of the inferior labrum.\textsuperscript{21,75,76}

**Long Thoracic Neuropathy**

From an anatomical point of view, the long thoracic nerve takes its origin from C5 through C7 and occasionally (8%) C8.\textsuperscript{10} After traveling anteriorly to the posterior scalene muscle, it traverses distally and laterally

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**Figure 19**  Axillary nerve. Schematic drawings illustrate the anatomy of the axillary nerve in relation to some relevant muscles of the shoulder girdle and the quadrilateral space as seen from (A) the anterior and (B) the posterior aspect of the shoulder. After arising from the posterior cord of the brachial plexus, the axillary nerve (arrow) traverses the inferior border of the subscapularis muscle (2) and then passes through the quadrilateral space, a narrow passageway delimited by the humerus, the teres major (3), the long head of the triceps (4), and the teres minor (5) muscles to enter the posterior aspect of the shoulder. The axillary nerve splits into an anterior branch (black arrowhead) that provides motor supply to the anterior and middle parts of the deltoid (1), and a posterior branch (outlined arrowhead) that supplies the teres minor and the posterior part of the deltoid continuing down as the superior lateral cutaneous nerve of the arm. Along its course, the nerve is accompanied by the posterior circumflex artery. (C) Sagittal ultrasound image over the infraspinous fossa in a 35-year-old professional volleyball player with axillary neuropathy. Note the atrophy of the deltoid and teres minor compared with the infraspinatus. The teres minor appears hyperechoic as a result of fatty replacement. (D) Oblique sagittal short tau inversion recovery magnetic resonance image reveals intramuscular edema with increased signal intensity in the deltoid (1) and teres minor (5).
to pass below the clavicle and under the first and the second rib. More distally, the long thoracic nerve descends along the chest wall in the midaxillary line to the outer border of the serratus anterior, sending branches to each of the digitations of this muscle\(^\text{10}\) (Fig. 20A). The serratus anterior, which forms the medial wall of the axilla, originates from the first through ninth ribs and inserts into the costomedial border of the scapula. It acts as a stabilizer of the scapula during the initial stages of abduction (Fig. 20B).

Long thoracic neuropathy most often derives from repeated microtrauma as a result of a stretching injury. This typically occurs in athletes (e.g., throwing sports like baseball, javelin, or when spiking or serving a volleyball or a tennis ball) when the head is tilted and rotated laterally away from the affected extremity and the arm is raised overhead.\(^\text{10}\) Direct trauma over the upper anterior chest and whiplash injury may also cause nerve compression.\(^\text{37}\) Nontraumatic causes include compression by distended bursae, such as the subcoracoid bursa or the subscapularis recess. Regardless of the pathomechanism, it is still unclear where the injury occurs along the course of the nerve. Physical examination reveals a distinct clinical picture with scapular
winging, particularly when the patient extends his or her arms and pushes against a wall\textsuperscript{78} (Fig. 20C). Direct evaluation of the long thoracic nerve is feasible only in part and for limited segments with US. The diagnosis basically relies on detection of denervation signs in the serratus anterior muscle. MR imaging is superior to US to recognize these signs (Fig. 20D).

**Spinal Accessory Neuropathy**

Although not a true peripheral nerve, the spinal accessory nerve (CN XI) can be acceptably included in the list of nerves around the shoulder because it supplies the trapezius and sternocleidomastoid. After exiting the skull through the jugular foramen, the spinal accessory nerve divides into two branches. The internal one joins with the vagus; the external is mainly a motor nerve containing some sensory fibers coming from C1 through C3.\textsuperscript{10} This latter branch courses underneath the digastric and the sternocleidomastoid and, more distally, crosses in diagonal the posterior cervical triangle bordered by the sternocleidomastoid anteriorly, the trapezius posteriorly, and the clavicle caudally (Fig. 21A). In this area, the spinal accessory nerve has a superficial course beneath the superficial cervical fascia and passes adjacent to lymph nodes. Thus it is vulnerable to blunt trauma, traction, and penetrating wounds or surgical procedures, such as radical neck dissection for neoplasm, carotid endarterectomy, and cervical lymph node biopsy.

Spinal accessory palsy causes a clinically distinct picture resulting from the paralysis of the trapezius, with drooping shoulder, asymmetry of the neckline, weakness

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**Figure 21** Spinal accessory nerve. (A) Schematic drawing shows the pertinent anatomy of the spinal accessory nerve (arrowhead) that emerges underneath the sternocleidomastoid muscle (1), becomes superficial at the posterior cervical triangle (2), and then enters and supplies the trapezius muscle (3). (B) Winged scapula in a 27-year-old woman with spinal accessory nerve palsy after cervical lymph node biopsy. Winging (arrow) involves the superomedial scapula. (C) Longitudinal ultrasound image obtained over the left cervical region in the same patient shown in (B). The spinal accessory nerve (outlined arrows) is seen crossing the sternocleidomastoid muscle and ending in a small fusiform neuroma (white arrow) suggesting complete nerve transection.
of forward elevation, and abduction of the arm and winging of the scapula. Concerning this latter sign and unlike winging as seen with serratus palsy, only the inferior tip of the scapula is prominent. EMG and nerve conduction studies are helpful to diagnose accessory nerve palsy and locate the level of injury. US can complement functional studies to depict the spinal accessory nerve through the posterior cervical triangle and is able to reveal, in pathological cases, stump neuromas or scarring tissue encasing it. For this evaluation, US seems more accurate than MR imaging owing to a higher spatial and contrast resolution.

REFERENCES