THE ANATOMY OF THE BRACHIAL PLEXUS AS DISPLAYED BY MAGNETIC RESONANCE IMAGING: TECHNIQUE AND APPLICATION

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Full field of view coronal chest magnetic resonance imaging (MRI) routinely displays bilateral images of the brachial plexus, surface anatomy, and anatomic structures. Eighty patients had chest radiographs correlated with surgery for thoracic outlet syndrome. The PA chest film findings correlated with the surgical findings: smaller thoracic inlet on the concave side of the cervicothoracic spine scoliosis, shorter distance between the dorsal spine of the second or third thoracic vertebral body to the concavity of the first ribs, asymmetric clavicles and coracoid processes, synchondrosis of the first and second ribs, and muscle atrophy on the side of the clinical complaints.

More than 235 patients were imaged. One hundred sixty-five of these were imaged with a 1.5-T unit and 3-D reconstruction MRI. Coronal, transverse (axial), oblique transverse, and sagittal plane T1-weighted, selected T2-weighted, and fast spine echo pulse sequences were obtained, 4- to 5-mm slice thickness, 40 to 45 cm full field of view, 512 × 256 matrix and 2 NEX. Two-dimensional time of flight (2D TOF), magnetic resonance angiography (MRA) sequences were obtained in selected patients. Coronal, transverse, and sagittal sequences were reformatted for evaluation. Saline water bags were placed between the neck and thorax to enhance the signal-to-noise ratio. Compromising abnormalities of the brachial plexus were confirmed at surgery. Compromise of the neurovascular supply seemed to be one etiology that could be demonstrated. The clinical history, technique, and anatomic bilateral brachial plexus imaging is stressed to improve patient care. The cervical rib is one of the compromising brachial plexopathies selected for this presentation. (J Natl Med Assoc. 1995;87:489-498.)

Key words • anatomy • brachial plexopathy
• nerve model • MRI • pathology
• 3-D color reconstruction

Conventional roentgenography, linear tomography, computerized tomography (CT), and magnetic resonance imaging (MRI) are radiographic modalities used to image the thorax, shoulder girdle, and soft tissues. Vascular structures, surface anatomy, and the soft tissues are incompletely imaged by conventional radiographic techniques. Computerized tomography extends the capabilities of radiographic imaging to obtain detailed transverse (axial) anatomic sections but CT does not definitively separate tumors from vascular and neurovascular structures. Computed tomography reconstructed imaging of soft-tissue anatomy is not satisfactory, and detailed peripheral nerve imaging is not possible. Magnetic
The brachial plexus lies within the fascial planes of the neck and axilla, but is routinely displayed on MRI of the thorax and shoulder girdle.\textsuperscript{1} Magnetic resonance imaging in the supine position allows bilateral sequential imaging of the thorax and the brachial plexus. This is the feature that gave us the opportunity to image the brachial plexus anatomy, construct 3-D color images, and present the anatomy and compromising abnormalities of the brachial plexus as displayed by MRI.\textsuperscript{2,7}

Compromising abnormalities of the brachial plexus and brachial plexopathies result from disorders of the cervicothoracic levels of the vertebral column, the first rib, vascular supply, and soft tissues.\textsuperscript{8,9} The anterior and middle scalene muscles, through which the brachial plexus nerve roots pass and adhere to the subclavian artery, arise from the cervicothoracic levels of the vertebral column. The muscles insert and, in part, support the first ribs. The first ribs are curved, flat, and slope obliquely to form most of the thoracic inlet. The slope that gives an anterosuperior directed upper surface changes with respiration and cervicothoracic spine scoliosis, and affects structures crossing the rib. The anterior scalene muscle and the posterior insertion of middle scalene muscle and the first ribs form the scalene triangle. The change in the slope of the first rib affects the interscalene triangle contents.\textsuperscript{2,5} The scalene muscles are an important visual anatomic landmark in the understanding of brachial plexopathy displayed by MRI.

The upper nerve roots of the brachial plexus descend along the margin of the middle scalene muscle and join the lower nerve roots to envelope the subclavian artery. The nerve roots bind to the artery within the scalene triangle to form a neurovascular bundle.\textsuperscript{10} This bundle passes with sympathetic fibers unprotected over the first rib through the scalene triangle, beneath the clavicle and subclavious muscle, inferior to the coracoid process and posterior to the tendon of the pectoralis minor muscle into the axilla.

The subclavian artery, similar to the artery within the femoral triangle, is unprotected\textsuperscript{4,8} but is not routinely cannulated for vascular studies. Different from the femoral artery, a muscle (the anterior scalene muscle) separates the subclavian vein from the subclavian artery. This makes the anterior scalene muscle an important anatomic landmark in determining compression (effacement) of the scalene triangle contents. Enlargements of the anterior scalene muscle or atrophy of the anterior scalene muscle increases or decreases the distance between the subclavian artery and the sub-

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**Figure 1.** Cadaver dissection demonstrating the "M" or "W" of the left brachial plexus. Legend: lateral cord (2 bar white arrows), brachial artery (BrA), median nerve (Me), musculocutaneous nerve (Mu), ulnar nerve (Ul), medial branch of the lateral cord of Mu (black single bar arrow), and lateral branch of the medial cord forming the median nerve (Me).

Resonance imaging separates proton densities within organ systems and does not require reconstruction or repositioning of the patient. The multi-planer MRI displays the anatomy of the brachial plexus and peripheral nerves for investigation by sequential imaging of landmark anatomy according to proton density distribution.\textsuperscript{2}

The anatomy of the brachial plexus and peripheral nerves are graphically displayed in classical textbooks.\textsuperscript{3,4} Anatomic and clinicopathologic nerve studies allow investigative radiological studies using MRI to go beyond textbook descriptions.\textsuperscript{5,6} Bilateral brachial plexus and peripheral nerve 3-D reconstruction imaging makes possible demonstration of the relationship of nerves to their surrounding landmark anatomy (Figure 1). The knowledge of peripheral nerve and brachial plexus anatomic imaging offers new avenues for teaching medical students, residents, and health professionals.\textsuperscript{1}
clavian vein as demonstrated on transverse MRI sequences.\cite{2} This distance may be measured on the first image or raw data of the magnetic resonance angiography (MRA) 2-D time of flight (TOF) of the brachial plexus.\cite{11}

A thin layer of deep fascia envelopes the neurovascular bundle of the upper limb. Four spaces are formed from the root of the neck to the lower part of the axilla. The spaces that may have clinical problems that compromise the brachial plexus\cite{8} include the intervertebral foramina, scalene triangle, costoclavicular, costocoracoid, and the axilla. In most individuals, the fascial plane spacing between soft tissues and osseous structures is adequate to perform routine functions without compromising the nerves and the artery that combine to form the neurovascular bundle. Pathology involving peripheral nerves alters fascial planes. Acute or permanent changes may alter the adjacent tissues, thereby compromising the vascular supply that nourishes the peripheral nerves.\cite{2,5,6} This results in patients presenting with clinical symptoms. These changes also may occur from articular motion of the shoulder girdle, autoimmune disease, hypertrophic enlargement of the scalene triangle muscles, congenital rib anomalies, pressure by ligaments, instances of abnormal insertion of the scalene (anomalous) muscles, fractures, primary and secondary lymphedema and tumors, crushing injuries of the thorax, and arteriosclerotic disease that results in vascular thrombosis and ruptured silicone breast implants.\cite{2,5,6,8} Patients’ complaints may stem from degenerative changes of their osseous structures. Aging and laxity of their muscular structures may result in complaints from congenital compromising abnormalities that were not obvious problems at a younger age.\cite{2,5,8}

Magnetic resonance imaging demonstrates soft-tissue detail by proton distribution and provides high resolution imaging of nerves, vascular structures, and the lymphatics.\cite{1,2,12,13} The phospholipids found in the myelin of nerves are high-intensity signals when visualized in vitro and intermediate- to high-intensity signals when demonstrated in vivo. Positive mode T1-weighted images show blood flow as low-signal intensities (black) and subcutaneous fat as high-signal intensities (white). Diminished blood flow may appear as an intermediate-signal intensity.\cite{14} The T1-weighted sequence displays the deep fascial layer of tissue containing the neurovascular compartments. Fast spine echo (FSE) with nonfat and nonwater suppression technique displays the long axis of peripheral nerves with high-signal intensities.\cite{2}

The signal-to-noise ratio decreases with FSE imaging, causing decreased contrast and resolution of the images. The low-signal intensities of flowing blood and the high-signal intensities of myelin combine to vary the high signal intensity of nerves. The signal intensity of nerves then may depend on the imaging axis of that nerve.\cite{1} The combination of a rich blood supply to the spinal cord and cerebral spinal fluid results in the intermediate-signal intensity of the spinal cord. Nerve roots may have high-signal intensities after they exit from the subarachnoid space. The low-signal intensity vertical bands of nutrient vessels may interrupt the high-signal intensity of nerves.\cite{2,10,14,15} Compression injuries of nerves involve an ischemic component and alter blood supply. Ischemia initiates inflammatory changes causing edema and fibrosis. Inflammation and edema diminishes the signal intensity of nerves and alters their architecture when compromised in autoimmune disease.\cite{12}

Bilateral imaging of the brachial plexus is based on the fact that the brachial plexus envelopes and adheres to a major artery forming a neurovascular bundle and that displaying the artery ensures imaging the nerves.\cite{5,10,15} In 1985, we presented our findings to David Maxwell of the UCLA anatomy department to supplement instruction in anatomy. He prepared a template list of anatomical structures for teaching the first-year medical student course in gross anatomy to determine if our team could demonstrate the anatomy of the thorax and shoulder girdle with MRI. We imaged the prepared list, including bilateral imaging of the brachial plexus. We presented our results for teaching medical students, residents, and other health professionals.\cite{1}

Compromising abnormalities of the brachial plexus had not been imaged by MRI. Therefore, we also presented our findings to the UCLA Department of Surgery. A list was prepared of 80 patients who had surgery for brachial plexus compression to determine if there were any consistent radiographic findings. The plain chest radiographs revealed several variations in alignment of the osseous structures which correlated with the MRI.\cite{2} We demonstrated our findings and suggested MRI as the imaging modality that might contribute answers prior to surgical management. The UCLA Department of Surgery then requested assistance with selected patients for bilateral brachial plexus imaging. As a result of our presentation, more than 235 patients have undergone bilateral brachial plexus MRI since our presentation.

In 1945, Sunderland’s anatomic nerve model demonstrated the blood supply of nerves,\cite{10} and in 1989, the gross anatomic nerve model of Collins et al\cite{14} demon-
Coronal abduction and external rotation of the upper extremities are used to determine if the change in arm position mimics the clinical complaint.

The coronal sequence is first to be imaged. The brachial plexus envelopes the artery (forming a neurovascular bundle), and the nerves are best imaged when the cursors are aligned to the arterial blood supply. The axillary artery margins vary in each patient and the cursors must be adjusted for each MRI brachial plexus examination. The cursors are positioned from the skin surface of the posterior chest wall to the skin surface of the anterior chest wall for symmetry and 3-D reconstruction and also to detect abnormalities that may mimic brachial plexopathies. The superior landmark is set at the base of the skull and the inferior landmark is set at the level of the kidneys. The image that best demonstrates the arterial blood flow to the upper extremities is selected as the baseline image for the remaining sequences. The transverse sequence is set from the baseline coronal image at the superior aspect of the third cervical vertebral body to the carina. The lateral margins of the shoulder girdle are imaged to ensure bilateral, simultaneous display of the brachial plexus. The oblique transverse sequence is set by aligning the cursors to the arterial blood supply of each upper extremity using the baseline coronal sequence. The cursors are centered to the plane of the axillary artery 2 cm below the inferior cord of the brachial plexus to the superior margin of the coracoid process. This sequence is necessary to detect signal intensity, architecture, and effacement of the long axis of the nerves, arteries, and veins.

The sagittal sequence is obtained by aligning the cursors lateral to the coracoid process and medially to the insertion of the anterior scalene muscle on the first rib. The sagittal plane is necessary to detect effacement of the neurovascular bundle by the coracoid process, pectoralis minor muscle, clavicle and subclavius muscle, axillary masses, and abnormalities of the scalene triangle. When an image sequence is completed, it is immediately transferred to another screen at an independent workstation for review and 3-D reformat display. The software for this 3-D reconstruction is already prepared in the 1.5-T MRI unit (Signa, General Electric Medical Systems, Milwaukee, Wisconsin). The images are stored on CT tape (GE 9800) format and on optical disks for 3-D color reconstruction at an ISG console (ISG Technologies Inc, Mississauga, Ontario, Canada). The entire study is monitored by the radiologist and requires 1½ hours. Selected color, black and white laser prints, and transparencies are obtained for

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**MRI IMAGING OF THE BRACHIAL PLEXUS Technique**

Plain chest radiographs (PA and lateral) are obtained and reviewed prior to the MR examination. The procedure is discussed and the patient examined. Respiratory gating is applied throughout the procedure to minimize motion artifact and maximize the contrast of the soft-tissue signal intensities. The patient is positioned supine in the body coil, arms down to the side (adduction and internal rotation), and imaging is monitored at the MRI station.

A body coil is used because it offers optimal full field of view for bilateral imaging of the brachial plexus and provides uniform signal-to-noise ratio across the imaging field that is necessary for 3-D reconstruction. Surface coils are limited to depth and field of view and are not adequate for bilateral imaging of the brachial plexus. Intravenous contrast agents are not administered. A water bag (500 mL normal saline) is placed on the right and the left sides of the neck above the shoulder girdle to increase signal-to-noise ratio for higher resolution imaging. A full field of view (40 to 48 cm) of the neck and the thorax is used to image both supraclavicular fossae. Contiguous (4 to 5 mm) coronal, transverse (axial), oblique transverse, and sagittal T1-weighted images are obtained. If there is clinical evidence of scarring, tumor, or lymphatic obstruction, T2-weighted images or FSE pulse sequences are obtained. Four imaging sequences are acquired: coronal, transverse, oblique transverse, and sagittal.

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**Illustration:**

Intravenous contrast agents are not administered. A water bag (500 mL normal saline) is placed on the right and the left sides of the neck above the shoulder girdle to increase signal-to-noise ratio for higher resolution imaging. A full field of view (40 to 48 cm) of the neck and the thorax is used to image both supraclavicular fossae. Contiguous (4 to 5 mm) coronal, transverse (axial), oblique transverse, and sagittal T1-weighted images are obtained. If there is clinical evidence of scarring, tumor, or lymphatic obstruction, T2-weighted images or FSE pulse sequences are obtained. Four imaging sequences are acquired: coronal, transverse, oblique transverse, and sagittal.

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**Discussion:**

This article describes a new technique that uses the knowledge of anatomy to analyze the various etiologies of thoracic outlet syndrome and to demonstrate effacement of nerves correlated with patients’ clinical complaints.
lectures and poster presentations; annotated images are preserved on VHS, archived digital tapes, and optical disks.

**Equipment**

Magnetic resonance images are obtained on the 1.5-T MR scanner. The 3-D reformatted images are videotaped on a separate work console at the monitoring station, and computerized color is applied to the images using the ISG console. A 512 × 256 matrix format is used.

**Case Reports**

**Case 1: Cervical Rib.** An 83-year-old, 50 kg female presented with a long history of hypertension treated with diazide, arthritis in the hands and knees, exploratory laparotomy, and total hysterectomy with bilateral salpingo-oophorectomy in 1988; she underwent exploratory laparotomy with adhesions lysis of small bowel obstruction in 1990. In addition, she gives a 5-year history of progressive atrophy and weakness in the right hand and ulnar distribution. She described a throbbing sensation in the upper forearm that would extend into the palm of the hand, especially the ulnar side. When holding objects, she would develop a tremor in her right hand.

In 1989, a neurologic evaluation indicated progressive atrophy and weakness in the right hand and ulnar distribution with likely median nerve involvement. She received physical therapy with protective elbow pads and hand splint. A repeat electromyogram and nerve conduction study in November 1993 indicated descriptions of a true right neurogenic thoracic outlet syndrome: marked thenar atrophy with normal median sensory nerve action potential, poor ulnar sensory potential, and chronic denervation/reinnervation changes in all C8/T1 muscles. Nerve conduction studies demonstrated no ulnar compression at the wrist or elbow, and ruled out an all-ular hand. The left upper extremity conduction studies were normal. The neurologic diagnosis was right neurovascular compression of the brachial plexus. Radiographs for a cervical rib were suggested. The radiographic reports made no mention of cervical ribs. A bilateral MRI of the brachial plexus was suggested to rule out compression at the scalene triangle. A PA and lateral chest radiograph were obtained the day of the MRI examination.

The PA chest radiograph (Figure 2) demonstrated bilateral asymmetrical cervical ribs and narrowing of the intercostal spaces on the concaved side of the scoliosis. Measurements between the dorsal spine of the third thoracic vertebral body to the concavity of the first ribs revealed a smaller right thoracic inlet. Cervicothoracic spine scoliosis, decreased soft-tissue muscle mass over the right cervical region, degenerative compression of the cervical vertebral bodies (C4-C6), degenerative changes of the cervicothoracic junction (C7-T1), and asymmetrical insertions of the first ribs at the sternum were present. The cervical ribs were small, asymmetric, posterior, and faintly displayed. The right cervical rib was larger and angled anteromedially to its lower insertion on the first rib.

The bilateral brachial plexus MRI examination demonstrated asymmetrical cervical vertebral spine pillars, cervicothoracic spine scoliosis (Figure 1), and degenerative compression of the cervicothoracic vertebra (Figure 4) and the bilateral cervical ribs. The right cervical rib compressed the C8 and T1 nerve root proximal to the formation of the displaced inferior trunk (Figure 4). The left cervical rib caused minimal superior effacement of the left 8th cervical nerve root and the adjacent sympathetic nerves.

The coronal images were the best sequence of the series to demonstrate the asymmetric degenerative changes of the cervical spine pillars (higher on the right than left) and compression of the cervical vertebral bodies (C4-C6) (Figures 3 and 4). The nerve roots followed the asymmetry of the cervical spine. Degenerative changes of the acromioclavicular joint accentuated the inferior angulation of the right clavicle and subclavus muscle. The subclavian arteries formed high loops over the first ribs, with the right subclavian artery higher than the left (Figure 3). The right cervical rib effaced the subclavian artery, the 8th cervical nerve, and the 1st thoracic nerve proximal to formation of the inferior nerve trunk, displaced anteriorly by the descending loop of the right subclavian artery (Figure 4). The left cervical rib did not appear to cause significant effacement of the nerve roots.

The transverse sequence demonstrated the enlarged head of the right clavicle, which was bowed anteriorly compared with the left clavicle, the asymmetric cervicothoracic spine, and atrophy of the right scalene muscles. The right nerve roots, divisions, and terminal branches appeared smaller. The cervical rib effaced the right C8-T1 nerve roots, sympathetic nerves, and the subclavian artery as the nerve roots crossed the apex of the right lung (Figure 5), and the spinal cord was tethered to the right. Blood flow decreased in the left internal jugular vein. The bilateral oblique transverse imaging sequence confirmed the above findings and displayed mild effacement of the C8 nerve root by the smaller left cervical rib.
Figure 2. PA chest radiograph demonstrating an apparent rotated appearance secondary to scoliosis. The larger right and left ribs are margined by small arrows. Legend: aorta (A), superior margin right first (1A) and left first ribs (2A), cervical vertebral bodies (C6 & C7) transverse process of the right and left T1 vertebral (arrow heads), ends of cervical ribs (single bar arrow), and right (RL) and left lungs (LL). Figure 3. Image 24 of the coronal series demonstrates asymmetry and splaying by the right cervical rib (outlined arrow). Legend: lateral pillars of the cervical spine (C3-C6), spinal cord (21), ventral ramus of the 2nd spinal nerve (2), C5 spinal nerve roots (5), C7 spinal nerve roots (7), right spinal accessory nerve (SA), right transverse process (Tp) of first (T1) and second (T2) thoracic vertebrae, right lung (RL), sympathetic nerve (S and arrowheads), right first rib (small arrows), and right middle scalene muscle (MS).

Figure 4. Image 27 of the coronal series demonstrates slight narrowing of the right subclavian artery (4 small arrows) and compressed (C4-C6) cervical vertebral bodies. Legend: right cervical rib (CR), C8 spinal nerve root (8), vertebral artery (VA), C4 & C5 spinal nerve roots (4 & 5), external jugular vein (ExJ), spinal accessory nerve (SA), brachiocephalic artery (BA), first rib (R), stellate ganglia (SG), middle cervical ganglia (MC), inferior (I) and middle nerve trunks (10), sympathetic nerve and right first rib (small arrows), first thoracic nerve root (1T), right and left vagus nerves (V), first thoracic vertebra (T1), right (RL) and left (LL) lungs, recurrent laryngeal nerves (33), left subclavian artery (S), trachea (T), esophagus (E), and aorta (A). Figure 5. Transverse image 18 demonstrates effacement of nerves by the right cervical rib. Legend: ansa subclavia (3), left normal C8 and right effaced C8 nerve roots (8), effaced first thoracic nerve root (4 small arrows) joining T1 nerve root (4 arrowheads), ascending (S) and descending (SD) loops of subclavian artery, external (EJ) and internal jugular (RJ & LJ) veins, anterior scalene muscles (RAS & LAS), common carotid arteries (RC & LC), trachea (T), esophagus (E), vertebral arteries (VA), dorsal spine (Sp) and spinal cord (21), multifidus muscle (Mul), spinal accessory nerves (SA), brachiocephalic artery (BA), sterno-cleidomastoid muscle (ST), common carotid artery (CC), aorta (A), supraclavicular nerves (Sc), clavicle (C), manubrium sternum (M), neck subcutaneous fat (4 black arrows), and right lung (RL).

Figure 6 was the first image of the right sagittal sequence that demonstrated the cervical rib effacing the C8-T1 nerve roots complementing the coronal and transverse sequences. The recurrent laryngeal nerve paralleled to its origin from the vagus nerve and the adjacent superior cardiac nerves. The left sagittal sequence was normal.

The 3-D color generated images (Figures 7, 8, 9, and 10) were cross referenced to the gray scale sequential images to demonstrate the in vivo anatomic relationship between the neurovascular bundles, osseous structures, and adjacent landmark anatomy. Figure 7 was rotated into a posterior oblique display to accentuate the degenerative compression of C4-C6 cervical vertebral bodies, the asymmetric cervicothoracic spine scoliosis, and the bilateral cervical ribs. The thoracic spine was convexed to the right at the T5-T6 level. Figure 8 demonstrated the nerve roots, nerve divisions, and
terminal branches of the brachial plexus. The right cervical rib position and the C8-T1 (T1 darken) next to the right long thoracic nerve crossed the first rib. The lateral position of the radial nerve and medial position of the right median and the ulnar nerves reflected the internal rotation adduction of the arms with the hands on the chest wall. The left brachial plexus appeared smaller.

The nerves and vascular structures were combined into one image (Figure 9). The image displayed asymmetry and the loops of the subclavian arteries. The left cervical nerve root joined the sympathetic chain. The right inferior nerve trunk and the median nerve roots (lateral to the inferior trunk) arched anteriorly and over the right subclavian artery. Figure 10 combined the osseous, nerves, and vascular structures into one image to demonstrate bilateral anatomic landmark relationships. The right subclavian artery arched high over the first rib and the cervical rib effaced the C8-T1 nerve roots. The smaller left cervical rib effaced the superior margin of the C8 nerve root and sympathetic nerve branches. The manubrium sterni asymmetric articulation with the clavicles complemented the PA chest radiograph (Figure 2).

The 3D images confirmed the gray scale imaging series and displayed the compression changes of the cervical vertebral spine. The cervical rib compression and effacement was displayed. The patient was informed of our findings. Because of her age, surgery was not recommended. Her physician elected to continue observation and physical therapy as tolerated.

**Case 2: Neurolemmoma of the Median Nerve.** A 28-year-old male presented with a painful palpable mass on the medial aspect of the right upper arm. The neurological examination determined the mass involved the median nerve. A bilateral brachial plexus MRI was requested to rule out possible multiple tumors prior to surgery. The radiologist recorded a brief history and modified physical examination to confirm the location of the mass. A bilateral brachial plexus imaging was performed with coronal and transverse sequences to ensure the proximal bilateral brachial plexus was normal and without any other tumor present.

The coronal and transverse sequences were within normal limits except for the mass involving the median nerve of the right upper arm. Saline water bags were placed along the long axis of the right upper extremity. Oblique sagittal T1 (Figure 11) and oblique sagittal (Figure 12) sequences were obtained of the right upper arm. The tumor was demonstrated and surgically proven to be a neurolemmoma. The patient tolerated the surgery without sequelae.

**DISCUSSION**

Bilateral imaging of the brachial plexus requires knowledge of landmark anatomy and the blood supply of the normal brachial plexus that allows the radiologist to use computerized imaging to explain the clinical manifestations of the pathology. The clinical history must be correlated with the anatomy to further understand the compromising brachial plexopathies displayed by MRI.

Radiology strives to increase the quality of imaging by subtracting the background and increasing the signal to noise ratio. The simple placement of saline water bags next to the neck and next to the long axis of the extremities provides increased signal-to-noise ratio and increased definition of peripheral nerve and soft-tissue imaging. Respiratory compensation (gating) diminishes artifacts caused by the uncontrolled movements of breathing (Figure 11) and increases artifacts in FSE pulse sequence imaging (Figure 12). Cursor lines indicate the position of each image and are required for cross reference between sequences. The absence of the numbered cursor lines impedes interpretation.

Surface coils are used exclusively by some institutions. Their studies are designed to include surface coils to image the brachial plexus. Although our institution has surface coils and the phased-array torso coils, these are not routinely used. Furthermore, the phased-array torso coils cost $250,000 or more. The surface penetration does not give uniform imaging that the body coil provides. We have been using saline water bags to enhance MRI at our institution for more than 9 years. Most health professionals and clinical radiologic-anatomists would not be able to afford the phased-array torso coils; the contiguous anatomic structures to those important in these cases would not be imaged. We may have found use for the phased-array torso coil, but this technique does not allow recognition of landmark anatomic structures in sequential imaging. The added feature would not allow us to use the different planes of imaging.

The authors stress enlarging selected images to demonstrate nerve effacement that we demonstrated in our cervical rib presentation (Figures 2 through 10). Cervical ribs are congenital abnormalities of the cervicothoracic spine. They may be present in patients and not cause clinical complaints until an injury of some sort occurs. Often they go undetected and do not present a problem. When chest radiographs are
Figure 7. 3-D osseous structures demonstrating asymmetry, scoliosis, cervical ribs (CR & CRL), and compressed cervical vertebra (C4-C6). Legend: cervical vertebra (C1-C7); left transverse processes (1Tr & 2Tr) of the 1st (R1) and 2nd (R2) ribs; anterior ribs (1A & 2A); coracoid process (19); acromioclavicular joints (AC); humerus (H); 1st, 2nd, and 12th thoracic vertebral bodies (T1, T2, & T12); body (B) of the manubrium sternum (M); and clavicle (C).

Figure 8. 3-D of nerve roots, divisions, and terminal branches of the brachial plexus and position of the right cervical rib. Legend: right (R) and left (L) nerve roots (4-8); superior (ST) and inferior (IT) trunks; middle (MC) and posterior (PC) cords; stellate ganglia (SG); axillary (Ax); dorsal scapular (Do), suprascapular (Su); radial (R), median (Me), ulnar (Ul), musculocutaneous (Mu), long thoracic (LT), and 1st thoracic (T1) nerves; and sympathetic nerve (Sy).

Figure 9. 3-D neurovascular bundles of brachial plexus, great vessels, and heart. Legend: right (R) and left (L) nerve roots (4-8); 1st thoracic nerve (T1); superior (ST), middle (MT), and inferior (IT) trunks; axillary (Ax), dorsal scapular (Do), suprascapular (Su), radial (R), median (Me), ulnar (Ul), musculocutaneous (Mu), long thoracic (LT), and 1st thoracic nerves (T1); aorta (A); pulmonary artery (P); left ventricle (LV); axillary (1), subclavian (s), common carotid (c), brachiocephalic (BA), and brachial (BrA) arteries; brachial (BrV), axillary (AV), and external jugular (ExJ) veins; and sympathetic nerve (Sy).

Figure 10. 3-D osseous, neurovascular bundles, heart, and great vessels demonstrating the mild right convexed cervicothoracic scoliosis. Legend: right (R) 1st rib (R1); cervical rib (CR); C4-C7 nerve roots; small left cervical rib (CRL); anterior rib (2A); acromioclavicular joints (AC); humerus (H); 1st, 2nd, & 12th thoracic (T1, T2, & T12) and cervical (C2-7) vertebral bodies; body (B) of the manubrium sternum (M); middle (MT) and inferior (IT) trunks; axillary (Ax), suprascapular (Su), radial (R), median (Me), and ulnar (Ul) nerves; pulmonary artery (P); left ventricle (LV); axillary (A), subclavian (s), common carotid (c), and brachial (BrA) arteries; brachial (BrV), axillary (AV), and external jugular (ExJ) veins; and sympathetic nerve (Sy).
reviewed, the cervical ribs are routinely listed as an incidental finding. Seldom does the radiologist receive a follow-up communication of their detection.

Our patient was 79 years of age before her complaints were related to a physician. The cervical ribs were not identified. Her surgical admissions were emergency clinical situations that did not permit quality chest images. The ribs were suboptimally visualized on the portable chest radiographs. The consulting neurologist suggested a bilateral brachial plexus MRI examination because he was aware of our procedure. The MRI confirmed the clinical neurologic examination. The bilateral cervical ribs, muscle laxity, and degenerative changes of the osseous structures all seem to have contributed to the diagnosis of a right thoracic outlet syndrome.5,8,15

The authors are aware of alternative diagnoses that may have caused her complaints. We are also aware that our narrative presentation included statements without all of the images displayed. We did present a more extensive report for the patient's file supported by these selected images. Unlike radiographic images, a diagnosis is not made from a single plain film.17,18 Multiple images are provided in an MRI sequence from which a
selected group may best demonstrate the abnormality. Since it is not possible to present all of the images, those selected best demonstrated the pathology.

CONCLUSION

3-D reconstruction is a useful tool to confirm gray scale MRI examinations. Tailored anatomic bilateral MRI of the brachial plexus correlated with the clinical history allows the study of brachial plexopathies. We plan to continue reporting compromising abnormalities of the brachial plexus from our MRI experience.

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