Ultrasound of Brachial Plexus: Technique, Mapping and Pathology

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Learning objectives

- To describe the technique for evaluating brachial plexus using high resolution ultrasound.
- To map the anatomy of brachial plexus on ultrasound.
- To describe the ultrasound features of various brachial plexus pathologies.
Background

Magnetic resonance imaging is currently the preferred method for direct imaging of the brachial plexus. Successful attempts were made to evaluate brachial plexus anatomy and pathology with high resolution ultrasonography in recent studies. The aim of the current study was to explore the potential of this technique for identification and mapping of the brachial plexus and in recognizing lesions in the region of the brachial plexus. Nature of the lesions, their extent and relation to adjacent anatomic structures were also assessed.
Findings and procedure details

Twenty two patients who presented to the radiology department with suspected brachial plexus pathologies were examined over a period of three years. The patients were examined with a high frequency linear transducer ranging from 12 to 17 MHz in supine and semilateral decubitus position without specific preparation. The list of cases include:

- Post-traumatic brachial plexopathies (12 cases)
- Primary tumors (2 neurofibromas, 1 schwannoma and 2 MPNST.)
- Secondary tumors (1 metastasis from carcinoma breast, 1 case of rhabdomyosarcoma infiltrating brachial plexus)
- Post irradiation injuries (1)
- Inflammatory (2 cases of Parsonage-Turner Syndrome)

RELEVANT ANATOMY

The brachial plexus is a major neural structure, providing motor and sensory innervation to the upper extremity. It is formed by the union of the ventral rami of C5, C6, C7, C8 and T1 nerves (Fig 1).

The fifth and sixth rami unite at the lateral border of scalenus medius as the upper trunk; the eighth cervical and first thoracic rami join behind scalenus anterior as the lower trunk; the seventh cervical ramus becomes the middle trunk. The three trunks incline laterally, and either just above or behind the clavicle each bifurcates into anterior and posterior divisions. The anterior divisions of the upper and middle trunks form a lateral cord that lies lateral to the axillary artery. The anterior division of the lower trunk descends at first behind and then medial to the axillary artery and forms the medial cord; it often receives a branch from the seventh cervical ramus. Posterior divisions of all three trunks form the posterior cord, which is at first above, and then behind, the axillary artery.

ULTRASOUND TECHNIQUE

Ultrasound examination of nerves of the brachial plexus is based on detection of some anatomic landmarks in the neck which are bones (roots), muscles (trunks) and vessels (divisions and cords). After exiting the neural foramina, the roots pass between the anterior and posterior tubercles of the transverse processes of the cervical vertebrae, in close relationship with the vertebral artery and vein.

PLANES OF EXAMINATION
Coronal planes are able to depict the nerve roots in the paravertebral area using the same longitudinal scan for the study of the vertebral artery and vein as a landmark. Moving the transducer slightly posteriorly, the vessels disappear and the roots appear as elongated hypoechoic structures exiting the neural foramina located over the costotransverse bar of the vertebra (Fig 2). Transverse planes are ideal to depict the relationship of the roots with the transverse processes at any given level. Absent anterior tubercle of the transverse process is used as a landmark for identification of C7 and assessment of the level of the nerve roots. For this purpose, scanning first reveals the C7 level and then moves either up or down on axial planes. The C7 root is detected in the same plane as the C7 vertebra, bordered only by the posterior tubercle (Fig 3).

**PARAVERTEBRAL REGION**

Shifting the transducer upward, the C5, C6 vertebrae are recognized due to the presence of prominent anterior and posterior tubercles. The nerve root appears as a hypoechoic structure in between the tubercles (Fig 4). From the anatomic point of view, the higher the level, smaller the space between the tubercles. Then, moving the transducer downward from C7, the lateral aspect of the T1 vertebra is flat without any tubercle. At this level, the C8 nerve root can be appreciated near the foraminal outlet. More caudally, identification of the T1 root is not always feasible. The deep cervical artery arising from the costocervical artery runs between the C7 and C8 nerve roots and is useful in identifying them.

**INTERSCALENE TRIANGLE**

The roots unite to form the three trunks: upper (C5 and C6), middle (C7) and lower (C8 and T1) in the scalene triangle. The interscalene triangle is bordered anteriorly by the anterior scalene muscle and posteriorly by the middle and posterior scalene muscles. Sweeping the transducer down to the interscalene region on short-axis planes, the nerve trunks are visualized. The nerve trunks are identified as oval hypoechoic structures arranged above the subclavian artery, which lies at the bottom of the interscalene triangle (Fig 5). Confident identification of the trunks can be done simply by following the nerves into the scalene triangle.

**SUPRACLAVERICULAR REGION**

The supraclavicular region is assessed in a sagittal-oblique plane with the probe slowly inclined medially and inferiorly. In the supraclavicular region, the nerves are visualized as
a cluster of hypoechoic rounded images that represent the divisions (Fig 6). The divisions follow, for the most part, the posterior aspect of the subclavian artery, just over the straight hyperechoic appearance of the first rib and apical pleura.

COSTOCLAVICULAR SPACE

This space cannot be assessed directly because of the clavicular shadowing. It is therefore explored by an infraclavicular approach.

INFRACLAVICULAR REGION

Crossing down the clavicle, in the infraclavicular area, the nerve cords continue their course along the axillary artery and behind the pectoralis minor muscle. Lateral cord is anterior to the axillary artery, medial cord is posterior to the lateral cord and the posterior cord lies superior to these two cords (Fig 7).

PATHOLOGY

Five main groups of pathology can be identified in brachial plexus which include,

1. Post-traumatic brachial plexopathies.
2. Primary tumors (benign and malignant).
3. Secondary tumors
4. Post irradiation injuries.
5. Inflammatory plexitis.

POST-TRAUMATIC BRACHIAL PLEXOPATHIES

Commonest of the pathologies. Mainly occur in young individuals, bike riders and in high velocity accidents. This group would include various imaging manifestations like

- AVULSION OF ROOTS WITH PSEUDOMENINGOCELE FORMATION

  - Pseudomeningoceles are seen as anechoic intraspinal or extraspinal cerebrospinal fluid collections along the course of the nerve. The nerve root can be absent in the typical location (Fig 8).

- STRETCH INJURY

  - Involved roots/trunks appear hypoechoic and bulky (Fig 9) but the continuity of the involved nerves remains intact. There could be surrounding soft tissue edema.
• RUPTURE /TEAR
- Complete discontinuity (Fig 10) of the involved nerve structure easily seen on ultrasound when it is followed from its root level. The ruptured ends show a wavy contour.

• POST TRAUMATIC NEUROMA
- Segmental fusiform thickening of the involved nerve of the plexus represents formation of a post traumatic neuroma(Fig 11)

PRIMARY NEUROGENIC TUMORS

• Uncommon.
• Include both benign and malignant.
• Primary tumors commonly encountered include Neuroma, Schwannoma, Neurofibroma and MPNST(Fig 12, 13).
• Presence of a mass in continuity with any part of the plexus can be easily appreciated when the plexus is properly traced. The nerve fascicles can either be seen compressed or replaced depending on the type of tumor. The US characteristics of these tumors are the same as those already described in other locations of the body. Doppler helps in identifying internal vascularity of the tumor. Relationship of the adjacent nerve roots with the tumor can be appreciated with meticulous technique.
• Conditions like neurofibromatosis with multiple nerve involvement can be easily diagnosed on ultrasound by the fusiform, nodular appearances of all the involved nerves (Fig 14).

SECONDARY TUMORS

• More common than primary tumors.
• Usually unilateral and more focal.
• History of known malignancy.
• The most common causes are Pancoast's Tumor, contiguous and metastatic spread from breast malignancy, soft-tissue tumours, lipoma, aggressive fibromatosis, and neck tumours.

Metastatic tumor appears as a welldefined solid mass with irregular margins and a hypoechoic echotexture. It can be seen encasing the nerves with an abrupt nerve-to-tumor interface. The involved nerves would show either thickening or complete loss of fascicular pattern (Fig 15). Tumor can also encase the adjacent vessels. Color Doppler imaging can depict intratumoral vessels and also assess the patency of the adjacent vessels.
RADIATION PLEXOPATHY

- Delayed onset
- Peak onset at 10-20 months.
- Difficult to distinguish post-radiation plexitis from recurrent tumour.
- In radiation fibrosis, US demonstrates diffuse thickening of the nerve fascicles in the absence of a focal mass. Unlike tumor infiltration, the nerve thickening is more uniform and some faint fascicular pattern is preserved (Fig 16). However, this finding is far from being specific to radiation fibrosis and the differentiation between radiation damage and residual tumor or recurrence can be problematic as the two conditions may coexist.

PARSONAGE-TURNER SYNDROME

Parsonage-Turner Syndrome, which is also known as "acute brachial plexus neuritis," is a rare clinical entity of unknown cause consisting of sudden severe shoulder pain followed by the onset of profound muscle weakness and flaccid paralysis of the shoulder girdle and upper arm. Peak rate of incidence is between the third and fifth decades with a slight male predominance. Viral infection, trauma, surgery and autoimmunity have been suspected to play a causative role. Usually no loss of sensation is associated with the weakness.

At US examination, the affected nerves appear bulky and hypoechoic. (Fig 17). Delayed imaging reveals atrophic, hyperechoic muscles due to denervation and fatty infiltration.
Images for this section:

**Fig. 1:** Anatomy of brachial plexus showing the roots, trunks, divisions, cords and terminal branches.

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**CORONAL PLANE - ROOTS**

**Fig. 2:** A: position of the transducer to acquire a coronal section of the brachial plexus roots B: ultrasound image showing C5,6,7 nerve roots (arrows) as curvilinear hypoechoic structures exiting from the neural foramina. They can be easily tracked in to the scalene triangle to form the trunks

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**PARAVERTEBRAL REGION - TRANSVERSE PROCESS**
**Fig. 3:** A: Image of the neck showing the location of the transducer in the lower cervical region. Transducer is placed axially to better identify the transverse processes. The arrows mark the movement of the transducer till the C7 transverse process is identified. B: Ultrasound image at C7 level showing C7 nerve root (*) as an oval hypoechoic structure exiting the neural foramina over the transverse process (TP). The posterior tubercle is seen as a sharp horn deep and inferior to the nerve root (arrow). Note the absence of the anterior tubercle in the image. [CCA- common carotid artery]

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**Fig. 4:** A: Image of the neck showing the location of the transducer in the lower cervical region. Transducer is placed axially to better identify the transverse processes. B: C5 vertebra showing transverse process with anterior and posterior tubercles. C: Ultrasound image at C5 level showing C5 nerve root (*) as an oval hypoechoic structure exiting the neural foramina over the transverse process (TP). The anterior (closer to the CCA) and posterior tubercles are seen as a sharp horns on either side of the nerve root (arrows). [CCA- common carotid artery]

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Fig. 5: A: position of the transducer B: picture showing the scalene triangle between the anterior and middle scalene muscles. C: ultrasound image in the scalene triangle shows nerve roots and trunks as hypoechoic oval cross sections between the muscles. D: shows the outline of the nerve roots and the trunks they form. The scalene muscles are also marked in the image SA- scalene anterior; SM- scalene medius.

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**Fig. 6:** A: image showing position of the transducer in the supraclavicular region B: Ultrasound image shows cross section of the divisions and cords in the supraclavicular region. These nerve structures are arranged in a triangular cluster posterosuperior to the subclavian artery. The subclavian artery (SCA) and subclavian vein (SCV) are marked in the picture.

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Fig. 7: A: position of the transducer in the infraclavicular region acquiring the sagittal section of the plexus B: Ultrasound sagittal section in the infraclavicular region shows the cross section of the cords along the axillary artery (A). The lateral cord (LAT) is seen anterior to the axillary artery with medial cord (MED) placed slightly posteriorly and the posterior cord (POST) superior to the lateral cord. The cords corkscrew around the axillary artery as they course down. The pectoral muscles are seen close to the transducer overlying the cords.

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Fig. 8: 22y/M with a h/o fall from bike presents with weakness in the left upper limb and wrist drop. Transverse section (A) at the level of C7 nerve root shows a diffusely bulky C7 nerve root (L) on the left side. The right side C7 nerve root is also given in the image for comparison. Coronal section (B) at the root level shows absence of the C8 nerve root in the paravertebral region with large anechoic fluid collection in the region correlating with complete transection of the root with pseudomeningocele formation. Extended field of view ultrasound image(C) along the course of the C8 nerve root shows complete transection and retraction (arrows) of the nerve root and a large pseudomeningocele (*) extending in to the infraclavicular region. TIRM coronal MRI (D) shows left C8 nerve transection with a large pseudomeningocele (arrow).

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Fig. 9: 25 y /M patient with h/o RTA and wrist drop on right side. The transverse section [A]of the roots and trunks in the right scalene triangle shows diffuse increase in bulk as compared with the opposite side. No loss of integrity seen on ultrasound. The coronal images [B,C] show the bulky C6,7,8 nerve roots on right side correlating with stretch injury.

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**Fig. 10:** 25y old male patient with h/o RTA presents clinically with suspected right brachial plexus injury. Coronal section [A] shows complete transection of C6,7 nerve roots in the scalene triangle with retracted roots, seen as irregular curvilinear hypoechoic bands with loss of continuity (arrows). Transverse section [B] of the roots in the scalene triangle are seen as thickened hypoechoic discontinuous structures(*)

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Fig. 11: 18Y/M with RTA. Coronal section [A] at the level of C7/C8 shows absence of the hypoechoic exiting nerve root correlating with complete root avulsion of C8. Anechoic fluid collection is noted at C8 level correlating well with pseudomeningocele [*] also seen on T2 coronal MR image[B]. Transverse image [C] in the supraclavicular region shows all the cords diffusely thickened with thick fascicular pattern suggesting neuroma [arrows] formation which is confirmed on the T2 coronal MR image[D]

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**Fig. 12:** 12y/F c/o tingling and numbness in the left arm and forearm. Brachial plexus image in the infraclavicular region (A) along the longitudinal axis of the cords show a well-defined heterogeneously hypoechoic mass lesion arising from the posterior cord (arrows). The nerve fascicles are clearly made out as linear hypoechoic tracks. The clavicle shadow (clav) is seen on the left side of the image. Sagittal section in the infraclavicular region (B) shows the tumor (T) in the region of the posterior cord. The lateral (*) and medial (**) cords are seen around the axillary artery (A). TIRM coronal MR image (C) shows a well-defined heterogenous mass in the supra and infraclavicular region. The posterior cord (arrow) is seen continuous with the lesion.

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**Fig. 13:** 33y old male patient presented with mass in the left axillary region associated with pain and numbness in the ulnar nerve distribution. [A] Longitudinal section of the ulnar nerve in the axillary region shows a well defined oval hypoechoic mass lesion arising from the nerve. The fascicular pattern(*) of the adjacent normal nerve is clearly defined on Ultrasound as hypoechoic linear bands. The lesion was removed en mass [B] and proved to be a schwannoma on histopathology.

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Fig. 14: Coronal section ultrasound (A) and TIRM MRI (B) of bilateral roots and trunks show diffuse nodular thickening of the nerves (arrows). There is a generalized involvement of all the nerves. Transverse section in the supraclavicular region (C) shows diffuse thickening of all the divisions (*) on both sides. Ultrasound and coronal MRI image at C1-C2 level show a well defined dumbbell shaped tumor causing cord compression(*)

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**Fig. 15:** 36y old female patient with Rhabdomyosarcoma of left arm c/o wrist drop. Ultrasound shows a large irregular hypoechoic mass lesion [arrows] in the axillary region engulfing the posterior (*) and lateral(**) cords and Axillary artery(AA). Fig.A shows long axis of the posterior and lateral cords engulfed by the mass. The axial section [B] of the posterior cord shows thickened fascicles with loss of perineural planes correlating with tumor infiltration. The axillary artery caliber is also narrowed. The medial cord (#) is spared.

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**Fig. 16:** 47y/F with h/o carcinoma left breast, post surgery and post radiotherapy status presented with left upper limb weakness. Transverse section (A) at paravertebral level shows diffuse thickening of the C7 nerve root (arrow). The normal right C7 nerve root is seen on the left half of the image. Longitudinal section (B) of the C7 nerve root shows fusiform thickening of the nerve root with thickened fascicles (arrows). Transverse section in the supraclavicular region (C) and coronal section of roots and trunks (D) show diffuse thickening involving all the roots, trunks and divisions (*) correlating with radiation neuritis.

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**Fig. 17:** 63y/M c/o right upper limb weakness since 20 days which started after a bout of viral fever. Ultrasound at the level of divisions (A) in the supraclavicular region shows diffuse thickening of all the right sided nerves (*) around the subclavian artery (SCA) with normal left sided divisions. The coronal image (B) shows bilateral roots (C5-8) (arrows) with increased bulk of the nerves on the right side.

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Conclusion

High resolution ultrasonography successfully depicted a spectrum of lesions of traumatic, neoplastic, and inflammatory nature in the brachial plexus. It provided useful information regarding the lesion site, extent, and anatomic relationships. The main disadvantages include poor visualization of C8 and D1 nerve roots in patients with short neck and the bony obstacles in evaluating the pre ganglionic region. The learning curve is long, but once the technique is mastered ultrasound can be efficiently and reliably used in evaluation and diagnosis of brachial plexus pathologies.
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