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Original Article

Magnetic resonance neurography of the brachial plexus

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ABSTRACT

Magnetic Resonance Imaging (MRI) is being increasingly recognised all over the world as the imaging modality of choice for brachial plexus and peripheral nerve lesions. Recent refinements in MRI protocols have helped in imaging nerve tissue with greater clarity thereby helping in the identification, localisation and classification of nerve lesions with greater confidence than was possible till now. This article on Magnetic Resonance Neurography (MRN) is based on the authors' experience of imaging the brachial plexus and peripheral nerves using these protocols over the last several years.

KEY WORDS

Brachial plexus; imaging; magnetic resonance neurography

INTRODUCTION

Imaging has historically played a limited role in detecting, defining and localising lesions of the brachial plexus. However, Magnetic Resonance Imaging (MRI) has now come to be increasingly recognised as the imaging modality of choice in such lesions.[1] Recent advances in MRI technique have helped in imaging the brachial plexus and other peripheral nerves with greater clarity thus permitting clinicians to arrive at a diagnosis with much greater confidence than was possible before.[2] Magnetic Resonance Neurography (MRN) is one such technique, which allows visualisation of nerve tissue with great accuracy.

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NORMAL ANATOMY

The brachial plexus has a complex anatomy, the proper understanding of which is essential to interpret the information obtained from MRN. The plexus innervates the skin and muscles of the entire upper extremity except for the trapezius and small part of skin adjacent to the axilla.[3] It is formed by the ventral rami of C5-C8 and T1 spinal nerves. C4 has an additional contribution in a prefixed plexus and similarly T2 has an additional contribution in a post-fixed plexus.

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The union of the ventral root, which has motor fibres, and dorsal root, which has sensory fibres, forms each spinal nerve. Each root is attached to the spinal cord through a number of rootlets. The cell bodies of motor fibres lie in the anterior horn of the spinal cord and those of sensory fibres lie in the dorsal root ganglion, which itself is present at the level of the intervertebral foramen. The spinal nerves pass through the interscalene triangle, which is situated between the anterior and middle scalene muscles. At the lateral border of the scalene triangle, the C5 and C6 spinal nerves join to form the upper trunk, C7 continues as the middle trunk and C8 and T1 join to form the lower trunk. Behind the clavicle, the trunks divide into anterior and posterior divisions. The anterior divisions of upper and middle trunks join to form the lateral cord. The anterior division of the lower trunk forms the medial cord and posterior divisions of all the trunks join to form the posterior cord. The medial and lateral cords course anterior to the subclavian artery and the posterior cord passes posterior to it. These cords run posterior to the pectoralis minor muscle and subsequently give off their terminal branches.[4,5] The musculocutaneous nerve and lateral root of median nerve arise from the lateral cord. The medial cord gives off the ulnar nerve, medial root of the median nerve and medial cutaneous nerves of arm and forearm. The axillary and radial nerves are branches of the posterior cord.

TECHNIQUE AND IMAGE EVALUATION

Prior to the examination, all contraindications to MRI must be ruled out by taking a detailed history of the patient. These include permanent cardiac pacemakers, cochlear implants, etc. At the authors' institution, patients are imaged in the supine position with arms at their sides in a 1.5T scanner (Magnetom Essenza, Siemens, Erlangen, Germany) using both cervical and body coils. A combination of various sequences in different planes is used for optimal assessment of the plexus. These comprise both two-dimensional and three-dimensional (3D) sequences. Axial T1-weighted (T1-W), axial T2-weighted (T2-W) fat-suppressed, coronal T1-W, coronal 3D Short Tau Inversion Recovery (STIR) Sampling Perfection with Application optimised Contrasts using a varying flip angle Evolutions (SPACE), sagittal STIR and sagittal 3D T2 SPACE sequences are included in the MRN study protocol.[2]

Scan area extends from C3 to T3 level. T1-W images delineate the normal plexus anatomy and its relationship to surrounding structures such as vessels, muscles and bones. T2-W images allow localisation of the pathology and its extent. Sagittal STIR images enable us to see the cross-section of the plexus. The 3D STIR SPACE sequence, in which the nerves appear bright against a dark fat-suppressed background, is mainly considered as MRN[6] [Figure 1]. Isotropic multiplanar and curved-planar reconstructions from these images beautifully depict the abnormality in the plexus.[7] Sagittal 3D T2 SPACE sequence that is focused on the cervical spine is used to generate myelography like images. It enables evaluation of spinal cord lesions and intra-dural roots. Intravenous contrast (gadolinium-based) is not used in cases of trauma but in cases where there is suspicion of neoplastic or inflammatory lesions.

By carefully analysing information obtained from this combination of sequences, we can trace the entire plexus, from its origin at the spinal cord till its terminal branches. The plexus components normally have a round or ovoid shape with size similar to adjacent arteries. They appear similar in signal intensity to muscle in T1-W images but brighter in T2-W fat-suppressed images. The fascicular pattern is seen both in T1- and T2-W images. The course of the nerves is smooth with preserved peri-neural fat planes. Enhancement is seen in cases where the blood-nerve barrier is disrupted, such as tumours and infections.[1,8,9] Therefore, we need to look for any change in the shape, size, signal intensity, course and enhancement pattern of the plexus. We additionally evaluate the adjacent muscles, vessels and bony structures. Radiographs can convey important findings such as fractures and are especially of value in cases of trauma.

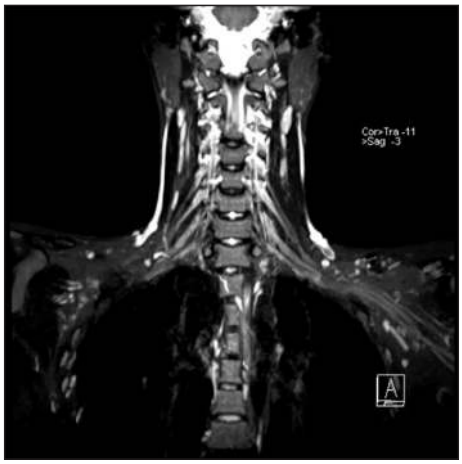

Figure 1: Coronal three-dimensional Short Tau Inversion Recovery(STIR) Sampling Perfection with Application optimised Contrasts using a varying flip angle Evolutions(SPACE) image showing the normal brachial plexus on both sides. The formation of trunks and cords can be visualised clearly on the left side

CLASSIFICATION

Brachial plexus lesions can be divided into two broad categories. These are — traumatic plexopathies and non-traumatic brachial plexopathies, which include neoplastic, inflammatory and compressive pathologies.

Traumatic plexopathies

An Indian study by Jain *et al*. and others found that road traffic accidents were the cause of traumatic brachial plexus injury in adults in 94% of the cases, and of these, 90% cases were associated with two wheelers.[10] Most of these patients are young and are compelled to suffer both physically and psychologically after such injuries due to functional compromise of an extremity which prevents them from carrying out daily activities. Proximal injury can lead to loss of motor end plates and muscle atrophy; therefore, timely diagnosis and intervention can maximise the functional return.[11]

Most of the brachial plexus injuries in adults are closed injuries. Important mechanisms of injury include traction injuries due to inferior displacement of the affected extremity with force and deviation of the neck to the opposite side, blunt force to the neck and shoulder which may crush the plexus and penetrating trauma which can partially or completely transect the nerves.[3] Most of the injuries, about 70-75%, are seen in the supraclavicular region, and about 75% of these are panplexal injuries. Infraclavicular injuries constitute the remaining 25% injuries.[11]

Over the past two decades, significant advances in MRI have enabled excellent evaluation of peripheral nerves using MRN, which is a high-resolution MRI technique.[12] It has gradually replaced computed tomography (CT) myelography as the imaging modality of choice for imaging patients with brachial plexus injuries. Its chief advantages are that it is a non-invasive procedure and it can evaluate the complete plexus from the roots to the terminal branches as compared to CT myelography, which can only be used to evaluate proximal injuries. Another disadvantage of CT imaging is that it exposes these patients (most of whom are young) to significant doses of radiation during the procedure. MRN in cases of trauma is done 6 weeks or later after the injury so that the plexus is not obscured by edema and/or haemorrhage.[2]

Based on a study of 819 cases of adult brachial plexus injuries, a new classification has been proposed by Chuang,[13] according to which level 1 injury represents pre-ganglionic injury, which involves the spinal cord, rootlets and intra-spinal roots. Level 2 injury represents post-ganglionic spinal nerve injury at the inter-scalene space. Level 3 injury is supra- and retro-clavicular, and it involves the trunks and divisions of the plexus. Level 4 injury is infraclavicular and involves the cords and terminal branches of the brachial plexus. In Chuang's study, 70% of injuries occurred at level 1 and 8%, 5% and 17% of the injuries were seen at levels 2, 3 and 4, respectively.[13]

One of the most important advantages of MR evaluation is that it helps to classify an injury as pre- and post-ganglionic or mixed. Pre-ganglionic injuries show signal intensity changes in the spinal cord in about 20% of cases which can be hyperintense in T2 images due to edema in the acute stage and myelomalacia in chronic injury. T2 hypointense signal can be seen due to hemosiderin deposition secondary to haemorrhage.[14] Other signs include hematoma near the nerve root exit, inability to visualise the ventral, dorsal or both nerve roots, discontinuity in their course, and pseudomeningocele.[15] A pseudomeningocele is an extravasated collection of cerebrospinal fluid due to the associated dural tear [Figure 2]. Sometimes a root can be avulsed without tearing of the dura, which is known as 'avulsion *in-situ*'.[4] Pseudomeningoceles can be seen in the spinal canal or extending along the spinal nerves over many centimetres.[3]

Patients with avulsed roots also show signal intensity changes in the para-spinal muscles due to their

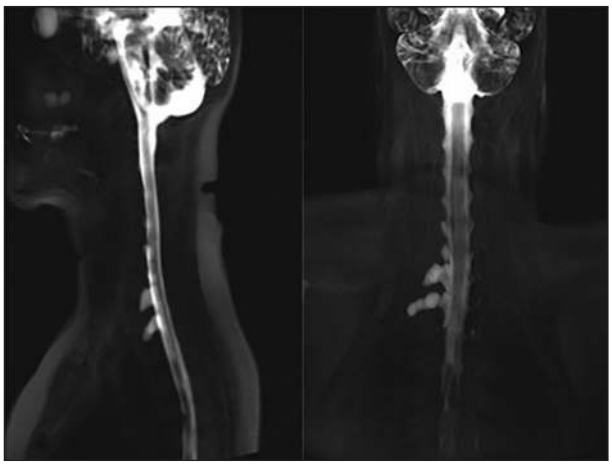

Figure 2: A 28-year-old man with history of road traffic accident 3 months back. Magnetic resonance myelography images in sagittal and coronal planes showing pseudomeningocoeles at C8 and T1 levels on the right side

denervation [Figure 3]. These changes occur due to movement of fluid from the intra-cellular space to the extra-cellular space and are not due to true edema.[9] In a non-enhanced MRI scan, hyperintense signal is seen in fat-suppressed images in the affected muscles in the acute phase. Volume loss occurs in the chronic phase. Intravenous contrast-enhanced scans show abnormal enhancement in the affected muscles in fat-suppressed T1-W images as early as 24 h after nerve injury.[16,17] However, many cases of root avulsions do not show evidence of para-spinal muscle denervation due to the multi-segmental nerve supply of these muscles.[5]

Seddon gave a classification for nerve injuries in 1943[18] in which, there were three groups of injuries. These included neuropraxia, axonotmesis and neurotmesis. Neuropraxia indicates a physiological conduction block but no structural damage to the nerve. Wallerian degeneration does not occur distal to the site of injury. In axonotmesis, the axon is severed but epineurium and perineurium are preserved. Here, Wallerian degeneration occurs distal to the injury. In neurotmesis, the entire nerve is ruptured, and healing without timely surgery leads to the formation of a neuroma.[11,18] Sunderland and Mackinnon[11] have further modified these patterns of injury. Seddon's classification can be used to describe post-ganglionic injuries to the brachial plexus radiologically. MRN shows mild enlargement of the nerve with T2 hyperintense signal in cases of neuropraxia. In axonotmesis, additional findings include fascicular enlargement, effacement or disruption. In neurotmesis, focal discontinuity can be seen in the nerve in the acute stage with fluid or granulation tissue at the site of disruption. Subsequently, this can be replaced by T2 hypointense soft tissue component due to fibrosis in the sub-acute and chronic stages [9] [Figures. 4-8]. There can be distal retraction of nerve fibres. Neuromas are also well-visualised. These can be either neuroma-in-continuity (NIC) or end-bulb neuromas depending on the severity of the injury. A NIC appears as a baseball-shaped mass lesion with nerve continuity on either side in MRN images. Adjacent scarring can be seen. In cases of an end-bulb neuroma, the affected nerve shows hyperintense signal in T2-W images and ends in a baseball-shaped mass. This looks like a balloon on a string or green onion.[19] Extrinsic compression of the post-ganglionic plexus by adjacent fracture fragments, callus associated with clavicular fracture and hematomas can also be visualised.[1] An MR angiogram can be done at the same time if there is suspicion of vascular injury [Figure 9].

Tumours

Tumours involving the brachial plexus can be either intrinsic or extrinsic. It is the extrinsic lesions that appear to be commoner than mass lesions originating in the plexus. These include metastatic disease from breast carcinoma, melanoma, bronchogenic carcinoma, head and neck carcinomas, osteosarcomas, eccrine carcinomas, mesotheliomas and malignant fibrous histiocytomas.[20] Enlarged metastatic lymph nodes can compress the plexus or invade its components [Figure 10]. There can also be involvement of the plexus due to the extension of adjacent neoplastic lesions. The most common of these is the Pancoast tumour, which arises from the lung apex. It can infiltrate not only the plexus but also the vertebral bodies, neural foramina, spinal canal and subclavian vessels[6] [Figure 11].

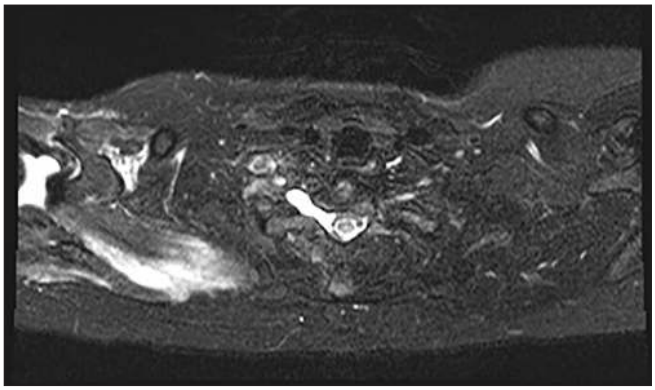

Figure 3: A 35-year-old man with history of road traffic accident 2½ months back. Axial T2-weighted fat-suppressed image showing pseudomeningocoele in the right neural foramen with non-visualisation of the C7 root suggestive of root avulsion. Also noted is denervation oedema in the right subscapularis and infraspinatus muscles

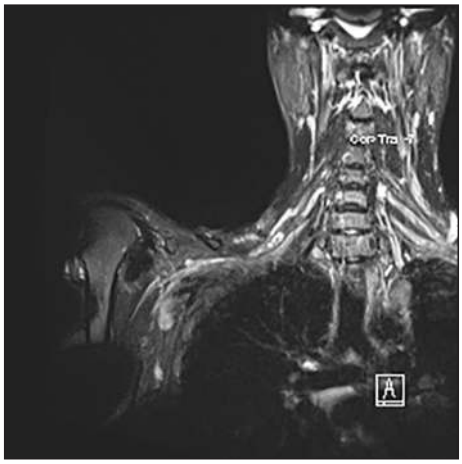

Figure 4: A 25-year-old man with history of road traffic accident 2 months back. Coronal three-dimensional STIR SPACE image showing normal roots on the left side and grossly deformed, disorganised right C5, C6 and C7 roots

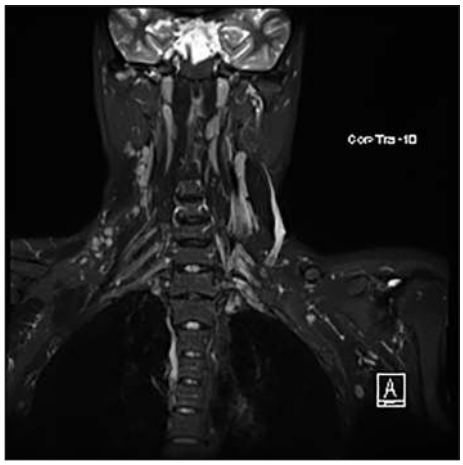

Figure 5: A 42-year-old man with history of road traffic accident 4 months back. Coronal three-dimensional STIR SPACE image showing normal roots on the right side and thickened, scarred left C6, C7 and C8 roots

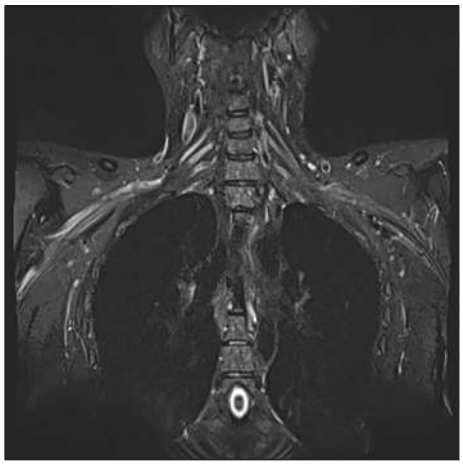

Figure 6: A 31-year-old man with history of road traffic accident 2 months back. Coronal three-dimensional STIR SPACE image showing normal brachial plexus on the left side. On the right traumatised side, the visualised plexus appears hyperintense with interspersed small hypointense foci due to scarring in the C7, C8 roots, trunks, divisions and lateral cord

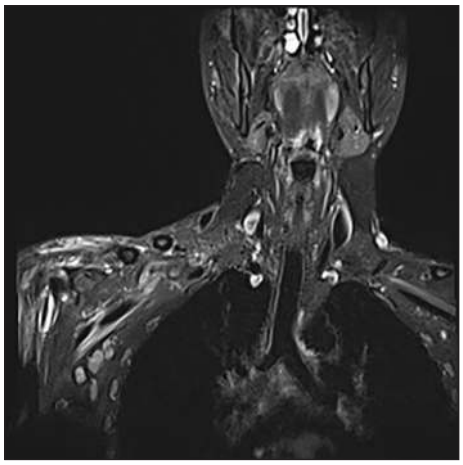

Figure 7: A 45-year-old man with history of road traffic accident 3 months back. Coronal three-dimensional STIR SPACE image showing distorted divisions and cords on the right side with heterogeneous signal intensity due to scarring. On the left side, normal lateral cord is seen adjacent to the axillary artery

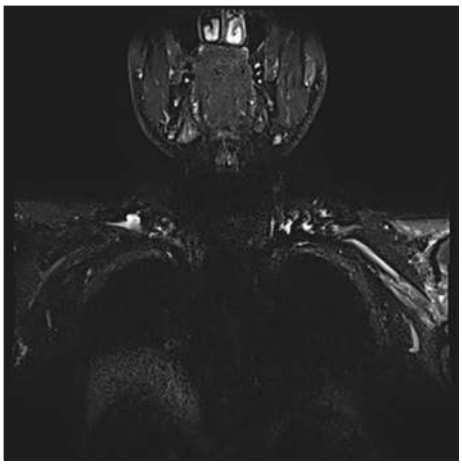

Figure 8: A 32-year-old man with history of road traffic accident 2½ months back. Coronal three-dimensional STIR SPACE image showing hyperintense lateral cord on the left side. The ulnar and median nerves appear thickened with heterogeneous signal intensity due to scarring

In lymphoma, there can either be compression or displacement of the plexus by enlarged lymph nodes or lymphocytic infiltration of the nerves.[3]

Intrinsic plexus tumours can be neurogenic or non-neurogenic. Neurogenic tumours include schwannomas, neurofibromas, plexiform neurofibromas and malignant peripheral nerve sheath tumours. Of these, neurofibromas are the most common, about 50-65%.[5] Schwannomas have a capsule, tend to expand eccentrically and displace nerve fibres around the periphery of the lesion [Figure 12]. Neurofibromas are fusiform, not encapsulated, oriented longitudinally along the nerve and tend to infiltrate the nerve.[5] Schwannomas and neurofibromas appear isointense to muscle in T1-W images, hyperintense in T2-W images and show intense post-contrast enhancement. Certain signs have been used to describe these benign tumours that include 'Split fat sign', 'Target sign', 'Fascicular sign' and 'Tail sign'.[7] Malignant peripheral nerve sheath tumours are less common. These lesions are usually secondary to neurofibromatosis I or after plexus irradiation to treat adjacent malignancies. The affected part of the plexus is enlarged, with hyperintense signal in T2-W images and shows moderate to severe contrast enhancement.[6]

Common non-neurogenic tumours are desmoid tumours and lipomas. Desmoid tumours are also referred to

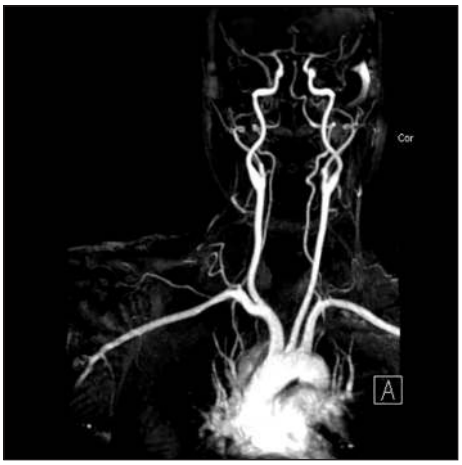

Figure 9: Magnetic Resonance angiogram showing the aortic arch and its branches. This patient had a right-sided brachial plexus injury. The angiography helped us to rule out associated arterial injury

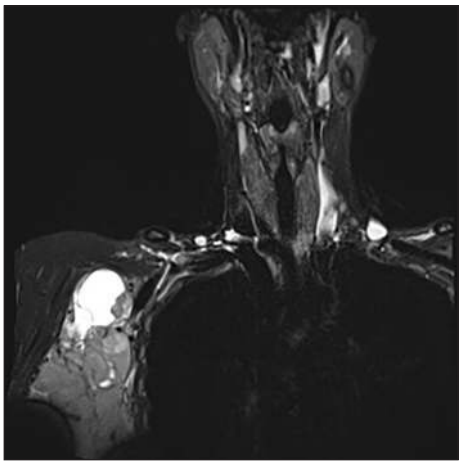

Figure 10: A 45-year-old female patient had a swelling in the right axilla and weakness in the ipsilateral upper limb. Coronal three-dimensional STIR SPACE image shows a large mass of metastatic lymph nodes in the right axilla causing extrinsic compression over the brachial plexus

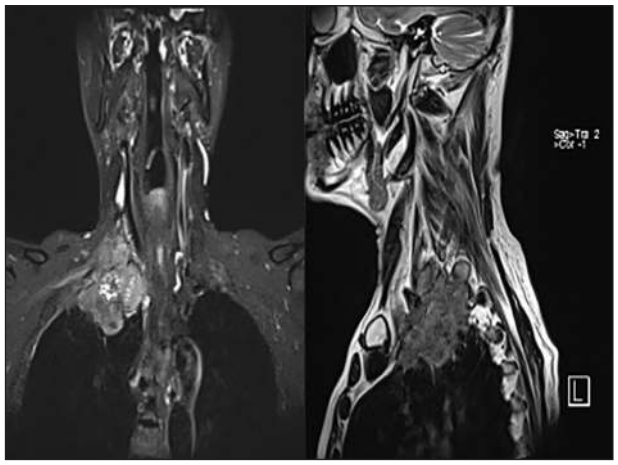

Figure 11: Coronal three-dimensional STIR SPACE and sagittal T2-W images showing a Pancoast tumour at the apex of the right lung in a 55-year-old male patient. The mass is infiltrating the roots and trunks of the right brachial plexus

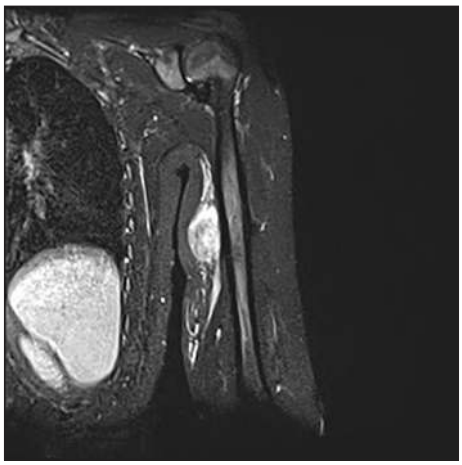

Figure 12: A 22-year-old female patient with left ulnar nerve schwannoma. Coronal three-dimensional STIR SPACE image showing a well-defined heterogeneous soft tissue mass lesion in the supero-medial aspect of left arm which is arising from the ulnar nerve

as non-metastasising fibrosarcoma or aggressive fibromatosis. These infiltrate the adjacent structures and surgical resection is difficult. They appear heterogenously hypo to isointense in T1-W images and hyperintense in T2-W images [Figure 13]. Lipomas show signal intensity corresponding to fat in all sequences and displace the adjacent plexus.[3]

Inflammatory

Inflammation of the components of the brachial plexus can be due to various causes that include radiation, immune-mediated plexopathies, sarcoidosis, viral infections, post-op infection of the plexus or adjacent structures, compression of the plexus by adjacent para-spinal abscess seen in tuberculous osteomyelitis of cervico-dorsal spine [Figure 14] or idiopathic disorders (Parsonage-Turner syndrome).[8,21] MRI helps to localise the pathology and thereby excludes other causes related to cervical spine or shoulder regions.

Idiopathic brachial plexitis is known as Parsonage-Turner syndrome. It is seen in young and middle-aged people, commonly in men and is usually unilateral. Up to 30% of cases may be bilateral. Patients develop sudden severe pain in the neck, shoulder and scapula region followed by weakness after a few weeks to months.[7,8] The most commonly involved muscles are the supraspinatus and infraspinatus that are supplied by the suprascapular nerve. Deltoid, teres minor and subscapularis may also be involved. Typically, MRI reveals T2 hyperintense signal in the affected muscles with a normal appearing plexus. There can be atrophy of the affected muscles in about

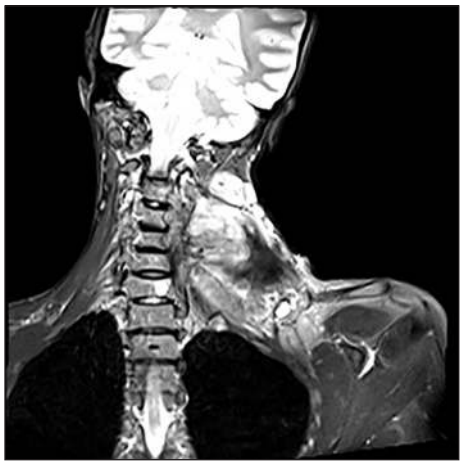

Figure 13: A 25-year-old female patient with a desmoid tumour in the left brachial plexus region. A large heterogeneous mass lesion is seen in the left side of the neck which is involving the left brachial plexus. The normal roots can be appreciated on the right side

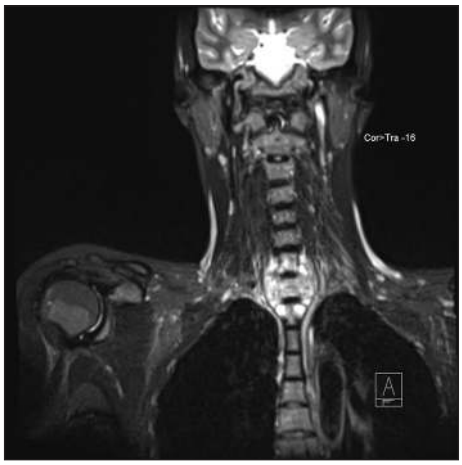

Figure 14: A 28-year-old female patient who presented with a history of fever, neck pain and features of brachial plexus involvement on the right side. Coronal three-dimensional STIR SPACE image showed erosions and altered marrow signal intensity in the C7, D1 and D2 vertebral bodies with associated bilateral para-spinal abscesses. The right para-spinal abscess had caused extrinsic compression over the plexus

60% of cases.[3] Diffuse enlargement and T2 hyperintense signal in the nerves may also be seen on MRN[7,8] [Figure 15].

Radiation plexopathy is seen in patients who have been irradiated in the axillary or supraclavicular regions for treatment of cancers. This type of plexopathy can develop even 5-20 years after the treatment.[22] Patients can present in three different patterns. Some present early either during radiotheraphy or within one to 2 months and appear likely to have an ischemic insult to the plexus. Some others present with reversible or transient plexopathy between 2 and 14 months after therapy. Most commonly seen is the delayed presentation that occurs in patients who have received doses more than 60 Gy.[3] MRN shows diffuse and uniform thickening of the involved plexus, mild to moderate hyperintense signal in fat-suppressed images and mild to moderate enhancement with contrast. In chronic cases, there is hypointense signal in T1- and T2-W images due to fibrosis.[6] In radiation plexopathy, no focal mass lesion is evident whereas in cases of neoplastic plexopathy due to recurrent tumour, a heterogeneously enhancing mass lesion can be visualised.

Thoracic outlet syndrome

The thoracic outlet includes three confined anatomic spaces, which are the interscalene triangle, the costoclavicular space, and the retro-pectoralis minor space. The brachial plexus, subclavian artery and vein pass through these spaces and dynamically induced compression of these structures leads to thoracic outlet syndrome (TOS) or entrapment syndrome. Symptoms are reproduced or aggravated by arm elevation or sustained use of the arm. Therefore, patients are usually scanned with the arm alongside the body and after arm elevation when using imaging modalities such as CT and MRI.[23]

The causes of TOS can include bony abnormalities such as a cervical rib, elongated C7 transverse process, exostosis/tumour/callus of the first rib or clavicle [Figure 16]; soft tissue lesions such as fibrous bands or congenital muscle abnormalities and post-traumatic or post-operative scarring.[23] MRI can visualise all the components of the thoracic outlet as well as identify causative factors of TOS.

In neurogenic TOS, there are changes in the size or T2 signal intensity of the plexus components or both.[7] The fat surrounding the brachial plexus can be effaced. There may be close contact with surrounding bones, hypertrophy of adjacent muscles such as scalenus, subclavius or pectoralis minor and abnormal muscles or fibrous bands.[23] Sometimes, visualisation of the normal course and calibre of the plexus can prevent unnecessary surgical intervention for suspected neurogenic TOS.[7]

CONCLUSION

Today, MRN is the imaging modality of choice for assessment of the brachial plexus especially due to

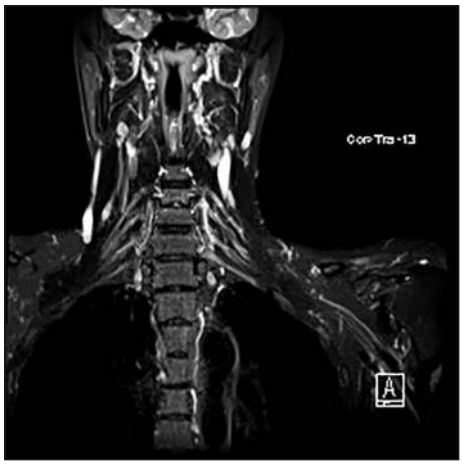

Figure 15: In this 48-year-old male patient with left-sided brachial plexus neuritis, coronal three-dimensional Short Tau Inversion Recovery Sampling Perfection with Application optimised Contrasts using varying flip angle Evolutions image shows hyperintense signal in the left brachial plexus as compared to right side

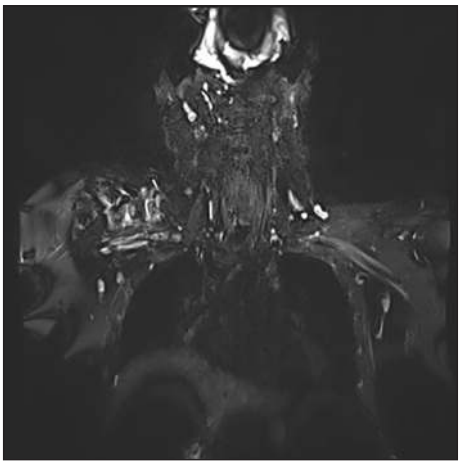

Figure 16: This 32-year-old man with a history of trauma had a right clavicular fracture. The extensive callus formation is causing extrinsic compression of the divisions and cords on the ipsilateral side while these structures appear normal on the left side

its excellent soft tissue contrast and its capability to evaluate the plexus in multiple planes. We can visualise in exquisite detail not just the plexus but also the aetiology of plexopathy with its location and extent. It is, however, important to choose the right combination of available MRI sequences and interpret them carefully to arrive at the correct diagnosis.

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Conflicts of interest

There are no conflicts of interest.

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