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To study the role of 3 Tesla MRI in patients with brachial plexus neuropathies and correlation with electrophysiological findings

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Abstract

Weakness, sensory loss, and loss of tendon reflexes in body regions innervated by nerves in the C5-T1 segmental distribution is seen in brachial plexopathy. Injuries are traumatic and non-traumatic. Non-traumatic brachial plexopathies can be due to either compression or infiltration by localised pathologies, or a more diffuse or systemic cause. More common causes are neoplasia and radiation fibrosis. The evaluation of peripheral nerve injuries has traditionally relied primarily on information gained from the clinical history, physical examination, and electrodiagnostic testing. Taken together, all of this clinical and diagnostic information often allows one to determine the location and severity of the underlying peripheral nerve problem. However, it may not be sufficient in diagnosing a focal entrapment neuropathy superimposed upon a more generalized peripheral neuropathy; localizing a focal lesion along a long segment of nerve which may be difficult to assess accurately with electrodiagnostic studies; distinguishing early between an axonotmetic grade of injury, which can recover through axonal regeneration, and a neurotmetic grade which cannot and therefore may benefit from a surgical exploration and repair procedure; and noninvasively diagnosing and determining the surgical resectability of peripheral nerve mass lesions such as tumors. Magnetic resonance neurography is a valuable adjunct to conventional MR imaging and EMG/NCV in the evaluation and

localisation of nerve root, brachial plexus, and peripheral nerve lesions. MR neurography demonstrates the location of the nerve damage, depicts the nerve continuity with or without neuroma formation, or may show a completely disrupted/avulsed nerve, thereby aiding in nerve injury grading for preoperative planning and complementing the findings generated from electrodiagnostic studies. 3D images are useful to evaluate the entire extent of the injury and are great for demonstrating abnormalities to the referring physicians for optimal presurgical planning. This article aims to assess the accuracy of MRI in diagnosing brachial plexus pathologies.

Method: This was a prospective study, conducted in a tertiary referral hospital. This consists of a study of 75 patients of clinically diagnosed brachial plexus neuropathy. Data collection for study was started after approval from the institutional research and review board, up to June 2020

Results: The diagnostic confidence of STIR T2 MR sequence was seen to be highest with a sensitivity of 95.08% and specificity of 85.71%. In only 3 out of 61 brachial plexuses, STIR T2 MR sequence failed to detect the abnormality.

Conclusion: The brachial plexus can be efficiently imaged and effectively interpreted when approached from a practical standpoint. Optimization of a practical brachial plexus imaging protocol is paramount to identify normal anatomy and associated pathology.

Key words: MR neurography, Brachial plexopathy

Abbreviations

MRI: Magnetic resonance imaging , TOS: Thoracic outlet syndrome, MRN: Magnetic resonance neurography, EMG: Electromyography, NCV: Nerve conduction velocity, NIC: Neuroma-in-continuity , PNS: Peripheral nervous system

Introduction

Brachial plexopathy causes weakness, sensory loss, and loss of tendon reflexes in body regions innervated by nerves in the C5-T1 segmental distribution[1]. Injuries sustained in road traffic accidents, particularly those involving motorcyclists, are a major contributing cause of traumatic brachial plexopathy[2]. Non-traumatic brachial plexopathies can be due to either compression or infiltration by localised pathologies, or a more diffuse or systemic cause. More common causes are neoplasia and radiation fibrosis[3]. The injuries are supraclavicular in 72% of cases and infraclavicular in 28% of cases. Common pathologies in the supraclavicular area include brachial plexitis (Parsonage-Turner syndrome), traumatic injury, neoplasms (metastasis, nerve sheath tumor, neurocutaneous syndrome, pancoast tumor), and TOS[4,5]. Brachial plexus injury is classified into three categories: preganglionic lesions, postganglionic lesions, and a combination of the two. A preganglionic lesion signifies avulsion of nerve roots, whereas a postganglionic lesion involves the nerve structure distal to the sensory ganglion. Postganglionic lesions are further classified into nerve ruptures and lesions in continuity. Imaging studies play an essential role in differentiating preganglionic injuries from postganglionic lesions, a differentiation that is crucial for determining the management of brachial plexus injury. With respect to preganglionic injuries, functions of some denervated muscles are restored with nerve transfers. Postganglionic lesions are repaired with nerve grafting or followed up conservatively[6]. Nerve injuries were classified by seddon in 1943 and expanded by Sunderland in 1951. Mackinnon and Dellon in 1992 added grade VI injury to Sunderland's grading scheme and defined it as a mixed type of injury

which denotes various types of injuries across the cross section of nerve. The classification system along with imaging findings in different types of nerve injuries is illustrated below[7].

Table 1

Degree of nerve injury	MRN (signal intensity)	Recovery potential	Surgery
I Neuropraxia	Nerve-increased T2 Signal intensity. Muscle-Normal	Full	None
II Axonotmesis	Nerve-increased T2 Signal intensity and diffusely enlarged	Full	None
III	Fascicles-enlarged or effaced due to edema. Muscles-denervation	Usually slow, incomplete	None or Neurolysis
IV NIC-neuroma in continuity	Nerve-focally enlarged with heterogeneous Signal intensity. Underlying diffuse abnormality ± Fascicles-disrupted with heterogeneous SI-Neuroma in continuity. Muscles-denervation	Poor to none	Nerve repair, graft or transfer
V Neurotmesis	Complete nerve discontinuity ± hemorrhage and fibrosis in the nerve gap and end-bulb neuroma proximally. Epineurial thickening. Muscles-denervation	None	Nerve repair, graft or transfer
VI Mixed injury (I to V)	Variable findings along the circumferential segment of the nerve (I-V) with heterogeneous SI due to fibrosis Muscles-denervation	Variable, can be poor to none	Neurolysis, Nerve repair, graft or transfer

MRN: Magnetic resonance neurography, SI: Signal intensity

Traditional imaging methods have limitations in clinical application. In recent years, however, with the development of 3.0 T magnetic resonance imaging (MRI), it has become possible to clearly display the brachial plexus root canal, which provides not only morphological information and the location of the injury, but also has a high value for clinical diagnosis[8].

MR neurography demonstrates the location of the nerve damage, depicts the nerve continuity with or without neuroma formation, or may show a completely disrupted/avulsed nerve, thereby aiding in nerve injury grading for preoperative planning and complementing the findings generated from electrodiagnostic studies[9]. MR neurography is an extremely useful modality to image the traumatized brachial plexus. It influences both surgical planning and outcome/prognosis[10]. The evaluation of peripheral nerve injuries has traditionally relied primarily on

information gained from the clinical history, physical examination, and electrodiagnostic testing[11].

Anatomical details - 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. 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. These branches are referred to as the proper ‘‘nerve roots’’ and extend from the neural foramina to the interscalene triangle [12]. 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.

Nerve Roots and Their Anatomic Relations

The ventral rami of the C5-C8 and T1 nerve roots unite to form the brachial plexus, between the anterior and middle scalene muscles. It may receive additional contributions from the C4 and T2 nerve roots. The dorsal scapular nerve (C5) and long thoracic nerve (C5-C7) to the serratus anterior muscle arise directly from the nerve roots[9,12,13].

Trunks and Their Anatomic Relations

The C5 and C6 nerve roots compose the upper trunk, C7 continues as the middle trunk, and C8 and T1 compose the lower trunk. The 3 trunks are formed within the interscalene triangle. The suprascapular nerve (C5 and C6) and the nerve to the subclavius arise from the superior trunk. The phrenic nerve (C3-C5) passes between the anterior and middle scalene and continues over the surface of the anterior scalene muscle [5].

Divisions, Cords, and Their Anatomic Relations

More laterally, the trunks ramify into the 3 anterior and 3 posterior divisions, which join to form 3 cords distal to the lateral margin of the first rib. The cords are the lateral, posterior, and medial cords, based on their relationship to the axillary artery. The lateral cord is formed by the anterior divisions of the upper and middle trunks and gives off the lateral pectoral nerve (C5-C7) and contributes to the median and the musculocutaneous nerves. The posterior divisions of all the trunks form the posterior cord, which gives off the subscapular nerves. The inferior trunk continues as the medial cord and gives off the median pectoral nerve (C8, T1), the medial brachial cutaneous nerve (T1), and the medial antebrachial cutaneous nerve (C8, T1)[5].

Branches

The cords end in 5 terminal branches: the median, ulnar, musculocutaneous, axillary, and radial nerves[5].

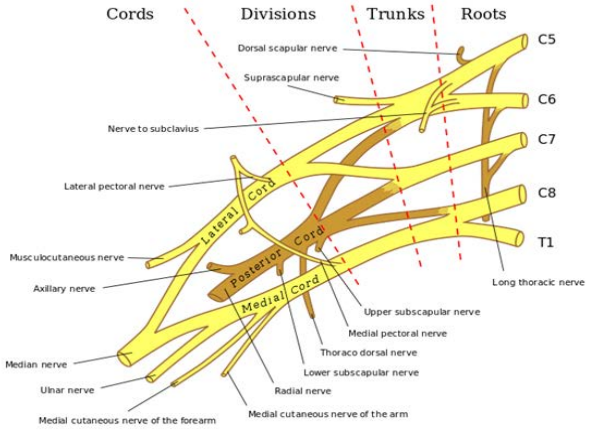


Figure 1: Diagrammatic representation of the structure of the brachial plexus.

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.

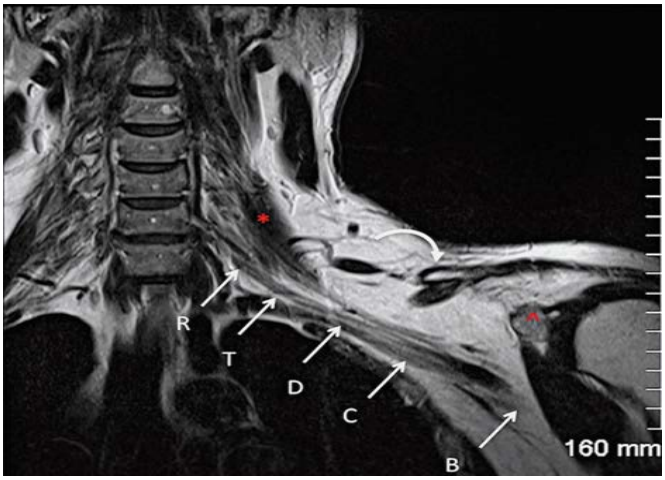


Figure 2: Schematic drawing showing anatomical relations of brachial plexus.

It illustrates the trunks exiting from interscalene space, a passageway delimited by the anterior scalene, the middle scalene, and the first rib. The trunks are located superior to the subclavian artery. The arrangement of the lateral, medial and posterior cords of the plexus relative to the axillary artery is also shown.

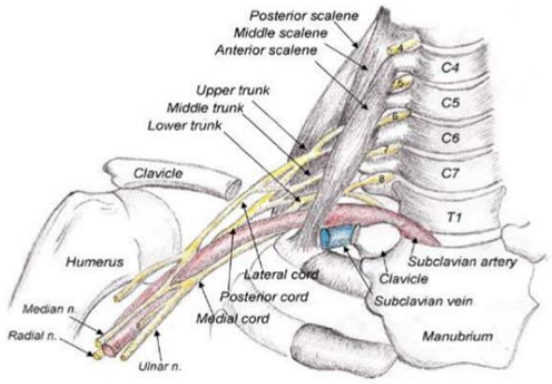


Figure 3: Normal anatomy of brachial plexus on MRI (coronal).

A coronal oblique T2W sequence shows the different segments of the brachial plexus. The roots (R) are located medial and within the scalene triangle; the middle scalene muscle (*) demarcates the lateral border of the scalene triangle. The trunks (T) are visualized at the lateral border of the scalene triangle, the divisions (D) between the first rib and the clavicle (curved arrow) and the cords (C) and the terminal branches (B) on both sides of the coracoid process of the scapula (^).

Etiology and pathogenesis

There are various causes of brachial plexus pathologies which includes traumatic brachial plexus injury and non traumatic causes. Non traumatic causes are neoplastic brachial plexopathy, radiation induced brachial plexopathy, neurogenic thoracic outlet syndrome, idiopathic and hereditary brachial plexopathies. Imaging modalities help in identifying the underlying aetiology which supplements the management of patient. The most common cause of

injury is motor vehicle crashes with or without fractures and dislocations of the cervical spine. Other etiologies include sports injury, gunshot wound, rucksack injury and iatrogenic traction injuries during anaesthesia.These injuries may concomitantly affect various upper limb nerves, such as the suprascapular, musculocutaneous and axillary nerves. TOS is a syndrome involving compression of a neurovascular bundle passing between the anterior scalene and middle scalene muscles. Benign mass lesions causing brachial plexopathy may include lipoma, fibromatosis, perineural cyst, hemangioma, lymphangioma, and so forth. Common malignancies affecting the brachial plexus include pancoast tumor, breast metastasis, lymphoma (neurolymphomatosis) and metastatic lymphadenopathy. Patients presenting with recurrent symptoms following radiation treatment for malignancy may have tumor recurrence or radiation plexopathy. Idiopathic brachial plexitis is seen with an incidence of 1.6/100,000, Proposed etiologies include immune versus inflammatory causes. It affects young and middle-aged patients, males more than females and may be bilateral in up to 30% of patients. Patients present with sudden onset of severe constant pain in the neck, shoulder, or upper arm, which within a few weeks, is followed by profound weakness and atrophy of the regional muscles[5].

From a surgical and prognostic point of view, the injuries are classified into 3 categories: preganglionic, postganglionic and a combination of both. It is important to carefully look for the nerve roots from the spinal cord to the extraforaminal location because nerve root avulsion requires a major procedure, neurotization. Postganglionic lesions are further classified into lesions in continuity (requiring rehabilitation/neurolysis) and nerve discontinuity (requiring nerve repair/grafting). The overall spectrum of injuries ranges from neuropraxia/stretch injury (most common) to axonotmesis, partial neurotmesis with neuroma in continuity formation to complete nerve lacerations (neurotmesis)/nerve root avulsions. Seddon gave a classification for nerve injuries in 1943 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[14,15]. Sunderland and Mackinnon 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. 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[15,16,17]. Extrinsic compression of the postganglionic plexus by adjacent fracture fragments, callus associated with clavicular fracture and hematomas can also be visualized[18]. MRN demonstrates the location of the nerve damage, depicts the nerve continuity with or without neuroma formation, or may show a completely disrupted/avulsed nerve, thereby aiding in nerve-injury grading for preoperative planning and complementing the findings generated from electrodiagnostic studies. 3D images are useful to evaluate the entire extent of the injury and are great for demonstrating abnormalities to the referring physicians for optimal presurgical planning. Pre and postganglionic injuries can also be differentiated by using EMG. Paraspinal muscle abnormality indicates that the injury is proximal to the brachial plexus trunks; however, an imaging study, such as a CT myelogram or MRN, is required to differentiate incomplete from complete root avulsion or a spinal rootlet avulsion. A dural tear with formation of a pseudomeningocele may be seen on conventional MR imaging, but this finding is not pathognomonic for nerve root avulsion. MRN also shows another key finding—regional denervation muscle changes. The edema-like T2 signal intensity can appear within a few days, while contrast enhancement in the abnormal muscles has been shown to appear within 24 hours of the injury. Abnormal enhancement of paraspinal (especially multifidus) muscles has been shown to be an accurate indirect sign of root avulsion injury, which can also be evident on STIR images. As part of the protocol, T2 SPACE images should be used to assess spinal cord signal abnormality, which may be evident in approximately 20% of patients with preganglionic injuries as increased signal from cord edema or myelomalacia with or without decreased signal from blood product deposition[6,8,19,20,21]. Minimal T2 hyperintensity of the C8 and T1 nerve roots is commonly seen as a nonspecific finding; altered T2 signal intensity extending into the lower trunk or associated nerve enlargement or both generally correlate with clinical findings of TOS. Although uncommon, involvement of the middle trunk or kinking of the nerve roots by a fibrous band or flattening due to an intramuscular course of the nerve roots, impingement by anomalous vessels, narrowing of the interscalene space by a hypertrophied muscle, or cervical ribs or costocostal pseudoarthrosis impinging the nerves may be seen as abnormal findings[19, 22-26]. Simultaneous depiction of the causative lesion, such as a cervical rib and associated displacement of the nerve with signal abnormality, is possible on curved reconstructions generated from isotropic 3D imaging. The treatment of TOS may be rehabilitation or surgery by anterior scalenectomy and anomalous rib resection. Although MRN is frequently used for presurgical planning, it may also preclude the suspected diagnosis of TOS, when it demonstrates a completely normal course and calibre for all nerve segments that are under suspicion, thereby presenting evidence against unnecessary surgery. A variant intermuscular course might not always be symptomatic. MRN is also useful for detection of focal fibrosis causing re-entrapment of the nerves, with persistent enlargement and T2 signal abnormality of the nerves in failed cases of thoracic outlet surgery. The peripheral nerve sheath tumors show classic MR imaging signs of the split fat sign, target sign, fascicular sign and tail sign[27]. MRN shows a focal or diffuse enhancing mass lesion in case of tumor recurrence, with asymmetric enlargement of

the plexus[28, 29]. In postradiation patients, the abnormality is generally geographic in the radiation field and diffuse and symmetric without focal masslike enhancement on contrast examinations. Post radiation fibrosis may also be seen as T1 and T2 hypointense fat stranding with distortion and kinking of the nerve segments. In brachial plexitis MRN may show diffusely enlarged and hyperintense nerves and scattered muscle denervation changes around the shoulder joint[30,31].

Material and method

Hospital based cross-sectional and quantitative study was conducted involving Department of Radiodiagnosis, Department of Orthopaedics, Department of Plastic surgery and Department of Neurosurgery, SMS Hospital, Jaipur, Rajasthan. It is descriptive type of observational study. Study duration was May 2019 to June 2020.

Equipment: 3T MRI Philips Ingenia Machine.

Sample Size: Sample size of 75 patients of clinically diagnosed brachial plexus neuropathy was acquired at alpha error 0.05 and power 80% assuming MRN change pre-imaging clinical impression in 75% patients as per study done by Stephen fisher et al.

Sampling Technique: Every eligible case was included in the study on the first come basis till sample size was achieved.

Statistical Analysis

Data expression is done in terms of sensitivity and specificity of modality with appropriate and necessary tabular presentation.

Diagnostic accuracy of the modality was then calculated.

Qualitative data were analysed in terms of percentage and proportion.

Study Population

Patients with clinically suspected brachial plexopathy referred to Department of Radiodiagnosis and Modern Imaging for MRI at SMS Medical College & Hospital, Jaipur.

Inclusion Criteria

- Patients suspected of having brachial plexus neuropathy on basis of history and clinical examination.
- Those who gave written and informed consent were included in the study.

Exclusion Criteria

- Patients unfit for MR studies due to orthopaedic implants or aneurysmal clips, cardiac pacemaker, Implanted cardiac defibrillator, Cochlear, otologic or other ear implant, Surgical staples, clips or metallic sutures, Metallic stent, Heart valve prosthesis.

Methodology

After approval from Institutional ethical committee, patients were selected after applying inclusion and exclusion criteria.

Prior to examination, written and informed consent was taken from the patient/guardian (in case of minor).

Prior to MR neurography proper precautions were taken and if MRI was contraindicated due to any reason, patient was excluded from study.

Co-relation of MRI findings was done with NCV or surgical finding, as available.

Technical Aspects of Imaging

Due to the complex anatomy of the brachial plexus, it is difficult to follow its segments in a continuous fashion on the true axial and true coronal images. Since the brachial plexus runs obliquely from superomedial to inferolateral in the coronal plane, on MR axial oblique and coronal oblique images were acquired in our study.

In order to do that, we increased the number of slices in the coronal localizer which allowed us to better identify the segments of the brachial plexus in that plane. Finally, the sagittal images were planned from the axial oblique dataset, perpendicular to the mid segment of the brachial plexus. By planning the images in an oblique fashion, following the course of the segments of the brachial plexus, the heart and lungs are avoided, thus reducing motion artifacts and eliminating the need for an in FOV saturation band.

We used Philips Ingenia 3 T MRI scanner with a dedicated protocol for visualisation of the brachial plexus. Our standard protocol included a three plane localizer followed by T1W FSE in the axial oblique, coronal oblique and sagittal oblique planes, a T2W FSE sequence in the axial oblique plane, and a axial oblique and coronal T2 FSE STIR sequence to suppress the fat signal. The slice thickness was 3 mm with a 0.1 mm interslice gap. Gadolinium was not routinely used. It is generally added for better characterization of a neoplastic process.

Table 2: MRI protocol for imaging of brachial plexus

sequences	TR (ms)	TE (ms)	ST (mm)	Gap	FOV (cm)
Coronal oblique T1	632	10	3	10%	30
Axial oblique T1	707	10	3	10%	30
Sagittal oblique T1	647	10	3	10%	40
Axial T2	5100	100	3	10%	32
Coronal oblique STIR	4500	110	3	10%	32
Axial STIR	4500	110	3	10%	32

Observations and Results

The present study was carried out in the department of Radio-diagnosis and Modern imaging, SMS Medical College and Hospital, Jaipur. It comprised of imaging by MRI of a total of 75 patients of brachial plexopathy. Following were the observations of this study.

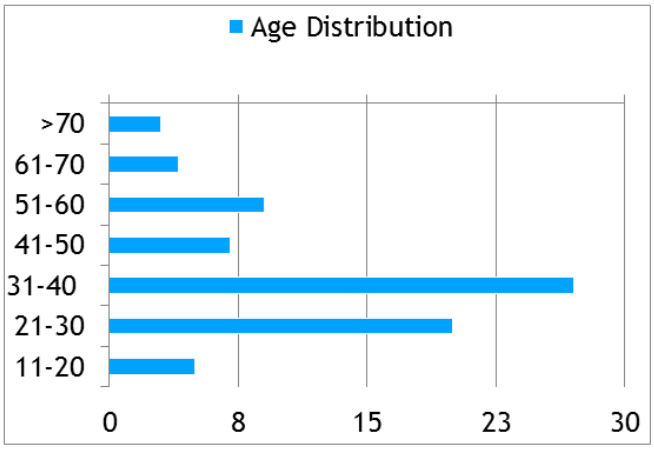
Age incidence

Most of the patients in the study belonged to younger age group with age ranging from 11 to 70 years. The mean age of the patients in the study was 35.40 years. The distribution pattern of the patients with regards to their age as seen in the present study is shown in Table 3 and Graph 1.

Table 3: Age Incidence

Age groups (In Years)	Number of cases	Percentage
11-20	5	6.66
21-30	20	26.66
31-40	27	36.00
41-50	7	9.33
51-60	9	12.00
61-70	4	5.33
>70	3	4.00
Total	75	100.00

Graph 1

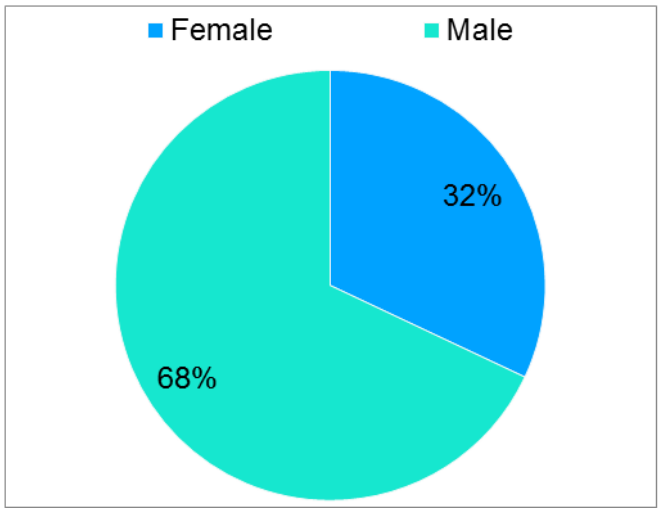


Sex distribution: Most of the patients in the present study were males with a male to female ratio of 2.12:1 as shown in Table 4 and Graph 2.

Table 4: Sex incidence

Gender	Number of patients	Percentage
Male	51	68
Female	24	32
Total	75	100

Graph 2: Percentage of sex distribution

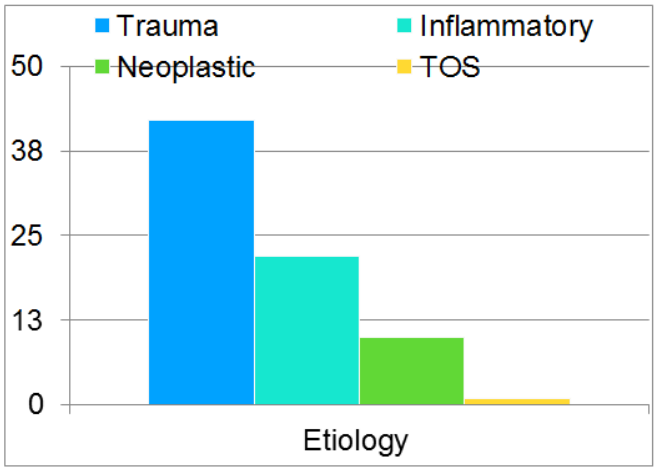


Etiology of brachial plexopathy: Trauma was observed to be the most common mode of injury accounting for 56% of the cases followed by inflammatory causes (29.33%), neoplastic causes (13.33%) and TOS (1.33%). The distribution of etiology as observed in the present study is shown in Table 5 and Graph 3.

Table 5: Etiology of brachial plexopathy

Etiology	Number of patients	Percentage
Trauma	42	56
Inflammatory	22	29.33
Neoplastic	10	13.33
TOS	1	1.33
Total	75	100

Graph 3

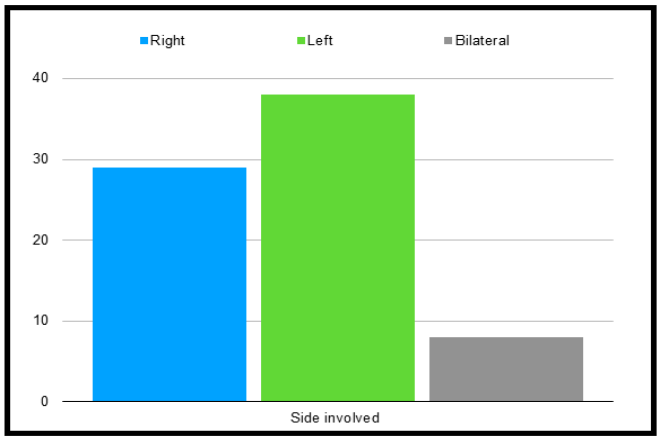


Side involved: Left side (50.66%) was more commonly affected than right (38.66%) and bilateral (10.66%) involvement. The side involvement, as observed in the present study, is shown in Table 6 and graph 4.

Table 6: Side involved

Side affected	Number of patients	Percentage
Right	29	38.66
Left	38	50.66
Bilateral	8	10.66
Total	75	100

Graph 4: Anatomical site of involvement of brachial plexus

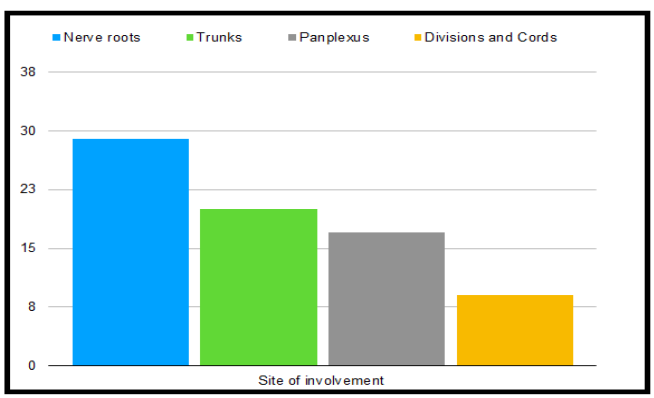


The most common site of involvement was trunks (38.66%) followed by nerve roots (26.66%), panplexus (22.66%), divisions and cords (12%) of brachial plexus. The site of involvement, as observed in the present study, is shown in Table 7 and graph 5.

Table 7: Site of involvement

Site of involvement	Number	Percentage
Trunks	29	38.66
Nerve roots	20	26.66
Panplexus	17	22.66
Divisions and cords	9	12
Total	75	100

Graph 5: Brachial plexuses with preganglionic involvement

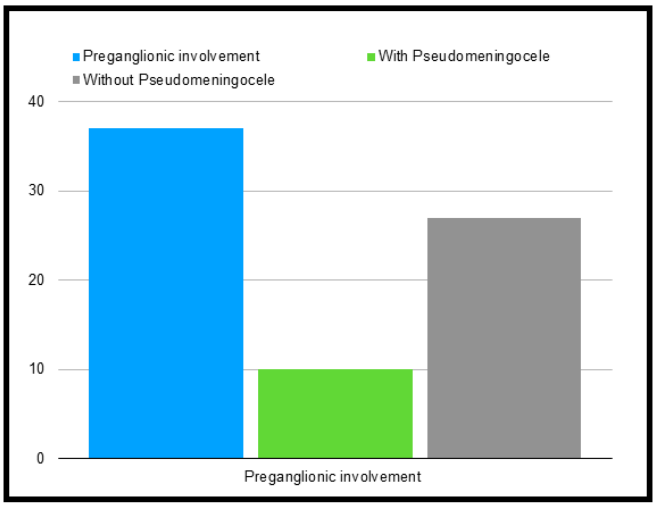


In total patients with preganglionic involvement (49.33%), pseudomeningocele formation was seen in 27.02% patients. The Brachial plexuses with preganglionic involvement, as observed in the present study, is shown in Table 8 and graph 6.

Table 8: findings in preganglionic involvement

	Preganglionic involvement	With pseudomeningocele	Without pseudomeningocele
Number	37	10	27
Percentage	49.33	27.02	72.97

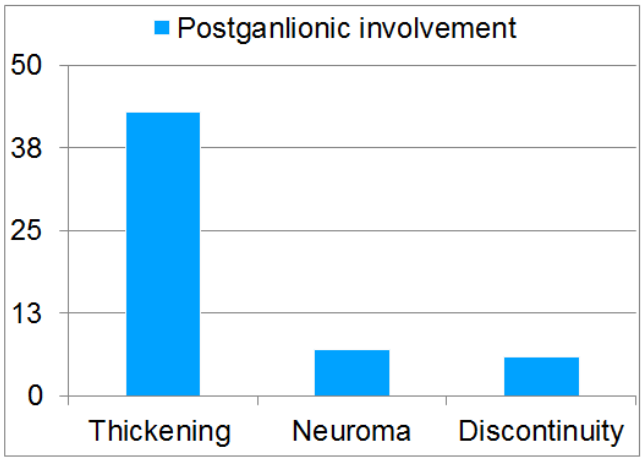
Graph 6



Brachial plexuses with postganglionic involvement: In postganglionic injury most common finding was nerve thickening (78.18%) followed by neuroma formation (12.72%) and discontinuity (10.9%). The Brachial plexuses with postganglionic involvement, as observed in the present study, is shown in Table 9 and graph 7.

Table 9: findings in postganglionic involvement

Postganglionic involvement	Number of patients	Percentage
Thickening	43	78.18
Neuroma formation	7	12.72
Discontinuity	6	10.90
	55	100

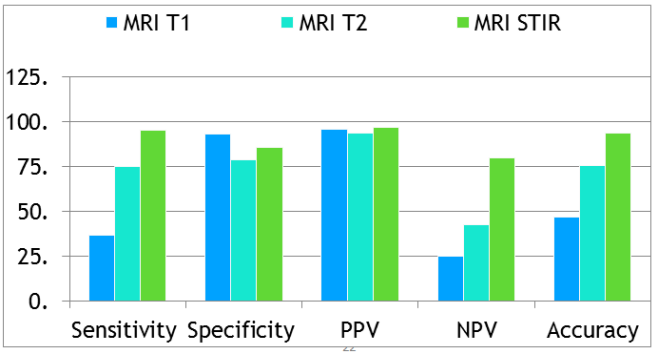


Graph 7

Table 10

	Sensitivity	Specificity	PPV	NPV	Accuracy
MRI T1	36.51	92.86	95.6	25	46.75
MRI T2	75	78.57	93.75	42.30	75.68
MRI STIR	95.08	85.71	96.66	80	93.33

Graph 8



Diagnostic confidence

Out of 75 brachial plexus, 61 were tested positive and 14 were tested negative on the gold standard electrodiagnostic study (NCV).

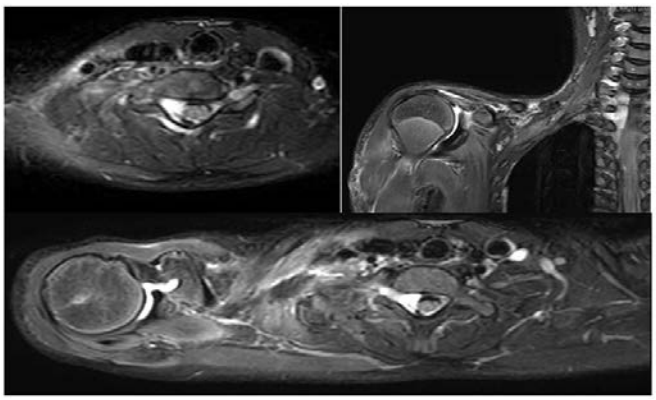
Sensitivity, specificity, PPV, NPV and diagnostic accuracy of T1 MR sequence was 36.51%, 92.86%, 95.6%, 25% and 46.75%.

Sensitivity, specificity, PPV, NPV and diagnostic accuracy of T2 MR sequence was 75%, 78.57%, 93.75%, 42.30% and 75.68%.

Sensitivity, specificity, PPV, NPV and diagnostic accuracy of STIR MR sequence was 95.08%, 85.71%, 96.66%, 80%, and 93.33% .

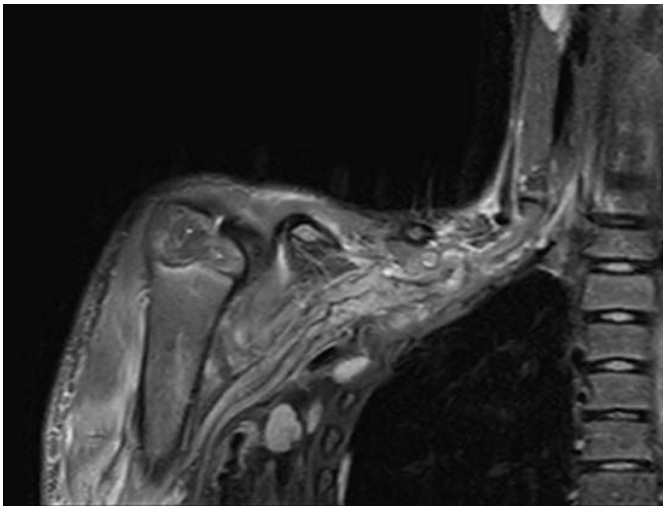
The diagnostic confidence of STIR T2 MR sequence was seen to be highest with a sensitivity of 95.08% and specificity of 85.71%. In only 3 out of 61 brachial plexuses, STIR T2 MR sequence failed to detect the abnormality.

Illustrations

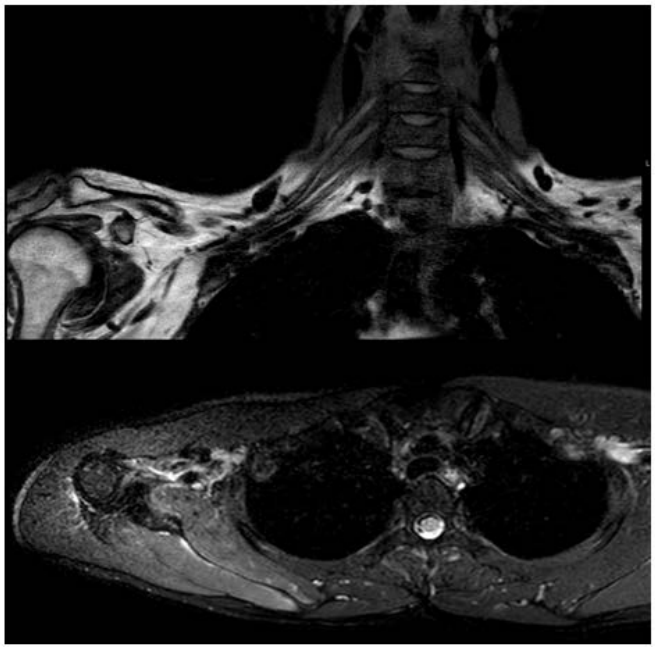


Case 1: Trauma: Nerve root avulsion. Axial and coronal oblique STIR sequences demonstrate avulsed

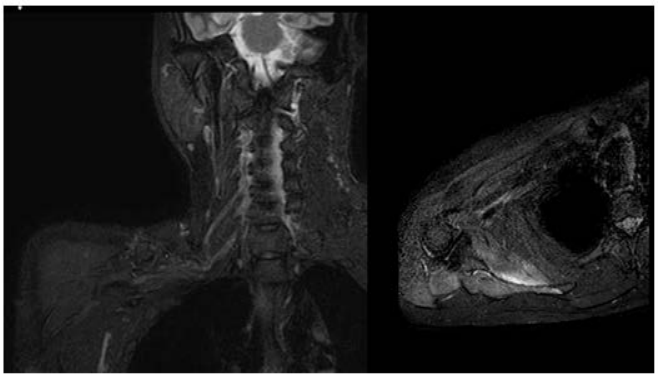
right T1 nerve root and C8 nerve root with pseudomeningocele formation. There are edematous changes in the trunks and divisions of the brachial plexus which are thickened and show increased signal intensity.



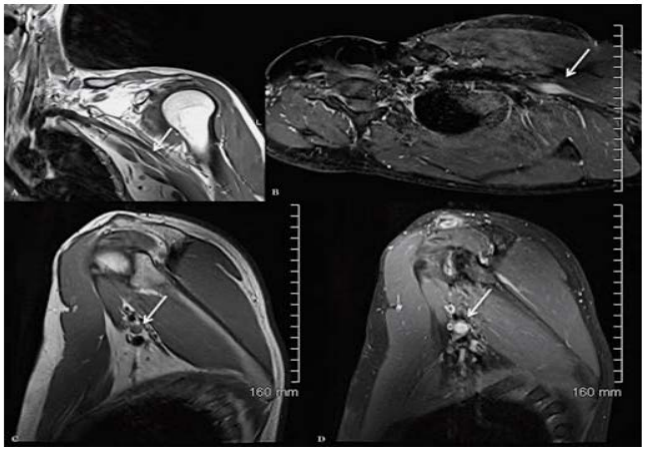
Case 2: Trauma: Neuroma in continuity (NIC). Coronal STIR image shows severed, enlarged and hyperintense trunks, divisions and cords of right brachial plexus with neuroma in continuity (NIC) formation, suggestive of postganglionic right brachial plexus injury.



Case 3: Idiopathic/Inflammatory: Axonotmesis. Coronal oblique T1 showing asymmetrically hyperintense and diffusely enlarged postganglionic segment of C5, C6 nerve roots and upper trunk of the right brachial plexus. Axial STIR showing diffuse hyperintensity involving supraspinatus, subscapularis and deltoid muscles.

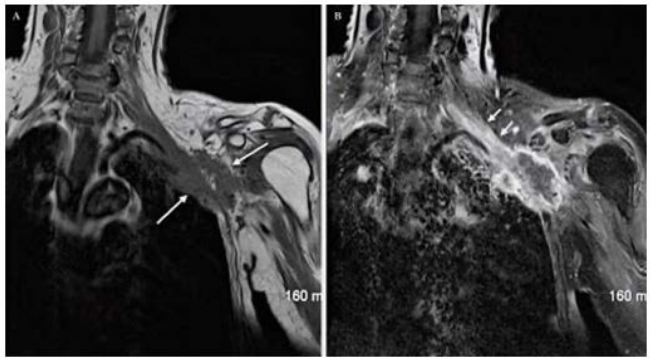


Case 4: Trauma: Nerve discontinuity/Neurotmesis. Coronal oblique STIR showing hyperintensity in C5, C6 and C7 postganglionic nerve. There is break in continuity of postganglionic segment of C6 nerve. Trunks appear clumped up. Axial STIR showing diffuse hyperintensity involving supraspinatus, subscapularis and deltoid muscles. Axial STIR is showing preganglionic injury in the form of pseudomeningocele formation noted at C7-T1 level with Root avulsion of C8 Nerve.



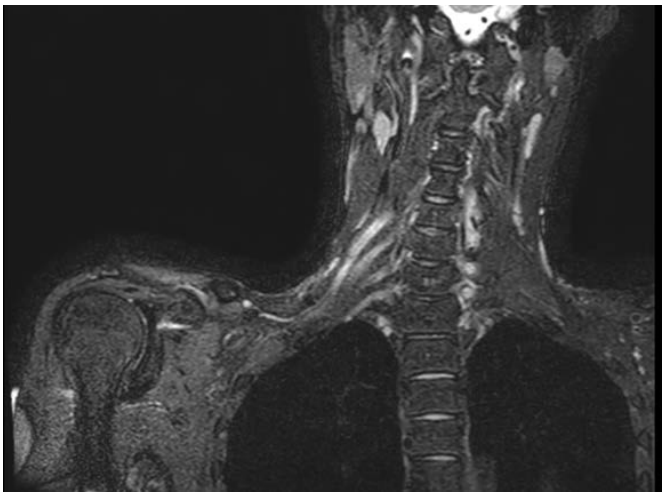
Case 5: Neoplastic: Schwannoma. Coronal oblique T1 (A), axial oblique T1 post-contrast with fat saturation (B), sagittal T1 (C) and sagittal T1-weighted sequence post-contrast with fat saturation (D) show a focal well-

defined enhancing mass lesion along the proximal branches of the left brachial plexus, likely consistent with a schwannoma.



Case 6: Neoplastic: Lung cancer. Coronal oblique T1 (A) and coronal oblique T1W sequence post contrast with fat saturation (B) demonstrate a necrotic mass in the left lung apex, with peripheral enhancement (long arrows) which shows extension to the thoracic wall and invasion of the divisions and cords of the brachial plexus.

In addition, there is malignant involvement of the proximal segment of the brachial plexus with thickening and post-contrast enhancement of the roots and trunks (shortarrows).



Case 7: Trauma: Stretch injury/Axonotmesis. Coronal oblique and axial STIR sequence showing thickening and increased signal intensity of the C5, C6, and C7 nerve roots of right brachial plexus. All the segments are in continuity. Noticed hyperintense signals in right supraspinatus and deltoid muscle.

Discussion

Neuropathy is a broad term encompassing motor as well as sensory symptoms and has varied aetiology. The diagnosis is suspected clinically on the basis of the patient's symptoms and examination. The imaging complement the diagnosis by identifying the exact site of involvement and the possible cause of neuropathy. Improved magnetic strength of MR machines has made the imaging of nerve possible.

We conducted a study to assess the role of MR neurography in 75 brachial plexopathy patients as compared to NCV, the gold standard. Our study included all patients with brachial plexus neuropathy symptoms. Birth related brachial plexus injury patients were not included in our study.

The present study was conducted on 75 patients with symptoms of brachial plexus involvement with an average age 35.4 years ranging from 11 to 70 years. The average age in present study is comparable to the average age as reported in the literature. The mean age in the study done by Crim J et al[65] was 43.2 years and in the study done by Abul-Kasim K et al[42] was 33 years. The mean age in the study conducted by Upadhyaya V[10] et al was 32.25 years.

Table 11: Comparison of mean age with other studies

Study	No. of patients	Age range	Mean age

Crim J et al[65]	70	13 to 75	43.2
Abul-Kasim K et al[42]	7	15 to 61	33
Upadhyaya V et al[10]	20	17 to 65	32.25
Present Study	75	11 to 70	35.4

Male to female ratio in the study conducted by Abul-Kasim K et al[42] was 7:0 and in the study done by Upadhyaya V[10] et al was 20:0 which shows that there were all males and no females. However, in the present study, the ratio of males to females was 2.12:1. The higher ratio in all the studies can be explained by the fact that males are more exposed to road traffic accidents which was the commonest cause of brachial plexopathy amongst the patients of the present study and their studies were only for traumatic cases. Therefore, series involving small number of patients including the present study may not be the real indicator of gender statistics.

Table 12 : Comparison of sex Distribution with other studies

Study	Males	Females	Ratio (M:F)
Abul-Kasim K et al[42]	7	0	7:0
Upadhyaya V et al[10]	20	0	20:0
Present study	51	24	2.12:1

Left sided brachial plexopathy predominated the present study with 50.66% which is not comparable with the other studies as shown in table 13.

Table 13 : Comparison of limb affected with other studies

Study	Total number of patients	Side affected	
		Right	Left
Abul-Kasim K et al[42]	7	73.43%	26.57%
Upadhyaya V et al[10]	20	66.66%	33.33%
Present study	75	50.66%	43.33%

In our study, the most common aetiology was the trauma and other causes were of idiopathic/inflammatory etiology, neoplastic and thoracic outlet syndrome. This is in corroboration with study by Fan YL et al[38] who presented a series of cases of brachial plexopathy in adults over a period of five years.

Table 14: Comparison of trauma as most common aetiology with other studies

Study	Percentage of traumatic cases
Fan YL et al[38]	60%
Upadhyaya V et el[10]	80%
Present study	56%

In our study, the most common site of involvement in brachial plexus is trunks followed by nerve roots, pan plexus and cords which is in agreement with study done by Upadhyaya V et al[10], they classified MRN imaging findings based on the level of injury—root, trunk or cord. These findings were correlated with those seen on surgical exploration. A good correlation was found in the majority (65%) of patients and average correlation (30%) in others.

We assessed MR neurography to identify the level of injury, whether preganglionic, postganglionic or both. In our study preganglionic involvent is seen in 37 of total patients, in which 10 patients had associated pseudomeningocele formation and rest of the patients had preganglionic injury without pseudomeningocele formation. Postganglionic injuries were further characterized by sudden and sunderland classification[7] of peripheral nerve injuries as thickening of nerve, discontinuity of nerve or neuroma formation. One of the most important advantage of MR evaluation is that it helps to classify an injury as pre- and postganglionic or mixed.

In our study we used T1 W, T2 W and STIR sequences which are based on Panasci DJ et al[28] who studied imaging techniques of the brachial plexus and demonstrated that T1-weighted axial and oblique coronal images supplemented by T2 weighted or STIR images are a standard protocol. The STIR pulse sequence has two advantages: (1) the bright signal from fat is suppressed with a larger field of view and (2) it has an increased sensitivity to water content compared to standard T2 pulse sequences.

3D STIR imaging is not only a reliable alternative to 2D STIR imaging, but it also better evaluates the anatomy, nerve site compression and pathology of the plexus, especially to depict space-occupying tumors along its course.

In our study, sensitivity, specificity, PPV, NPV and diagnostic accuracy of T1 MR sequence was 36.51%, 92.86%, 95.6%, 25% and 46.75%, of T2 MR sequence was 75%, 78.57%, 93.75%, 42.30% and 75.68% and of STIR MR sequence was 95.08%, 85.71%, 96.66%, 80%, and 93.33% respectively. The results are in agreement with studies by Wade R et al[66], who reported MRI sensitivity and specificity of 93% and 72% and Mohammed GD et al[67] who reported MRI sensitivity, specificity, and accuracy for preganglionic injury 96%, 95%, and 95% respectively, while for postganglionic injury, MRI sensitivity, specificity, and accuracy were 60%, 100%, and 99%, respectively. In study conducted by Alberto et al[68] sensitivity, specificity with 95% confidence intervals (CIs) were 81% and 91% along with diagnostic accuracy of 87%.

Table 15: Comparison of Diagnostic values with other studies

Study	Sensitivity	Specificity	Accuracy
Wade et al[66]	93%	72%	89%
Mohammed et al[67]	96%	95%	95%
Alberto et al[68]	81%	91%	87%
Abul-Kasim et al[42]	90%	87%	88%
Present study	**95%**	**86%**	**93%**

In our study, T1 MR sequence had a specificity as high as 92.86% but had low sensitivity (36.51%) while STIR sequence had a sensitivity of 95.08% and accuracy of 93.33%.

Therefore, results obtained in the present study are similar & comparable to the results reported in the literature.

Summary & Conclusion

- A total of 75 patients of brachial plexopathy were evaluated to assess sensitivity, specificity and diagnostic accuracy of 3 Tesla MRI along with comparison of different sequences of MRI.
- The average age of the patients in the present study was 35.40 years with a range from 11 to 70 years with a significant male preponderance (68%).
- The most common etiology was trauma (56%) with more left sided involvement (50.66%).
- The most common anatomical site of involvement was trunks (38.66%).
- In postganglionic involvement most common finding was nerve thickening (78.185) whereas pseudomeningocele was not seen in 72.97% of preganglionic involvement.
- The sensitivity, specificity and diagnostic accuracy of STIR MRI sequence was 95.08%, 85.71% and 93.33% which were higher than T1 and T2 MRI sequences.
- The observations of the present study therefore do indicate that MRI is an extremely useful modality to image the brachial plexus because it accurately localise the anatomical site of injury/lesion. It can describe the injury/lesion from the roots till the terminal nerves and differentiates them into preganglionic and postganglionic, which highly influences both surgical planning and outcome/prognosis.
- The brachial plexus can be efficiently imaged and effectively interpreted when approached from a practical standpoint. Optimization of a practical brachial plexus imaging protocol is paramount to identify normal anatomy and associated pathology.

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