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Magnetic Resonance Imaging in Traumatic Brachial Plexopathy: A Guiding Light for Surgeons

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Abstract

Background: The brachial plexus is a group of major neural structures providing sensory and motor innervations to the upper limb. The brachial plexus originates from four cervical (C5-C8) and the first thoracic root (T1).

Objectives: The aim of the current study was to evaluate the role of MRI in the diagnosis and localization of traumatic brachial plexopathies and co-relate MRI findings with intraoperative findings wherever possible.

Methods: A total of 40 patients with traumatic brachial plexitis underwent a dedicated MRI at our institution. Clinical and electrodiagnostic tests were done in all patients. The findings of MR imaging were correlated with surgical findings as concordant (CR), partially concordant (PC), or nonconcordant (NC). Patients who were not operated were followed over a period of six months to one year.

Results: Road traffic accidents (n=32) were the most common cause of brachial plexopathy in our study. Clinical evaluation revealed sensory symptoms in 28 (70 %), motor symptoms in 25 (63%), and autonomic manifestation in 2 (5%) patients. The electrodiagnostic tests were abnormal in 30 (75%) of our patients. MRI findings included pre-ganglionic injury (n=5, 12.5%), post-ganglionic injury (n=17 42.5%), mixed injury (n=9 22.5%) and normal in 9 (22.5%) patients. MRI findings were perfectly concordant with surgical findings in 23(66%), partially concordant in 8(23%), and nonconcordant in 4(11%) patients. MRI has a sensitivity of 87.88%, specificity of 100%, and accuracy of 89.47% for traumatic brachial plexopathy evaluation.

Conclusion: MRI is an essential component of traumatic brachial plexopathy evaluation. MR imaging, although not absolutely perfect, helps in the localization of injury in traumatic plexopathies (pre vs. post-ganglionic), thereby acting as a guiding light for surgical management. Normal MRI in traumatic brachial plexopathy is an enigma, and management in these patients should be based on clinical and electrodiagnostic tests.

Keywords: Magnetic Resonance Imaging (MRI), Road Traffic Accident (RTA), Nerve Conduction Velocity (NCV), Constructive Interference in Study State (CISS).

Introduction

The brachial plexus is a group of major neural structures providing sensory and motor innervations to the upper limb. The brachial plexus originates from four cervical (C5-C8) and the first thoracic root (T1). The brachial plexus has been divided into four parts which include five ventral rami of the roots, three trunks, six divisions (three anterior and three posterior) and three cords.[1] The brachial plexus can be involved in a number of different pathologies ranging from trauma to tumours and even idiopathic brachial plexopathy (Parsonage-Turner syndrome). Traumatic brachial plexopathy can be broadly divided into open and closed injuries. Closed injuries are traction injuries and, depending

on the level of injury, can be divided into supraclavicular, retro clavicular, infraclavicular and mixed injuries. Supraclavicular lesions are more common and are subdivided into preganglionic and postganglionic injuries. This subdivision is essential to decide the surgical management of brachial plexus injuries as preganglionic injuries (nerve root avulsion) may require neurotisation techniques or musculotendinous transposition, whereas postganglionic lesions can be repaired locally.[2] Physiologic grading of nerve injuries has been put forth by Sunderland and consists of five degrees. First-degree injury (neurapraxia) is a reversible conduction block with an intact anatomical continuity. Second-degree injury (axonotmesis) includes

damage to the axons with distal Wallerian degeneration; complete recovery occurs because of the intact endoneural tubes. Third-degree injury is characterised by damage to the continuity of the endoneural tubes. Fourth-degree injury has complete disorganization of the nerve, which is, however still continuous, and there can be some recovery, but without a useful degree of function. Fifth-degree injury (neurotmesis) includes a complete interruption of the nerve.[3]

Diagnosis of brachial plexopathies has long been dependant on clinical and electromyographic studies, however in the recent decade or two, imaging modalities with the capability of direct visualization of the plexus have come forth. Various imaging modalities have been used to study brachial plexus injuries, including magnetic resonance imaging (MRI), computed tomography (CT), and ultrasonography (USG); however, MRI has emerged as the imaging modality of choice for the evaluation of the brachial plexus due to its superior soft-tissue resolution and multiplanar capabilities.[4-7] MR imaging plays an essential role in differentiating preganglionic injuries from postganglionic lesions. This differentiation is crucial for determining the management of brachial plexus injury, especially in the setting of trauma. MRI can also directly visualize the extraforaminal brachial plexus injuries in the form of thickening and increased T2/STIR signal suggestive of edema or fibrosis. MRI can also identify secondary causes of brachial plexopathy after trauma, including hematoma or clavicular fracture causing nerve root compression.[8] However, the imaging of the brachial plexus is challenging due to its complex anatomy and distribution in space, which becomes even more challenging in the setting of trauma. Another limitation of MRI may be the time required for imaging which may be uncomfortable for the injured patient.

Objectives

Our study aims at unravelling the imaging features of traumatic brachial plexopathy and assessing whether MRI can act as a guiding lamp for surgeons in the treatment of these injuries.

Materials and Methods

The study was conducted in the Department of Radiodiagnosis and imaging, Sheri Kashmir institute of medical sciences, Srinagar, over a period of three years from Nov 2017 to Oct 2020 and included the patients who presented with sensory-motor or autonomic abnormalities of upper extremities or with abnormalities in nerve conduction velocity test in post-traumatic event. The study included a total of 40 patients. Patients with open injuries, known cases of vascular diseases of the upper extremity, and those in whom MRI was otherwise contraindicated (implants, MRI incompatible prosthesis) were excluded.

Patients with trauma and suspected brachial plexus injury were evaluated clinically, and nerve conduction velocity tests were done in all the patients. A preliminary diagnosis of brachial plexopathy was established using clinical and electrophysiological criteria. After stabilization, the patients were taken for MRI to establish the level and extent of the injury. All MR studies were performed using a 1.5 Tesla MR system using Body coil and cervical coil (Magneton Avanto. Siemens medical system, Erlangen Germany). Respiratory gating was applied throughout the procedure to reduce motion artifact. Imaging was done from the cervical third to dorsal third vertebral level. The various imaging sequences were used in our institution are as under:

1. **Localiser HASTE;** TR 7ms, TE 2.4ms, Slice thickness 7.8mm, Distance factor 30.

2. **Coronal T2 TURBO SPIN ECHO (TSE);** TR 929-1200ms, TE 9.6ms, Slice thickness 2-3mm.

3. **Axial T2 TSE;** TR 7992m , TE 114ms Slice thickness 2.0mm (Right and left), Distance factor 10.

4. **Sagittal T2 TSE;** TR 7992ms, TE 114 ms, Slice thickness 2.0mm (Right and left), Distance factor10.

5. **Coronal STIR/ TIRM Coronal;** Ti 150 ms, TR 5760ms,TE 74ms, Slice thickness 2.5mm,Distance factor 0.

6. **T2 weighted CISS in axial plane;** TR 5.95ms, TE 2.98ms, Slice thickness 0.70mm, Distance factor 20.

7. **T2 weighted space in coronal plane 3D;** TR 1500ms,TE 133ms,Slice thickness 1.50mm,Distance factor 0.

The images were transferred to a dedicated workstation and evaluated by a radiologist with five years of experience in musculoskeletal imaging. The evaluator was blind to the clinical and NCV findings. The level of involvement and the extent of the injury to the nerves were noted including the signal changes on different sequences. Any additional findings (hematoma, fractures) were also noted. Edema was reported if the plexus components were mildly thickened with hyperintense signal inT2W and fat-suppressed images. A pseudo-meningocele was seen as an extra-dural fluid collection which was extending into the neural foramen and

was iso- intense to CSF on all sequences. Fibrosis was indicated by the distorted appearance of the plexus with a heterogeneous signal. Post-traumatic neuroma was suggested by a well-defined mass-like lesion along the course of the nerve. Any signal abnormality in the shoulder or paraspinal muscles was also noted. MR imaging findings were correlated with surgical findings, especially with regard to the level of involvement (pre or post-ganglionic). We recorded the surgical correlation of our MRI findings as concordant (CR), partially concordant (PC), and non-concordant (NC). Findings were concordant when MRI and surgical findings matched each other completely, partially concordant when surgical findings were in addition to what MRI had already delineated, and non-concordant when MRI failed to pick up the surgical findings completely.

The plastic surgery department performed all the surgeries. The incision location, whether proximal or distal, was based on the MRI finding of the injury level. The type of repair, whether nerve transfer or primary repair, was also based on the type of injury, whether pre-ganglionic or post-ganglionic, respectively. Intra-operatively the integrity of the nerves was assessed by electromyography. The surgical findings were well recorded, and each MRI finding was sought during the surgery.

In patients with no MRI abnormality, the decision on surgical management was based on clinical and NCV findings. Patients who were not operated were followed over a period of 6 months to 1 year to document recovery.

Statistical analysis

The data was collected and evaluated using SPSS 21.0. Descriptive data were analyzed by frequencies and categorical data by percentages, and continuous variables by means and standard deviations. Continuous variables were compared using Student's t-test. For all comparisons, a p-value of <0.05 was considered statistically significant.

Ethical Consideration

Informed written consent from all the patients was taken in our study.

Results
Patient profile

We evaluated a total of 40 patients with 33 males (83%) and seven females (17%) having a mean age of 35 ± 8 years (range 16-60 years). The majority of our patients presented after a road traffic accident (n=32), and only 7 had non-RTA-related injuries (4 with sports-related injuries and three with falls from height).

Clinical profile

Sensory symptoms were present in 28 (70%) patients; motor symptoms were present in 25 (63%) patients and autonomic manifestation in 2 (5%) patients. All our patients underwent a nerve conduction test after stabilization to get an overview of the injury. The electrodiagnostic tests were abnormal in 30 (75%) of our patients, helping in the diagnosis of the plexus injury.

MRI Imaging

MR imaging in our patients was done after patient stabilization and after a mean time of 4 weeks ± 2weeks. Based on the MRI findings, we divided the patients into those with MRI suggestive of pre-ganglionic injury (n=5), post-ganglionic injury (n=17), and mixed injury (n=9). In nine of our patients, no MRI abnormality was seen (Figure-1), out of which four were operated (1 showed pre-ganglionic and three postganglionic injuries) while five others were not operated based on clinical and NCV findings and were followed up. The MRI imaging findings are indicated in (Table-1).

Table-1. Showing MRI findings in patients with traumatic brachial plexopathy including both pre and post-ganglionic injuries

| Type of injury	T2/STIR Hyperintensity of post ganglionic plexus	Pseudo-meningocele	Cord hyperintensity	Cord displacement	Neuroma/ hematoma	Non visualization of roots in canal (CISS imaging)	Muscle hyperintensity (para spinal/rotator cuff muscles)
Pre-ganglionic	none	4(80%)	3(60%)	3(60%)	none	4(80%)	2(40%) PS
Post-ganglionic	14(82%)	8(47%)	2(18%)	none	9(53%)	2()	5(29%) RC
mixed	6(66%)	8(89%)	3 (33%)	6(66%)	2(22%)	8(89%)	2(22%)PS 1(11%)RC
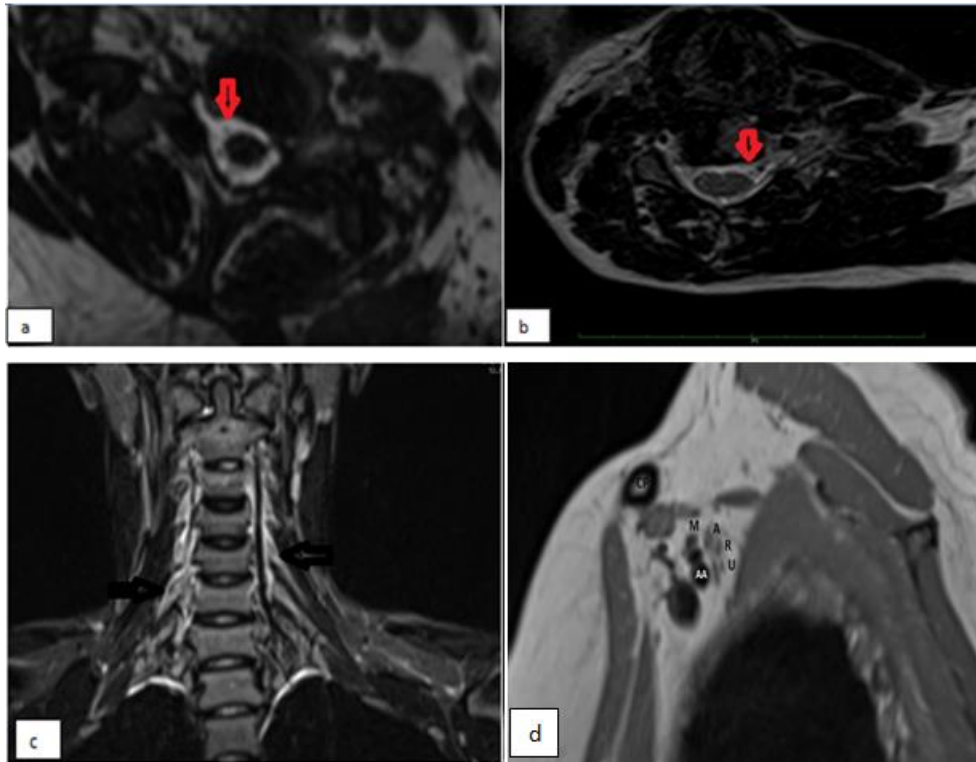
Figure-1. (Normal brachial plexus MRI) T2 axial CISS images (a,b) showing the nerve roots within the canal on right side (arrow in a) and entering the foramen on left side (arrow in b). T2 TIRM coronal images (c) showing the normal extra-canalicular roots, trunks and divisions (arrows). T1 sagittal oblique images at the level of coracoid process showing the relationship of branches from cords with axillary artery (AA). CP- coracoids process, AA- Axillary Artery, M- Musculocutaneous nerve, A- axillary nerve, R- radial nerve AND U- ulnar nerve.
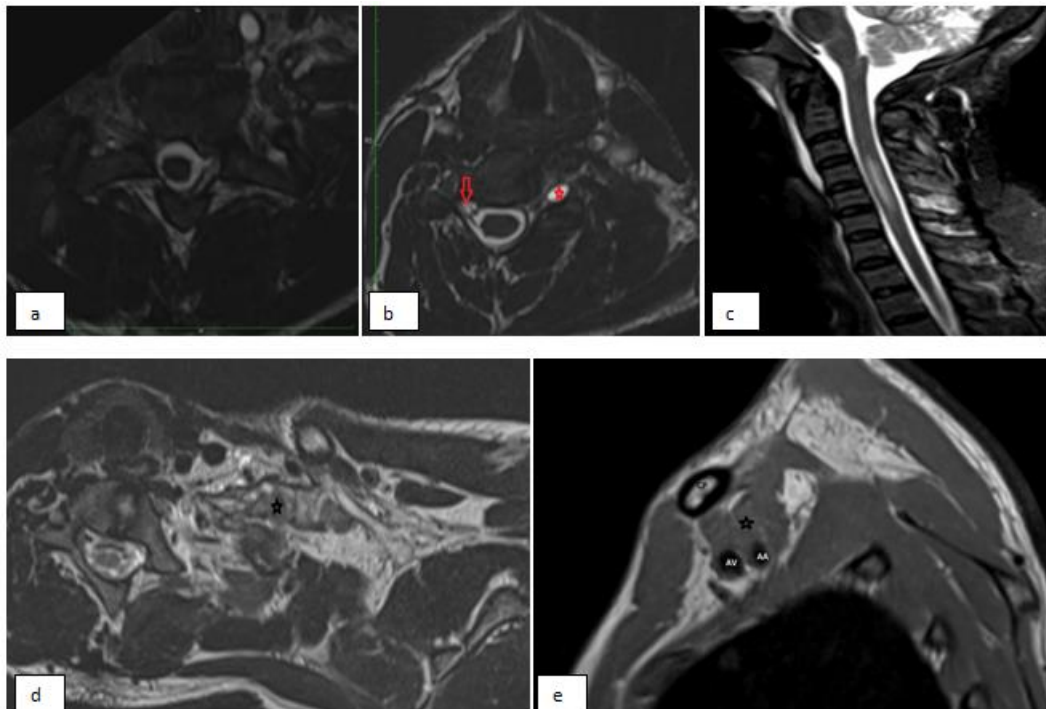

Figure-2. T2 HASTE axial image (a) showing clumped hyperintense nerve roots, trunks and divisions (star) suggestive of post ganglionic injury. T2 STIR coronal image (b) showing clumped nerve roots (star) and fluid around the clavicular head of sternocleidomastoid tendon. T2 SPACE coronal images (c and d) showing the clumped hyperintense roots (black arrow in c) and continuity of root in the foramen (red arrow in c) suggesting post ganglionic injury. A pseudo meningocele is also noted (arrow in d)
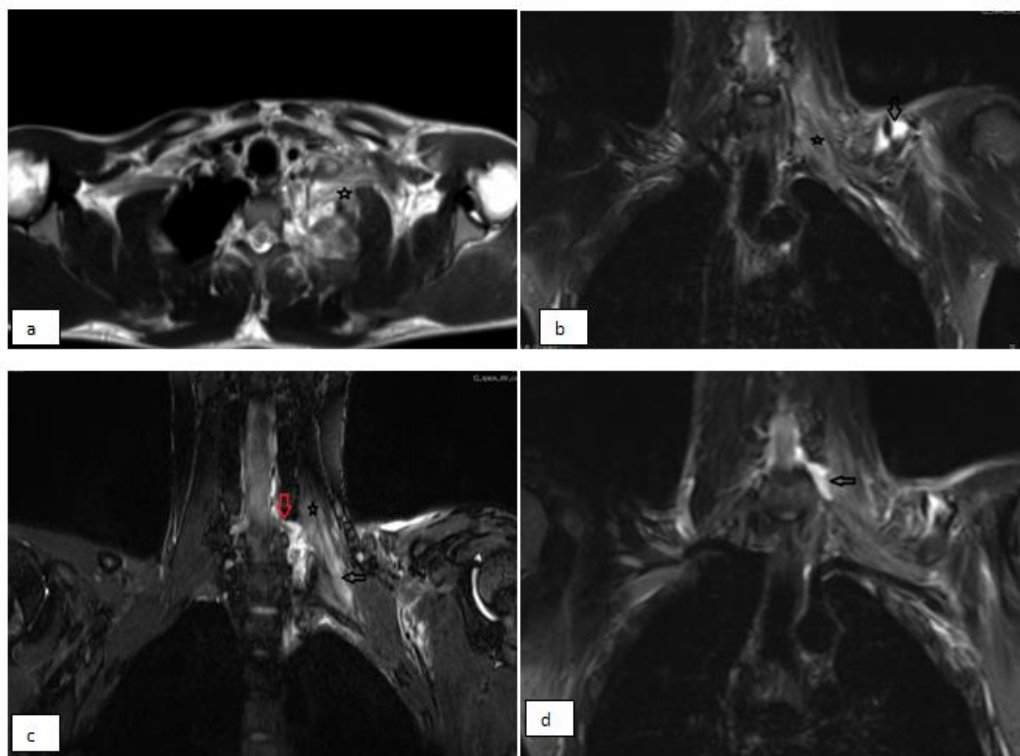
Figure-3. T2W HASTE axial image in a 10 year boy post RTA showing the presence of pseudo meningocele (arrow), absence of intra canalicular roots and mild deviation of cord towards right side indicating pre ganglionic injury. Extraforaminal roots appear normal (star). T2W HASTE sagittal (b) and coronal (c) images in the same patient showing pseudo meningoceles involving C7 and C8 roots (arrows) with normal extra-foraminal plexus (star).
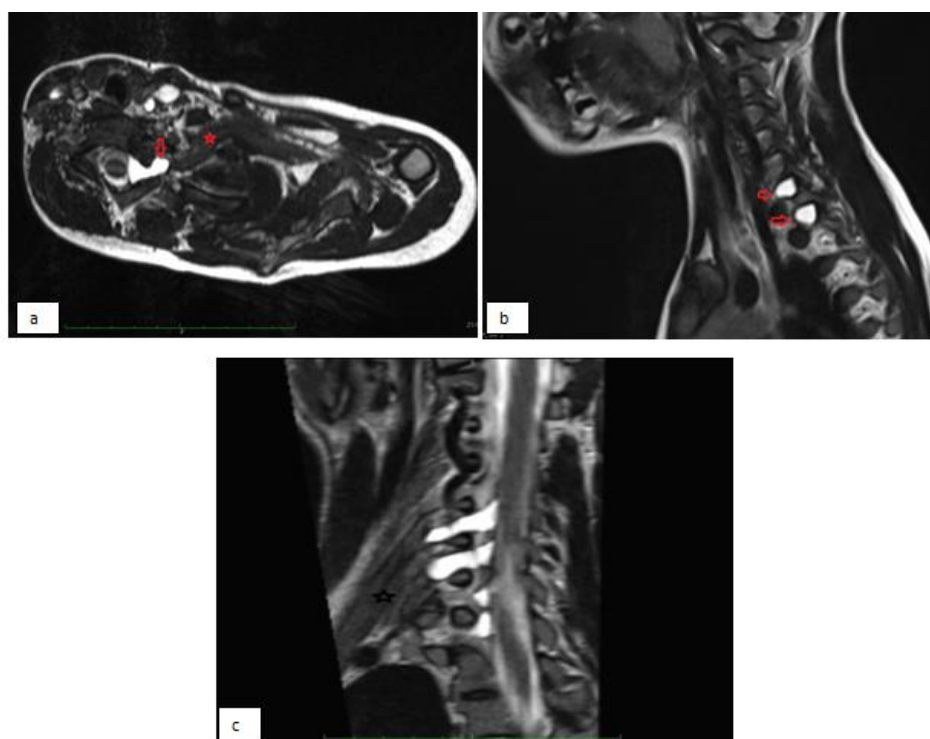
Figure-4. (Mixed pre and post- ganglionic injury)T2 CISS(a) and T2W HASTE axial images in a 25 year male with trauma showing the presence of pseudo-meningocele(star in b), absence of intra canalicular roots on left side and deviation of cord to right side(a). The normal intracanal roots are shown on right side (arrow in b). T2W HASTE sagittal image (c) showing cord hyperintensity at root attachment site suggesting pre ganglionic injury. T2W HASTE axial (d) and T1W oblique sagittal (e) images in the same patient showing clumping of the extra foraminal plexus at the level of coracoid plexus with T1 iso and T2 mildy hypeintense signal suggestive of post ganglionic injury with haematoma. CP-Coracoid Process, AA- Axillary Artery, AV-Axillary Vein.

Table-2. Correlation of MR findings with surgical findings

	Surgical findings		
	Consistent		Non consistent
Correlation grade	Concordant	Partially concordant	Non concordant
MRI findings	23(66%)	8(23%)	4(11%)

MRI and Surgical correlation

Out of 40 patients, 35 patients underwent surgery based on MRI findings or in cases with negative MRI based on clinical and NCV findings. We found that the MRI findings were perfectly concordant with surgical findings in 23(66%) of the patients. In 8(23%) patients, MRI detected an injury, but additional injuries were detected when these patients underwent surgery, making the findings partially concordant. In four patients, MRI could not detect any abnormality, but when these patients were operated, traumatic brachial plexopathy was observed (Table-2).

In five patients, no surgery was performed as MRI was normal and clinical and NCV features did not warrant surgery. On follow up all these patients showed recovery over a mean time of 8 months. Based on these numbers, our study showed that MRI has a sensitivity of 87.88%, specificity of 100%, and accuracy of 89.47%. The PPV and NPV were 100% and 92%, respectively, while LRNeg was 0.11.

Additional bony abnormalities:

Other bony abnormalities include the presence of fracture clavicle (n=5 12.5%) and vertebral fractures (n=3 7.5%) and were found mainly in patients with RTA (n=7) and fall from height (n=1).

Discussion

We conducted an MRI study in 40 patients with post-traumatic suspected brachial plexus injury. The study was done between 3-7 weeks post-traumatic event. Our patients included 33 males (83%) and seven females (17%) having a mean age of 35 ± 8 years. The male dominance in our study is because RTA and other traumatic events, including sports-related injuries, are more common in males in our part of the world due to less participation of females in outdoor and sports activities. RTA was the cause of traumatic brachial plexopathy in a majority (n=32 80%) of our patients. These findings are quite similar to that of Jain et al;[9] who in their study found traumatic brachial plexopathy to be more common in young males following RTA.

The presentation of patients in our study was in the form of motor (63%) or sensory symptoms (70%). Only two patients had autonomic features in the form of Horner's syndrome, indicating a high injury (T1). We conducted nerve conduction tests in all our patients and found NCV abnormalities in 30 (75%) of our patients. We believe that although clinical and NCV findings were positive in a significant number of our patients, these methods are difficult to assess, especially in the acute setting. Also, these tests are less likely to help differentiate pre- and post-ganglionic injury, which is essential in managing these patients. Lack of direct visualization of the injury (neuroma/hematoma, bony and spinal cord injuries) is another drawback of these methods. Therefore, although clinical and electrodiagnostic tests are the initial evaluating methods in traumatic brachial plexopathy, they lack the specificity and the information necessary to guide the management of these patients. Clinical and electrodiagnostic tests can however, be very helpful in cases where imaging is negative. In our study, 9 (22.5%) patients had a normal MRI; out of these, 4 underwent a surgery based on clinical and electrodiagnostic test results indicating lack of recovery (absence of motor unit potentials and many fibrillation potentials whereas the presence of voluntary motor unit potentials with limited fibrillation potentials signifies better prognosis). These findings are very much concordant with previous studies involving the management of brachial plexus injuries.[10-13]

Imaging of brachial plexus injury has become a routine in the management, giving important and essential information to the surgeons and physicians. The imaging in the early days was dependant on radiographs and Computed tomography. CT myelography was used with some success but was invasive in nature. Magnetic Resonance Imaging, especially with its newer sequences and the ability to achieve thin slice images, has revolutionized brachial plexus imaging. MRI is useful in assessing post-traumatic patients and the investigation of choice for patients with tumors, radiation plexitis, idiopathic brachial plexitis, and metastasis to the brachial plexus. In our study, we performed MRI in all patients after a mean period of 4-6 weeks as the imaging was distorted in the acute setting, and it helped in the

management of traumatic brachial plexitis. MRI successfully identified patients with preganglionic injury (n=5) from those with postganglionic (n=17) and mixed (pre- & postganglionic) injuries (n=9) (Figure-4). This demarcation is essential for management purposes. The findings that were commonly observed with preganglionic injuries included cord displacement to the opposite side (60%), cord hyperintensity at root attachment site (60%), non-visualization of the root in the canal (80%), and pseudo-meningocele formation (80%) (Figure-3 and Figure-4). Among these, the first three were exclusively seen in preganglionic injuries, thereby making them the MRI features to look for when one is suspecting a preganglionic injury. Pseudo-meningocele, although present in 80% of the patients with preganglionic injury, was also found in 47% of the patients with post-ganglionic injury. The MRI features that we found in postganglionic injuries included T2/STIR hyperintensity of the roots, trunks, cords, or divisions, which was found in 82% of the MRI-positive patients (Figure-2). The other features included pseudo-meningocele formation, hyperintensity in paraspinal and shoulder girdle muscles, and neuroma/hematoma formation (Table-1). Our findings are similar to many previous studies, including those of Volle et al;[14] Hems et al;[15] Upadhyaya et al;[16] and Abdul-kasim et al;[17] who in their studies found similar findings in pre and post-ganglionic brachial plexus injuries although the frequency was somewhat different.

In our study, 35 patients underwent surgery based on MRI findings (n=31) or clinical and NCV findings where MRI was normal (4 patients). Five patients were followed up and showed improvement in both clinical and NCV features without undergoing surgery. On correlating surgical findings with MRI imaging features, we found that MRI was completely concordant with surgical findings in 66% of the patients and partially concordant in 23% of the cases. In four cases (11%), MRI was normal, but on surgery, brachial plexus injury was found (1 preganglionic and 3 post-ganglionic). There was no false-positive MRI in our study. In our study, the sensitivity, specificity, and accuracy of MRI vis-à-vis traumatic brachial plexopathy were 87.88%, 100%, and 89.47% respectively. Our numbers are in opposition to many old studies, including those of Volle et al;[14] Carvalho et al;[18] and Ochi et al;[19] who in their studies found a much lower sensitivity and specificity of MRI in detecting traumatic brachial plexopathy. This opposition is probably because

these studies were done when MRI was in its infancy, and no special 3D sequences were available. Also, the minimum slice thickness in that era was about 5 mm, which made roots within the canal almost impossible to visualize. However, our findings are consistent with the results of some recent studies using improved MRI sequences and thin slice images, including the studies of Hems et al;[15] and Upadhyaya et al;[16] who in their studies found a good correlation of MRI findings with surgical findings. Therefore, MRI is an essential component of traumatic brachial plexus management as it can reliably differentiate pre from post-ganglionic injuries. Surgically for pre-ganglionic injury, treatment is usually with nerve transfers, while post-ganglionic lesions may undergo microsurgical re-anastomosis or grafting or could be followed up conservatively.[20,21]

Regarding MRI sequences, we found that T2 weighted CISS and SPACE sequences were particularly helpful in identifying nerve disruption and preganglionic injuries. Postganglionic injuries were usually associated with signal abnormality (T2/STIR hyperintensity) of the nerve roots. Although contrast-enhanced thin slice images have been used with some benefits by some authors, we did not use contrast in our study as practicable, and surgically important information was achieved with the sequences we employed.

We studied nine patients with possible brachial plexus lesions due to trauma, but no abnormalities were present on MR imaging. Five among them were followed over time and showed spontaneous resolution with nonsurgical management. Four patients were operated based on clinical, and NCV abnormalities, and surgery revealed neurotmesis of the axillary and radial nerves in three patients, and one patient had a preganglionic injury. Spontaneous resolution after traumatic brachial plexopathy is known especially in patients with no direct visualization of nerve injury on MRI and documented by Van H Es et al.[22] in their study involving 18 patients. Thus, in patients with a normal MRI, the clinical and NCV findings should guide the management as many of these patients undergo spontaneous resolution. However, further studies with a large group of such patients may be required to corroborate these findings.

The limitations of our study include the limited number of patients; a more significant number of patients in each group may be required to further unravel the entity of traumatic brachial plexopathy. Contrast-enhanced images were not taken in our study, although some studies have indicated its

advantages, especially in the differential of neuromas/hematomas and in assessing denervated muscles. The study was done on a 1.5T MRI scanner when 3T scanners are being used in some parts of the world with better image quality and results.

Conclusions

MR imaging is a sine qua non in the assessment of traumatic brachial plexopathies and should be done in all cases after 4-6weeks of trauma. MR imaging, although not completely perfect, helps in localisation of injury in traumatic plexopathies (pre vs. post-ganglionic), thereby acting as a guiding light for surgical management. Normal MRI in traumatic brachial plexopathy is an enigma, and management in these patients should be based on clinical and electrodiagnostic tests.

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Authors' Contribution

All authors attest that they meet the current ICMJE criteria for authorship.

Conflict of Interests

The authors declared no potential conflict of interests with respect to the research, authorship, and/or publication of this article.

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