Journal of Peripheral Nerve Surgery (Volume 2, No. 1, July 2018) 34-40

REVIEW ARTICLE

Imaging in Traumatic Brachial Plexopathy

Vaishali Upadhyaya[1], Divya Narain Upadhyaya[2]

Introduction

Patients suffering from brachial plexus injury will usually have significant functional impairment of the affected upper limb. This not only leads to a loss of work hours, but also a lot of emotional and financial stress on the patient and the family. Appropriate use of indicated imaging modalities at the right time enables proper and accurate assessment of the site and extent of injury and facilitates management and prognostication by the treating surgeon, who can then plan his surgical approach accordingly. This article helps the reader to understand the role of different imaging modalities such as Plain Radiographs, Ultrasound (US), Computed Tomography (CT) Myelography, Magnetic Resonance Imaging (MRI) and Magnetic resonance Neurography (MRN) in evaluating patients with brachial plexus injuries.

Radiographs

After a thorough clinical evaluation, plain radiographs are often the first line of imaging investigations to be ordered in the presence of an injury in the region of the neck and shoulder. While they have limited usefulness in demonstrating soft tissue injuries, they do give an important indirect evidence of the severity, level and extent of the injury sustained by the surrounding soft tissues. X-Rays of the cervical spine, including antero-posterior (AP) and lateral views, can reveal any fractures of the cervical vertebrae which may be associated with a spinal cord injury. Also, fractures of the transverse processes of the cervical vertebrae may have an associated root injury of the corresponding spinal nerve. AP and axial X-rays of the shoulder can detect fractures of the humerus and scapula, thus providing a clue to the damage sustained by the adjoining portions of the brachial plexus (Figs.1 and 2).

✉ Vaishali Upadhyaya
vshali77@yahoo.co.in

[1] Department of Radiology, Vivekananda Polyclinic and Institute of Medical Sciences, Lucknow.

[2] Department of Plastic Surgery, King George's Medical University, Lucknow

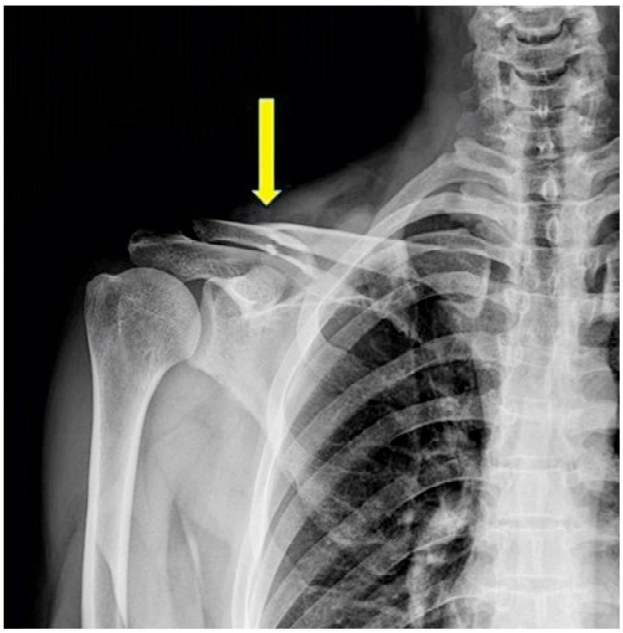

Fig.1 Radiograph of the right shoulder joint in a patient with brachial plexus injury showing clavicular fracture in lateral-third.

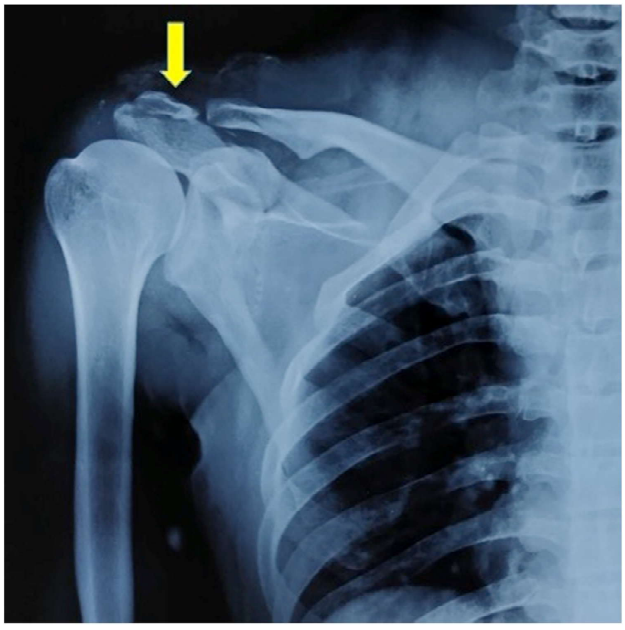

Fig.2 Radiograph of the right shoulder joint showing acromial fracture with adjacent soft tissue swelling in a patient with brachial plexus injury.

A plain X-ray of the chest can detect fractures of the clavicle and the ribs. The first and the second rib are well protected by the overlying clavicle and their fracture usually indicates that a severe trauma has been sustained in this region. Displaced clavicular fractures or fractures of first and second ribs can therefore injure the adjacent divisions or cords of the brachial plexus. Sometimes the chest radiograph may also show rib fractures other than the first and the second ribs. Fractures of the third, fourth and fifth ribs will usually preclude the use of the accompanying intercostal nerves as a donor nerve during nerve transfer surgery later on, due to their possible transection due to the rib fracture. Elevation of the ipsilateral hemi-diaphragm indicates damage to the phrenic nerve, thus pointing to an injury to the roots or the spinal nerves[1].

Ultrasound (US)

US is an easily available, cost-effective, non-invasive imaging modality which does not entail exposure to ionizing radiation. It has a wide range of musculoskeletal applications, although it is not commonly used to image the injured brachial plexus. It can be used in patients with brachial plexus injury to see for evidence of post-ganglionic lesions. It does require a well trained sonologist with a sound knowledge of brachial plexus anatomy to carry out this procedure.

A linear array transducer with probe frequency of 10-18MHz is needed for the scan[2]. The average time taken for the scan ranges from 30-40 minutes in trained hands.

In cases of trauma, the US can help demonstrate large pseudomeningocoeles, which have a significant extension beyond the neural foramina, and empty neural foramina in case of root avulsions. Thickening of the nerves as compared to the uninjured side due to edema can also be demonstrated (Fig.3). Nerve disruption is seen as a gap in the plexus components with a wavy contour distally. Scarring in the plexus appears as soft tissue thickening of variable echogenicity which appears to be blending with the nerves and the nerves may not be visualised separately (Fig.4). Neuromas are visualized as fusiform mass lesions of the plexus components, and can be end neuromas or neuromas-in-continuity. A haematoma is usually seen as a collection adjacent to the plexus[2,3,4,5].

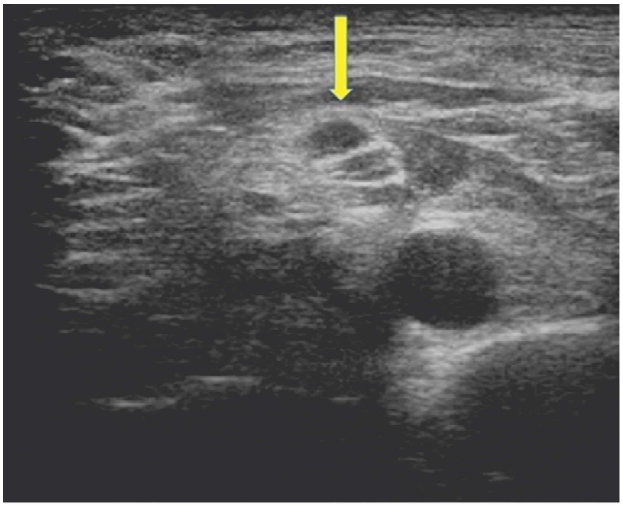

Fig. 3 High resolution US image in a patient with right brachial plexus injury showing thickened hypoechoic trunks in the supra-clavicular fossa.

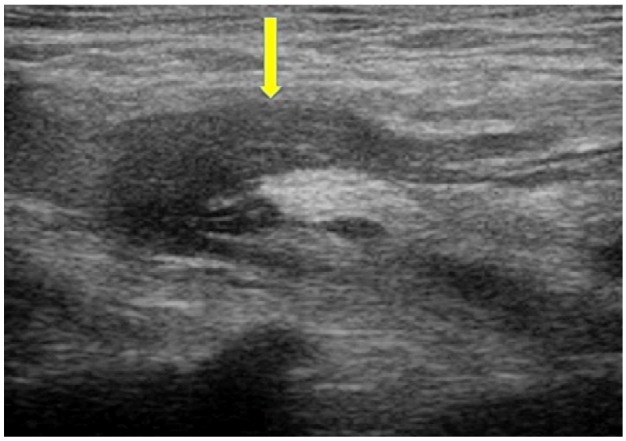

Fig. 4 High resolution US showing enlarged scarred upper trunk in a patient with right brachial plexus injury.

The advantage of US is that it can be performed even in those patients in whom MRI is contra-indicated or those who have severe claustrophobia. The evaluation can also be done by the bedside if the patient is critically injured and cannot be brought to the MR scan room and findings can easily be compared with those of the normal side. Limitations include its inability to visualize the entire plexus, especially the preganglionic part due to the overlying bones. It is difficult to assess the C8 and T1 nerve roots as well as lower trunk by US as these nerves are inferiorly and deeply placed. Operator dependence is an important drawback and without proper training and experience, the study will not be able to give any useful information to the referring surgeon[2,3,4].

US , by itself, may not be enough to completely evaluate the injured brachial plexus but with its

advantages, it can be considered complementary to MRI.

CT Myelography

Myelography combined with a CT examination is called CT Myelography. It involves injection of an intra-thecal contrast agent after lumbar puncture followed by a CT scan. The images thus obtained enable visualization of the cord surrounded by contrast and the ventral and dorsal nerve roots coursing through it can be seen separately (Fig.5). The timing of the study is important. It is recommended that the study be done at least a month after the injury to allow for resolution of any haematoma at the site of root avulsion and formation of a pseudomeningocoele. This would prevent displacement of contrast by the haematoma[1].

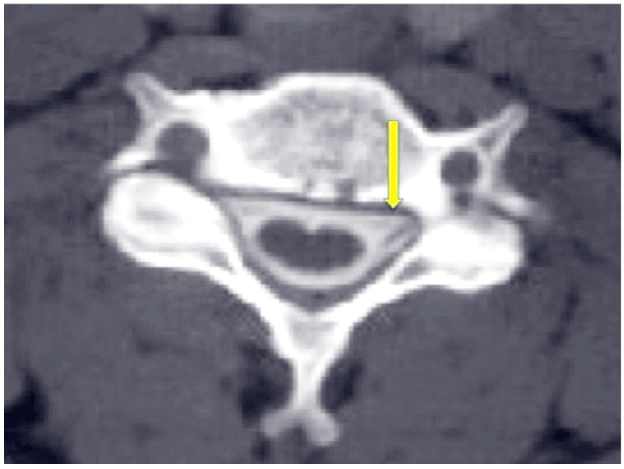

Fig. 5 CT Myelogram image showing the spinal cord with intact ventral and dorsal roots on both sides at C5 level.

The advantages of CT myelography are that it allows optimal assessment of the pre-ganglionic plexus with separate visualization of ventral and dorsal roots and delineation of root avulsions, especially partial avulsions and pseudomeningocoeles[6,7]. It has a sensitivity and diagnostic accuracy ranging from 85-100% in the detection of root avulsions[8,9,10,11,12]. With older CT scanners, it was difficult to assess C8 and T1 roots due to artefacts from the shoulder but with modern multidetector CT scanners, these disadvantages have been overcome.

The drawback of CT Myelography is that it is an invasive procedure with associated complications such as headache, infection and seizure[13]. Moreover, it exposes patients, most of whom are young to ionizing radiation. Sometimes, tortuous vessels and scar tissue may look like nerve roots and avulsion may be missed[14]. Cord displacement due to a pseudomeningocoele can be well visualised but changes in the cord such as edema or contusion may be missed due to poor soft tissue contrast of CT. This is also the reason why CT is not able to optimally assess injury to the post-ganglionic plexus[15]. Hence, nowadays, CT Myelography is only done in those patients in whom an MRI and MRN study cannot be safely performed[16] (**Table1**).

Table 1: Advantages and Limitations of CT Myelography

Advantages of CT Myelography	
1.	Less time taking
2.	Lesser cost as compared to MRN and wider availability
3.	Good visualization of preganglionic plexus
4.	Ventral and dorsal roots can be seen separately
5.	Can detect partial or complete root avulsions and traumatic pseudomeningocoeles
6.	High sensitivity and accuracy of >90% for root injuries
Limitations of CT Myelography	
1.	Invasive procedure with associated complications
2.	Exposes patients to ionizing radiation
3.	Poor soft tissue contrast
4.	Not good for evaluating post-ganglionic plexus
5.	Intrinsic cord abnormality can be missed
6.	Cannot differentiate between preganglionic and postganglionic injury

Magnetic Resonance Imaging (MRI) and Magnetic Resonance Neurography (MRN)

In the year 1993, Filler and colleagues reported the first neurogram of a human nerve in situ. This was made possible by suppressing the signal from other structures so that the nerve appeared bright and stood out prominently against the dark background[17]. This technique is now utilised to visualize the peripheral nerves including the brachial and lumbosacral plexuses. It has many applications including imaging of nerves in trauma, entrapment neuropathies, neoplastic processes and inflammatory conditions which affect the peripheral nerve. Today MRI with MRN has emerged as the imaging modality of choice in evaluating patients with brachial plexus injuries, both in adults and children[18,19,20,21,22,23].

The MRN protocol includes a combination of two-dimensional (2D) and three-dimensional (3D) sequences. The T1-weighted (T1W) sequence is acquired in the axial and coronal planes. It enables assessment of the anatomy of the brachial plexus as well as its relationship to adjacent structures. T2-weighted (T2W) fat-saturated (FS) sequence is obtained in the axial plane. It allows us to assess the location and extent of the pathology. Short Tau Inversion Recovery (STIR) sequence is acquired in the sagittal plane. It helps us to see the plexus components in cross-section. 3D STIR SPACE (Sampling Perfection with Application Optimized Contrasts) sequence is obtained in the coronal plane. In this sequence, the plexus can be traced up to the terminal branches. It enables comparison with the opposite side. 3D T2 SPACE sequence is acquired in the sagittal plane focusing on the cervical spine. It can be used to assess intra-dural roots and myelogram-like images can be generated which are used to detect pseudomeningocoeles[15,24].

After trauma to the brachial plexus, patients are scanned after about 6 weeks so that edema and haemorrhage do not obscure relevant imaging findings[15].

On MRN study, imaging of the spinal nerves can reveal evidence of either pre-ganglionic injury or post-ganglionic injury or both. Edema or haemorrhage can often be found in the spinal cord in acute cases or myelomamlaciain case of a chronic injury. Edema appears hyperintense in T2W images while haemorrhage appears hypointense[6]. Failure to visualise the spinal nerves can be due to root avulsion from the spinal cord and there may be an associated pseudomeningocoele at the same level due to dural sheath laceration of the affected spinal nerve. The latter appears as a fluid collection which shows similar signal intensity to CSF and extends from the spinal canal into the neural foramina (Figs.6 and 7).

Pseudomeningoceles are an indirect evidence of root injury and have, conventionally, often been understood to be indicative of a root avulsion. This, however, may not always be true. Sometimes, the roots may not be avulsed and yet a pseudomeningocoele may be visualised on MRN due to root sheath laceration and vice versa. MR imaging has a sensitivity and diagnostic accuracy of >85% for root injuries[9,10,12,25]. There may or may not be signal intensity changes in paraspinal muscles due to denervation as muscles have a multi-segmental nerve supply[26].

If the injury is post-ganglionic and mild, there may only be slight nerve enlargement with T2 hyperintense signal. With more severe injury, there may be rupture with evidence of nerve discontinuity, collection at the site of rupture and distal retraction. Subsequently fibrosis may ensue. This will lead to clumping of nerves with deformed contour and interspersed hypointense signal in T2W images (Figs. 8 and 9).

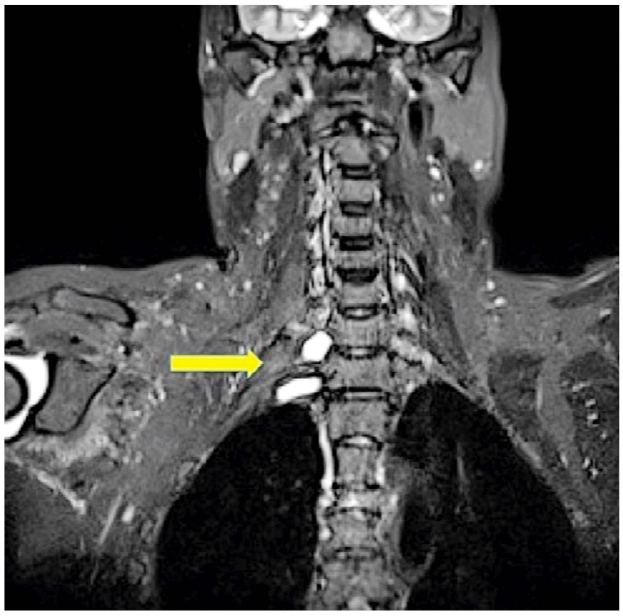

Fig. 6 MRN image in a patient with brachial plexus injury showing extra-dural fluid collections extending from the spinal canal into the right neural foramina at C8 and D1 levels, suggestive of pseudomeningocoeles.

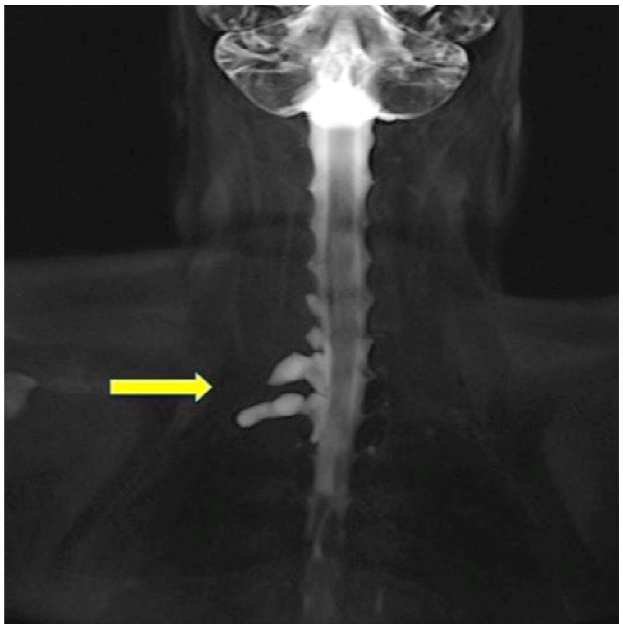

Fig.7 MR Myelogram image showing the pseudomeningocoeles at right C8 and D1 levels.

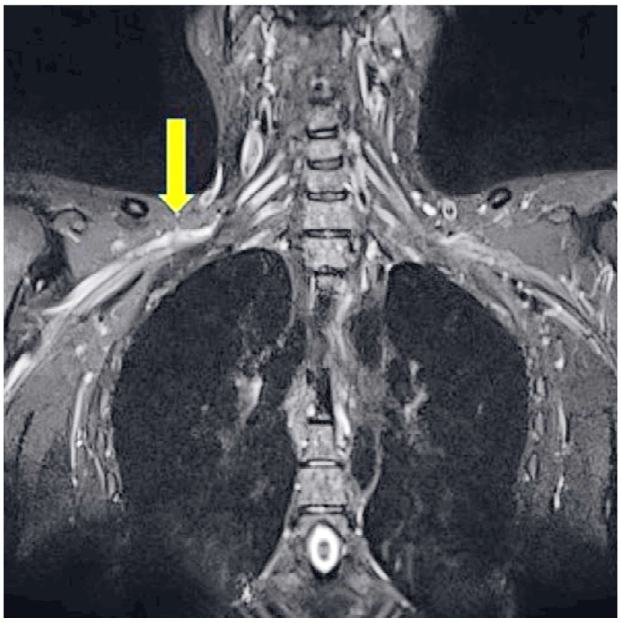

Fig. 8 Coronal 3D STIR SPACE image in a patient with right brachial plexus injury showing edema in the spinal nerves, trunks and cords with interspersed foci of low signal intensity due to fibrosis. The visualized plexus on the left side appears normal.

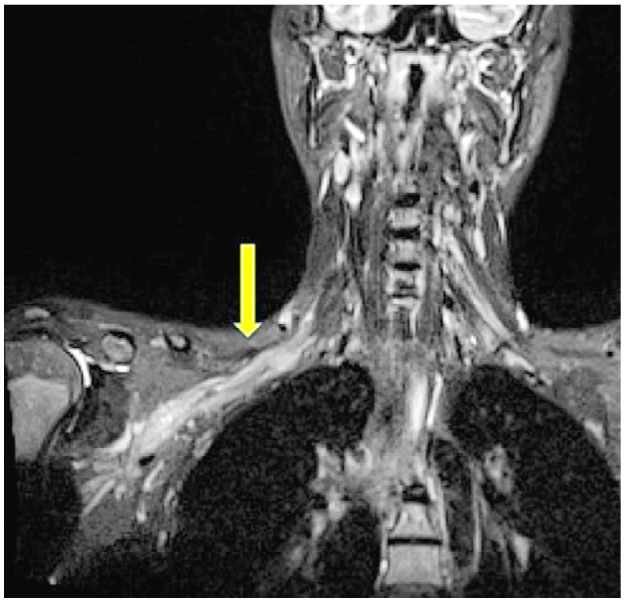

Fig. 9 Coronal 3D STIR SPACE image in a patient with right brachial plexus injury shows clumped and thickened trunks and cords with heterogeneous signal intensity due to scarring.

Both end-neuromas and neuromas-in-continuity can be seen. These appear as small nodular mass lesions either at nerve endings or along their course (Fig.10). Sometimes, the plexus can be compressed by displaced clavicular fractures and callus or haematoma associated with clavicular fracture (Fig.11). All these findings can be easily and accurately delineated in multiple planes used for the MRN study.

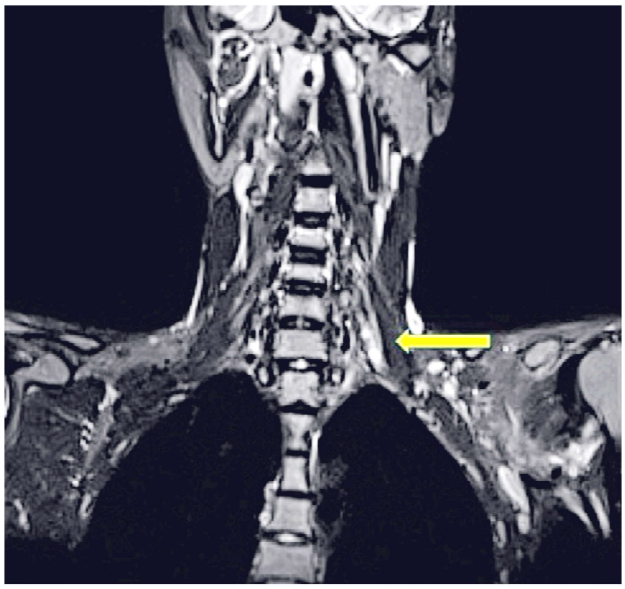

Fig. 10 Coronal 3D STIR SPACE image in a patient with left brachial plexus injury shows small nodular hyperintense mass lesions along the left C6 spinal nerve which are suggestive of neuromas.

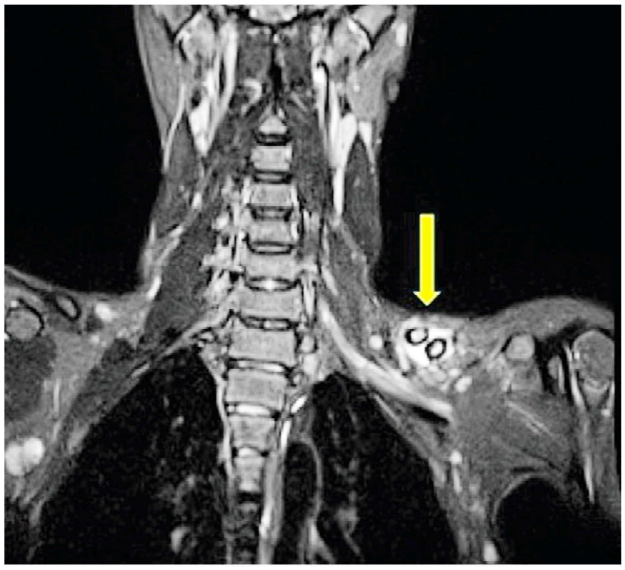

Fig. 11 Coronal 3D STIR SPACE image in a patient with left brachial plexus injury showing left clavicular fracture with an adjacent collection. The clavicular fragments are not causing extrinsic compression over the adjacent plexus.

The advantages of MRN are that it is non-invasive, multi-planar and does not expose patients to ionizing radiation as compared to CT Myelography. It has excellent soft tissue contrast and can beautifully assess the entire plexus, from the origin of the rootlets from

the spinal cord till the named terminal branches. Hence, it facilitates evaluation of both pre- and post-ganglionic injuries. This has an important bearing on patient management, surgical planning and prognostication[27,28].

The limitations of MRN are that it cannot be done in patients in whom MRI is contra-indicated such as those with pacemakers, cochlear implants etc. Young patients and those who are claustrophobic may need sedation. The MRN study has a time-taking protocol and usually takes about 30-40minutes to image one patient. Due to this, motion artefacts may impair image quality if patients are uncooperative. MRI is more expensive and less widely available as compared to US or CT (Table2).

Table 2: Advantages and Limitations of MR neurography

Advantages of MR Neurography	
1.	Multiplanar
2.	Non-invasive
3.	No radiation exposure
4.	Excellent soft tissue contrast
5.	Good visualization of both preganglionic and postganglionic plexus
6.	Can detect cord lesions such as edema or haematoma
7.	Can detect partial or complete root avulsions, pseudomeningocoeles, nerve edema, fibrosis/ scarring, disruption and neuromas
8.	High sensitivity and accuracy of >90% for root injuries
9.	Can differentiate between preganglionic and postganglionic injury
Limitations of MR Neurography	
1.	Cannot be done if MRI is contra-indicated such as in those patients with pacemakers or cochlear implants
2.	Cannot be done if patient is claustrophobic
3.	Time-consuming, so motion artifactsartefacts are a problem
4.	Costlier with lesser availability as compared to CT

A Diffusion-weighted (DW) sequence can be added to the MRN protocol. It helps to visualize the long course of the nerves of the plexus and can easily localize the site of injury in traumatic plexopathy. However, its limitations are that it cannot assess the preganglionic plexus and cervical nerves above C5 due to their small calibre and cerebrospinal fluid flow artifacts[29]. Recent development includes Diffusion Tensor Imaging (DTI) which can enable generation of tracts of nerve fibres. This technique is based on the fact that there is anisotropic diffusion of water molecules in nerve tracts in white matter[27,30,31,32]. However, DTI is time consuming as yet and not commonly in use in routine clinical practice.

Conclusion

In patients with traumatic brachial plexopathy, after the initial radiographs have been acquired, MRN is the next study which needs to be done after a gap of about 6 weeks. In case the MRN study is not possible, other options include high resolution US or CT Myelography. Either of these can be done depending upon the clinical situation and the assessment of the brachial plexus surgeon.

References

1. Moran SL, Steinmann SP, Shin AY. Adult brachial plexus injuries: Mechanism, patterns of injury, and physical diagnosis. Hand Clin 2005;21: 13-24.
2. Lapegue F, Faruch-Bilfeld M, Demondion X, Apredoaei C, Bayol MA, Artico H, et al. Ultrasonography of the brachial plexus, normal appearance and practical applications. Diagn Interv Imaging 2014; 95: 259-75.
3. Graif M, Martinoli C, Rochkind S, Blank A, Trejo L, Weiss J, et al. Sonographic evaluation of brachial plexus pathology. Eur Radiol 2004; 14: 193-200.
4. Haber HP, Sinis N, Haerle M, Schaller HE. Sonography of Brachial Plexus Traction Injuries. AJR 2006; 186: 1787-91.
5. Zhu YS, Mu NN, Zheng MJ, Zhang YC, Feng H, Cong R, et al. High-Resolution Ultrasonography for the diagnosis of Brachial Plexus root lesions. Ultrasound in Med. & Biol 2014; 40: 1420-6.
6. Yoshikawa T, Hayashi N, Yamamoto S, Tajiri Y, Yoshioka N, Masumoto T, et al. Brachial plexus injury: Clinical Manifestations, Conventional Imaging Findings, and the Latest Imaging Techniques. Radiographics 2006; 26: s133-143.
7. Rankine JJ. Adult traumatic brachial plexus injury. Clin Radiol 2004; 59: 767-74.
8. Carvalho GA, Nikkhah G, Matthies C, Penkert G, Samii M. Diagnosis of root avulsions in traumatic brachial plexus injuries: value of computerized tomography myelography and magnetic resonance imaging. J Neurosurg 1997; 86:69-76.
9. Abul-Kasim K, Backman C, Bjorkman A, Dahlin LB. Advanced radiological work-up as an adjunct to decision in early reconstructive surgery in brachial plexus injuries. J Brachial Plex Peripher Nerve Inj 2010; 5: 14.

10. Doi K, Otsuka K, Okamoto Y, Fujii H, Hattori Y, Baliarsing AS. Cervical nerve root avulsion in brachial plexus injuries: magnetic resonance imaging classification and comparison with myelography and computerized tomography myelography. J Neurosurg 2002; 96: 277-84.
11. Yamazaki H, Doi K, Hattori Y, Sakamoto S. Computerized tomography myelography with coronal and oblique coronal view for diagnosis of nerve root avulsion in brachial plexus injury. J Brachial Plex Peripher Nerve Inj 2007; 2:16.
12. Bowen BC, Pattany PM, Saraf-Lavi E, Maravilla KR. The brachial plexus: normal anatomy, pathology, and MR imaging. Neuroimag Clin N Am 2004; 14: 59-85.
13. Tse R, Nixon JN, Iyer RS, Kuhlman-Wood KA, Ishak GE. The Diagnostic Value of CT Myelography, MR Myelography, and Both in Neonatal Brachial Plexus Palsy. AJNR Am J Neuroradiol 2014; 35: 1425-32.
14. Amrami KK, Port JD. Imaging the brachial plexus. Hand Clin 2005; 21: 25-37.
15. Upadhyaya V, Upadhyaya DN, Kumar A, Pandey AK, Gujral R, Singh AK. Magnetic resonance neurography of the brachial plexus. Indian J Plast Surg2015; 48: 129-37.
16. Delman BN, Som PM. Imaging of the brachial plexus. In: Som PM, Curtin HD, editors. Head and Neck Imaging. 5th ed. St Louis: Elsevier Mosby; 2011.pp 2743-70.
17. Filler AG, Howe FA, Hayes CE, Kliot M, Winn HR, Bell BA, et al. Magnetic resonance neurography. Lancet 1993; 341: 659-61.
18. Filler A. MR Neurography and Diffusion Tensor Imaging: Origins, History & Clinical Impact of the first 50,000 cases with an Assessment of Efficacy and Utility in a prospective 5,000 Patient Study Group. Neurosurgery 2009; 65: A29-A43.
19. Filler AG, Kliot M, Howe FA, Hayes CE, Saunders DE, Goodkin R, et al. Application of magnetic resonance neurography in the evaluation of patients with peripheral nerve pathology. J Neurosurg1996; 85: 299-309.
20. Grant GA, Goodkin R, Maravilla KR, Kliot M. MR neurography: diagnostic utility in the surgical treatment of peripheral nerve disorders. Neuroimag Clin N Am 2004; 14: 115-33.
21. Vargas MI, Viallon M, Nguyen D, Beaulieu JY, Delavelle J, Becker M. New approaches in imaging of the brachial plexus. Eur J Radiol 2010; 74: 403-10.
22. Upadhyaya V, Upadhyaya DN, Kumar A, Gujral RB. MR neurography in traumatic brachial plexopathy. Eur J Radiol 2015; 84: 927-32.
23. Upadhyaya V, Upadhyaya DN, Mishra B. MR neurography in traumatic, non-obstetric paediatric brachial plexopathy. Eur Radiol 2018;28(6):2417-2424.
24. Chhabra A, Thawait GK, Soldatos T, Thakkar RS, Del Grande F, Chalian M, et al. High-resolution 3T MR neurography of the brachial plexus and its branches, with emphasis on 3D imaging. AJNR Am J Neuroradiol 2013; 34: 486-97.
25. Gasparotti R, Ferraresi S, Pinelli L, Crispino M, Pavia M, Bonetti M, et al. Three-dimensional MR Myelography of Traumatic Injuries of the Brachial Plexus. AJNR Am J Neuroradiol 1997; 18: 1733-42.
26. Aralasmak A, Karaali K, Cevikol C, Uysal H, Senol U. MR imaging findings in brachial plexopathy with thoracic outlet syndrome. AJNR Am J Neuroradiol2010; 31: 410-7.
27. Mallouhi A, Marik W, Prayer D, Kainberger F, Bodner G, Kasprian G. 3T MR tomography of the brachial plexus: Structural and microstructural evaluation. Eur J Radiol 2012; 81: 2231-45.
28. Lutz AM, Gold G, Beaulieu C. MR Imaging of the Brachial Plexus. Neuroimag Clin N Am 2014; 24: 91-108.
29. Takahara T, Hendrikse J, Yamashita T, Mali WPTM, Kwee TC, Imai Y, et al. Diffusion-weighted MR Neurography of the Brachial Plexus: Feasibility Study. Radiology 2008; 249: 653-60.
30. Chhabra A, Zhao L, Carrino JA, Trueblood E, Koceski S, Shteriev F, et al. MR Neurography: Advances. Radiol Res Pract 2013; 2013: 809568.
31. Gasparotti R, Lodoli G, Meoded A, Carletti F, Garozzo D, Ferraresi S. Feasibility of diffusion tensor tractography of brachial plexus injuries at 1.5T. Invest Radiol 2013; 48: 104-12.
32. Tagliafico A, Calabrese M, Puntoni M, Pace D, Baio G, Neumaier CE, et al. Brachial plexus MR imaging: accuracy and reproducilbility of DTI-derived measurements and fibre tractography at 3.0-T. Eur Radiol2011; 21: 1764-71.