Pictorial Review

Imaging in peripheral neuropathy: Ultrasound and MRI

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ABSTRACT

Peripheral neuropathy (PN) can be due to either entrapment or other causes such as trauma, infection, inflammation, and mass lesions. Evaluation of peripheral nerves was previously limited to history, clinical examination, and electrodiagnostic tests. However, now, with advances in imaging, both ultrasound (US) and magnetic resonance imaging (MRI) enable excellent evaluation of the peripheral nerves. US can be used for preliminary imaging of patients with PN and MRI can be done if US results are inadequate or equivocal.

Keywords: Ultrasound, Magnetic resonance imaging, Peripheral nerves, Peripheral neuropathies

INTRODUCTION

Conventionally, peripheral nerves have been evaluated using a combination of history, clinical examination and electrodiagnostic tests, which include nerve conduction velocity and electromyography. However, they have certain limitations which include their invasive nature, operator dependence, inability to identify the cause of nerve pathology, and inability to assess the relationship of the nerve to its surrounding structures.[1]

In recent times, however, significant advancements in ultrasound (US) and magnetic resonance imaging (MRI) have revolutionized the evaluation of patients with peripheral neuropathy (PN). It is now possible to visualize a peripheral nerve throughout its course, evaluate it for changes in morphology and internal characteristics (echotexture on US/signal intensity on MRI), compare it with the contralateral side, and document denervation changes in the muscles innervated by the nerve that is assessed. This has facilitated early diagnosis, and optimum management of patients, and helped alleviate their symptoms.

US is an excellent modality for imaging the peripheral nerves. It is non-invasive, cheap, and widely available. It has excellent spatial resolution, enables dynamic assessment and tracing of the entire nerve, and comparison with the contralateral side. US can be done in those patients in whom MRI is contra-indicated.[2,3] Operator-dependence remains an important limitation of this modality. Other drawbacks include difficulty in assessing those nerves which are deep to bony structures and suboptimal visualization in the presence of scarring [Table 1].

MRI with its high contrast resolution, multiplanar imaging capabilities, and non-invasive nature enables excellent visualization of the peripheral nerves. Deep seated nerves in the pelvis and upper thigh are best imaged by MRI. It enables simultaneous evaluation of adjacent bones and soft tissues. Both acute and chronic denervation changes in the innervated muscles can be easily

identified on MRI.[1,4] Its limitations, however, include its high cost, limited availability as compared to US, and the longer time needed to complete the examination. Moreover, it cannot be done in patients with pacemakers and cochlear implants, or those who are claustrophobic [Table 2].

Both US and MRI have their advantages and limitations, and thus they should be considered as complementary investigations which can help the physician achieve the ultimate aim of establishing a correct diagnosis and facilitating patient management. An essential prerequisite for nerve imaging by both these modalities is a thorough knowledge of anatomy of the peripheral nerves including their superficial and deep cutaneous branches. Radiologists should have a clear understanding of which modality may be appropriate in a particular case scenario. The aim of this

pictorial review is to demonstrate to the reader the wonderful spectrum of nerve pathologies by both US and MRI.

DISCUSSION

Technical aspects and normal appearance of peripheral nerves

For US of the peripheral nerves, a linear-array transducer of high frequency is used. A transducer of 5–17 MHz (up to 23MHz) can be used for evaluating superficial nerves while a transducer of 5–12 MHz can be used for deeper nerves. A normal nerve has a honeycomb appearance in transverse section which is due to hypoechoic nerve fascicles against a background of echogenic connective tissue, which includes endoneurium and perineurium [Figure 1a]. The margins of the nerve also appear echogenic due to the presence of epineurium. When compared to the adjacent structures, nerves are more echogenic than muscles but lesser so than tendons [Figure 1b]. Sound knowledge of the local anatomy and relation of nerves to the adjacent bony, muscular and vascular landmarks enables them to be traced along their course, and imaged in the transverse and longitudinal axis. Most of the peripheral nerves can be assessed well by US except for those which are deep-seated or subjacent to bones, such as the roots of the brachial plexus, retroclavicular brachial plexus, lumbosacral plexus, and sciatic nerve in the pelvis and upper thigh.[3,5-7]

An evaluation of peripheral nerves by MRI uses a combination of two and three-dimensional T1-weighted (T1W) and fluid-sensitive sequences such as T2-weighted (T2W) with fat saturation or short tau inversion recovery (STIR), which is known as magnetic resonance neurography (MRN). Three-dimensional sequences such as 3D T2W sampling perfection with application optimized contrasts using varying flip angle evolutions (SPACE) and 3D STIR SPACE are part of the evaluation of the brachial and lumbosacral plexuses. These high-resolution sequences enable excellent visualization of the entire plexus and facilitate detection of the site and extent of pathology. A normal nerve demonstrates signal intensity
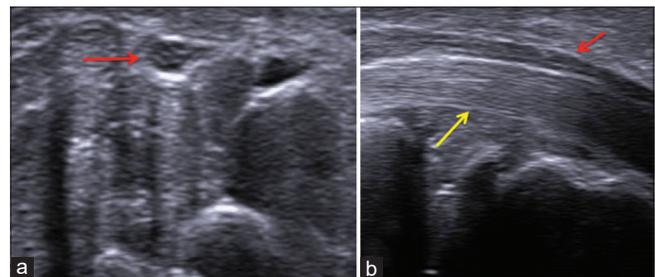
Table 1: Advantages and limitations of US.

Advantages	Limitations
Cost effective	Operator dependent
Widely available	Steep learning curve
High spatial resolution	Difficult to assess deep seated nerves or those subjacent to bones
Dynamic imaging	Limited by dense scarring and calcification
Lesser scan time	Decreased reproducibility of findings as compared to MRI
Comparison with contralateral side	
Can guide interventional procedures	
Can be done when MRI is contra-indicated or limited by susceptibility artifacts	
Detection of multifocal disease	

US: Ultrasound, MRI: Magnetic resonance imaging

Table 2: Advantages and limitations of MRI.

Advantages	Limitations
Shallow learning curve	Expensive
High contrast resolution	Limited availability
Increased reproducibility of findings as compared to US	Longer scan time
Evaluation of deep seated nerves	Limited area of scan
Simultaneous assessment of bones and soft tissues	Contra-indicated in patients with pacemakers, cochlear implants
Denervation changes in muscles	Limited utility in the presence of foreign bodies, metal, or hemorrhage
Post-surgical evaluation	

MRI: Magnetic resonance imaging, US: Ultrasound

Figure 1: Transverse axis US image (a) and longitudinal axis US image (b) at the level of the wrist joint showing the median nerve (red arrows). The nerve has a honeycomb appearance in (a) and appears less echogenic than flexor tendons (yellow arrow) in (b).

similar to muscle on T1W images and appears similar to or mildly hyperintense to muscle on T2W images, due to the intra-fascicular endoneurial fluid [Figure 2a and b]. The fascicular appearance is seen both on T1W and T2W images. The margins of the nerve are smooth with maintained perineural fat planes. The MRN study may be supplemented by intravenous gadolinium-based contrast in cases where there is suspicion of a mass lesion or inflammation/infection. This enables superior detection of pathology as normal nerves do not enhance with contrast.[8,9]

Newer US and MRI techniques in the diagnosis of PN include elastography and diffusion tensor imaging (DTI), respectively. US elastography can detect neuropathy according to differences in nerve stiffness and DTI can provide functional information about nerve regeneration. However, these techniques are not yet incorporated into routine clinical practice. Further discussion about these techniques is beyond the scope of this article. At present, there is no role of US contrast in nerve imaging.

Clinical applications

PN can be classified as either entrapment neuropathy due to nerve compression, or non-entrapment neuropathy which can be due to trauma, infection, inflammation, or mass lesions.[10] Both US and MRI enable localization of the site of the pathology, identify the cause and extent of nerve involvement and visualize changes in the innervated muscles.[11,12] Together, US and MRI are instrumental in facilitating diagnosis and management of patients with peripheral neuropathies.

Entrapment neuropathy

Nerves are prone to compression as they pass through myofascial planes, or travel through confined spaces such as fibro-osseous or fibromuscular tunnels, close to a joint. Enlargement of the contents of the tunnel due to tumor, edema, hematoma, or repetitive muscle contraction can result in further narrowing of these spaces, leading to nerve compression. Common sites of entrapment include the
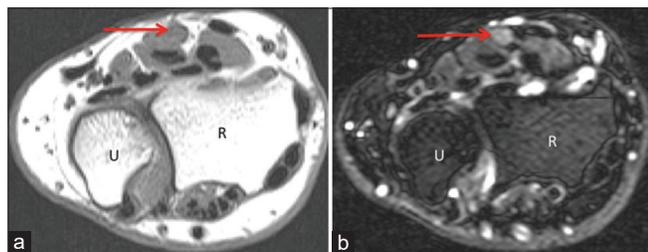

Figure 2: Axial T1W image (a) and axial T2W fat saturated image (b) at the level of distal radio-ulnar joint (R-radius, U-ulna) showing the median nerve anteriorly (red arrows). The median nerve appears isointense to muscle in (a) and mildly hyperintense in (b).

carpal tunnel for the median nerve, and the cubital tunnel for the ulnar nerve. Compression of the nerve impairs venous return resulting in swelling of the nerve with development of ischemia and when this sequence of events occurs repeatedly, it leads to progressive nerve damage.[13]

In entrapment neuropathy, the aim of imaging is to confirm the clinical diagnosis, visualize the site of compression, and identify the cause of the compression. This compression may be from a ganglion cyst, tumor, tenosynovitis, bony lesion, fracture/dislocation, fibrous band, or an anomalous muscle. On US, the entrapped nerve appears hypoechoic with loss of the fascicular pattern indicative of edematous intraneural changes. It demonstrates increased vascularity on color Doppler and enlargement of the nerve proximal to the site of compression. This change in nerve caliber can be ascertained by measurement of the cross-sectional area (CSA) [Figures 3-7]. US has high spatial resolution, enables dynamic evaluation of the nerve and quick comparison with the opposite side. With time, denervation changes are seen in muscles innervated by the nerve. These denervation changes
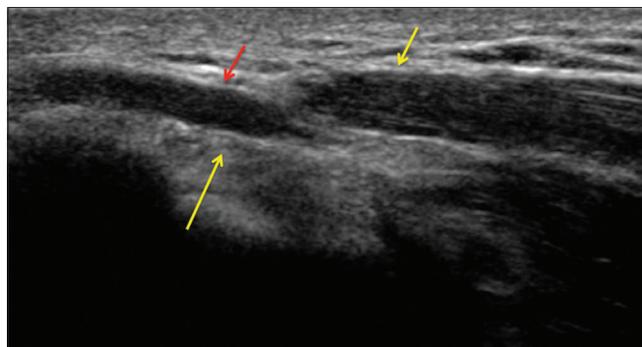

Figure 3: Longitudinal axis US image showing compression of the ulnar nerve with proximal enlargement (red arrow) between the two heads of the flexor carpi ulnaris (yellow arrows).
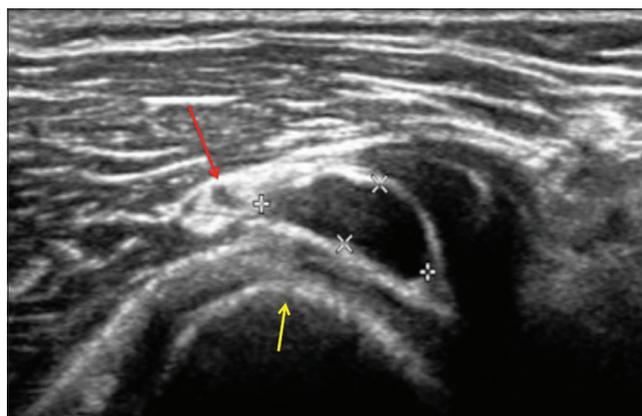

Figure 4: Longitudinal axis US image at the level of the radial head (yellow arrow) showing compression of the posterior interosseous nerve (red arrow) by a ganglionic cyst arising from the radiocapitellar joint (marked by calipers).

result in hyperechogenicity of the muscles with decreased muscle bulk.[4,14]

On MRI, the affected nerves show changes in both morphology and signal intensity. There is flattening of the nerve at the site of entrapment and proximal enlargement. In severe cases, the nerve shows hypointense signal on T2W images at the site of entrapment and hyperintense signal, both proximally and distally. There is loss of the fascicular appearance and perineural fat can be effaced [Figure 8a and b]. MRI along the long axis of the nerve demonstrates the site of entrapment and changes at this level.[8,15] The muscles innervated by the affected nerve demonstrate denervation edema in the acute phase, and fatty infiltration with atrophy in the chronic phase.

Traumatic neuropathy

Peripheral nerves can be injured by various mechanisms. The most common of these is the crush-avulsion type of blunt injury sustained during road traffic accidents, fall from height or compression by a heavy object. Another mechanism of nerve injury is the traction injury when a nerve is stretched beyond its capability such as in Erb palsy, or with fractures of the extremities, where nerves course in close proximity to the bony fragments. Nerves can also suffer transection injuries leading to nerve discontinuity caused due to sharp objects such as a knife, glass fragments, or bullets.[16-19]

Sir Seddon in 1943 classified nerve injuries into three types which include neurapraxia, axonotmesis, and neurotmesis. In neurapraxia, a conduction block occurs at the site of injury but there is no structural damage. Recovery is spontaneous and takes about 12 weeks. In axonotmesis, the axon is injured but the perineurium and epineurium are spared. There is lack of conduction distal to the injury site but recovery occurs slowly with time. In neurotmesis, the entire nerve and connective tissue layers are ruptured with loss of continuity and hence, spontaneous recovery is not possible.
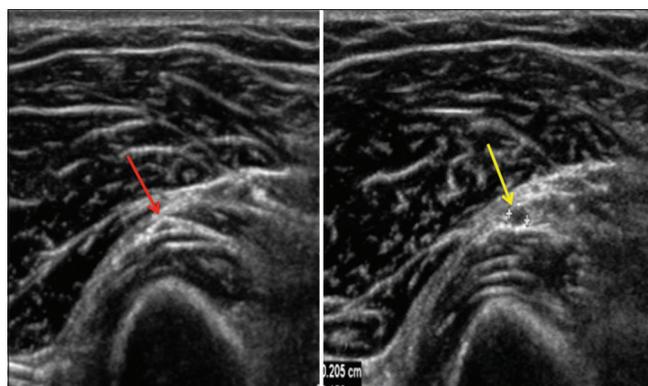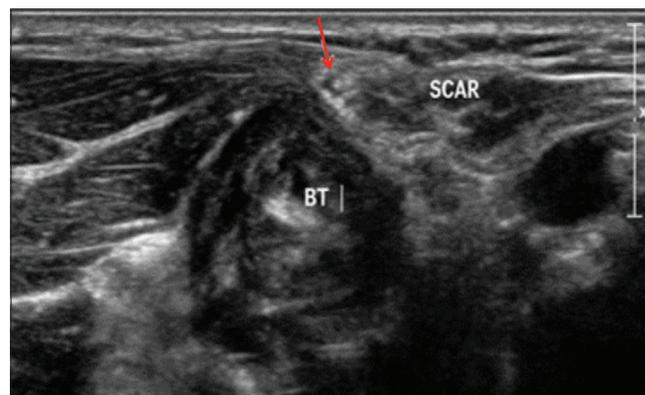

Figure 5: Transverse axis US images showing compression of the posterior interosseous nerve as it passes through the supinator fascia (red arrow) with proximal enlargement (yellow arrow).

Figure 7: US image at the level of right elbow joint showing scar tissue after biceps tendon (BT) repair which is adherent to the lateral antebrachial cutaneous nerve (red arrow) causing nerve thickening and clinical neuropathy.
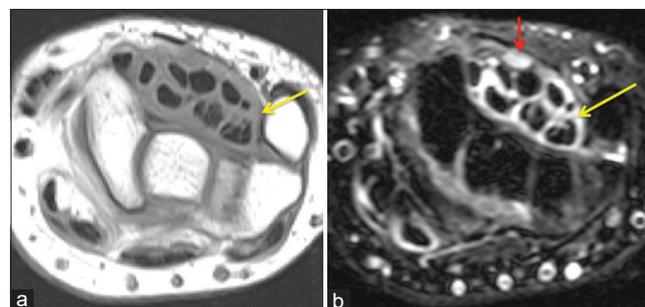

Figure 6: Transverse axis US image showing the enlarged left lateral femoral cutaneous nerve (red arrow) due to impingement by the inguinal ligament.

Figure 8: Axial T1W image (a) at the level of the carpal tunnel shows intermediate signal intensity around the flexor tendons and axial T2W fat saturated image (b) showing hyperintense signal suggestive of tenosynovitis (yellow arrow). In the axial T2W image (b), the median nerve is compressed and shows hyperintense signal (red arrow).

Another classification was given by Sir Sunderland in 1951. As per this classification, nerve injuries are classified into five types. Type I is similar to neurapraxia and type II is similar to axonotmesis. In Types III, IV, and V, there is increasing degree of connective tissue injury with involvement of the endoneurium, perineurium and epineurium respectively. Type V injury is similar to neurotmesis in the Seddon classification. Type IV and V injuries result in formation of neuroma in continuity and proximal end-bulb neuroma respectively. A mixed type of injury, type VI, was later added by Mackinnon.[20-22]

In nerve trauma, US can show enlarged hypoechoic nerves with effaced fascicular pattern. There will be loss of continuity in complete transection. A neuroma in continuity or end bulb neuroma can be seen in type IV and V injuries, respectively, as a focal hypoechoic soft-tissue lesion [Figure 9a and b]. The denervated muscles will show altered echogenicity.[23] In MRI, the traumatized nerves can appear enlarged with hyperintense signal on T2W images or show heterogeneous signal intensity. There can be fascicular enlargement, effacement or disruption [Figures 10 and 11]. A neuroma-in-continuity appears as a non-enhancing fusiform lesion with heterogeneous signal intensity. Denervated muscles will

Figure 9: Longitudinal axis US images of the forearm (a) and at the level of ankle joint (b) in two different patients showing transection injury of the median nerve and deep peroneal nerve with intervening scar tissue (yellow arrow) and neuromas of the proximal and distal stumps (red arrows).

Figure 10: Axial T2W fat saturated image (a) and Coronal 3D STIR SPACE image (b) in a child with history of right foot drop after an intra-muscular injection in right gluteal region two months back showing an enlarged and hyperintense right sciatic nerve (red arrows).

show changes in signal intensity and bulk, depending on the time of injury.[24]

Both US and MRI can effectively demonstrate the gap between separated nerve segments in case of complete nerve transection and this is important for surgical planning.[6,24] US can be especially useful in those cases when susceptibility artifacts due to hemorrhage, metal fragments, or foreign bodies are obscuring the injured nerve in MRI. However, MRI has the advantage of simultaneously assessing other osseous and soft-tissue injuries and findings are considered more reproducible than those of US in the literature.[25]

Infective neuropathy

Infective neuropathy can be caused by direct infiltration of the nerves by microbes, or indirectly due to inflammatory reactions evoked by them. These microorganisms include *Mycobacterium leprae*, hepatitis C virus, HIV, *Borrelia burgdorferi*, varicella zoster, and herpes simplex viruses.[26] Of these, Leprosy, which is a granulomatous infection caused by mycobacterium leprae is a common cause of PN in the Indian subcontinent.

Both US and MRI are suitable for evaluating the peripheral nerves of patients with leprosy. Imaging helps to assess deeper nerves which are difficult to examine clinically, assess disease severity and at follow-up to determine the patient's response to therapy.[27] Findings on US and MRI include thickening of the nerves, hypoechoic echotexture on US, and hyperintense signal on T2W MRI images, changes in the fascicular appearance or loss of the fascicular pattern, formation of microabscesses or larger abscesses with coalescence of smaller lesions, perineural inflammatory changes, and denervation changes in muscles [Figures 12 and 13].[27-29]
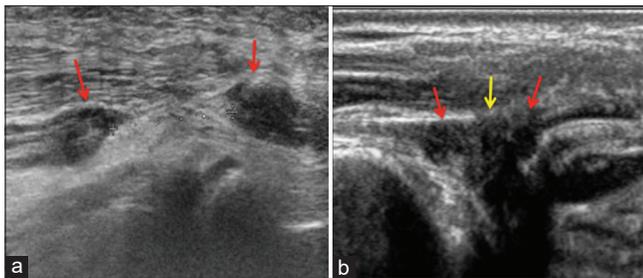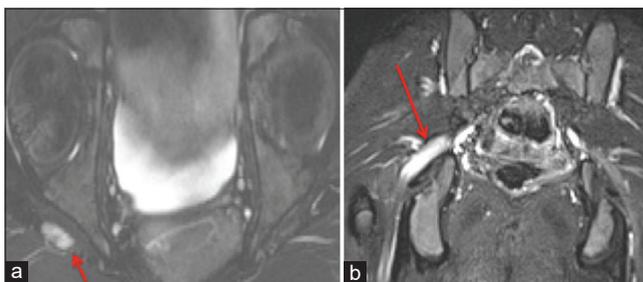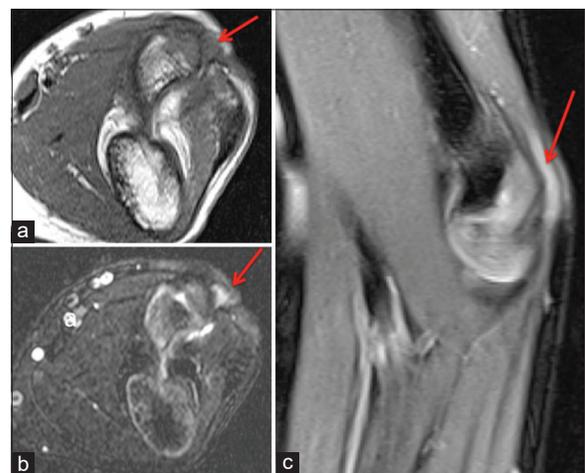

Figure 11: Axial T1W image (a), axial T2W fat saturated image (b) and sagittal PDW fat saturated image (c) in a child with history of operated supracondylar fracture three months back showing an enlarged ulnar nerve (red arrows) with hyperintense signal in (b) and (c), consistent with scarring.

Inflammatory and hereditary neuropathy

Chronic inflammatory demyelinating polyradiculoneuropathy (CIDP), multifocal motor neuropathy (MMN), and multifocal acquired demyelinating sensory and motor neuropathy (MADSAM), also known as Lewis-Sumner syndrome, are few immune-mediated neuropathies. Imaging can supplement the information provided by clinical evaluation and electrophysiological tests help to document the diagnosis and ensure appropriate management of these conditions.

In CIDP, MRI shows bilaterally symmetrical enlargement of the brachial plexus and lumbosacral plexus with hyperintense signal in fluid-sensitive sequences [Figure 14]. However, atypical variants can show bilaterally symmetrical or asymmetrical, extensive focal or diffuse involvement.[14] In MMN and MADSAM, both US and MRI show asymmetric fascicular enlargement with increase in the nerve CSA of the nerve, hyperintense signal on T2W images with post-contrast enhancement and increased vascularity.[30]

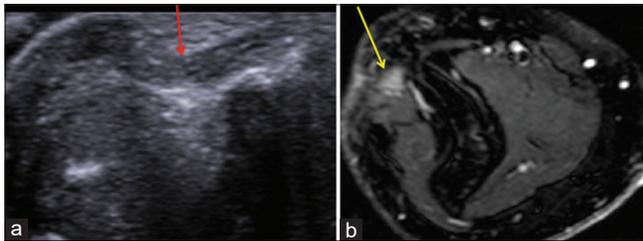Parsonage-Turner syndrome, also known as acute idiopathic brachial plexus neuritis refers to a condition in which there is weakness of the shoulder muscles preceded by neck or shoulder pain. MRI of the brachial plexus reveals unilatera, or bilateral asymmetrically enlarged nerves with hyperintense signal in fluid-sensitive sequences and denervation changes in the muscles [Figure 15]. The suprascapular nerve, superior trunk, axillary, and long thoracic nerves are frequently involved. The proximal plexus is involved more than the distal.[31]

Charcot-marie-tooth disease (CMT) and hereditary neuropathy with liability to pressure palsies (HNPP) are inherited disorders where the diagnosis is based on clinical evaluation, family history, electrophysiological tests, and genetic assessment. Depending on predominant involvement of the myelin sheath or axon, CMT can be classified as CMT1 or CMT2.[14] In CMT, MRI shows bilaterally symmetrical enlargement with hyperintense signal on fluid-sensitive sequences in the brachial plexus, lumbosacral plexus, and peripheral nerves. There is fascicular atrophy with increased fat deposition in the epineurium between the fascicles.[32] US can facilitate differentiation between CMT and HNPP as it can detect multiple sites of fascicular and nerve enlargement in the

Figure 12: Longitudinal axis US image (a) and axial T2W fat saturated image (b) in a patient with leprosy showing thickened hypoechoic right ulnar nerve (red arrow) and enlarged ulnar nerve with hyperintense fascicles (yellow arrow).
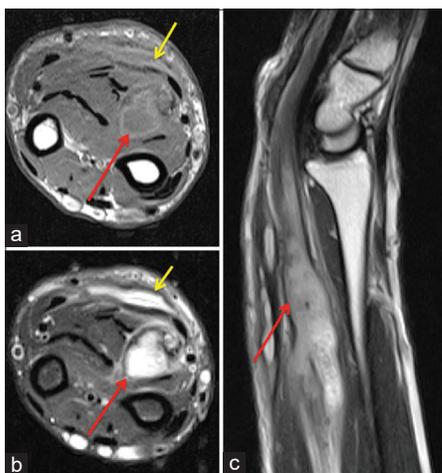

Figure 13: Axial T1W image (a), axial T2W fat saturated image (b) and sagittal T2W image (c) in a patient with leprosy showing a median nerve abscess (red arrows) in the distal forearm which has ruptured subcutaneously (yellow arrows).

Figure 14: Axial T2W image(a) and coronal 3D STIR SPACE image (b) in a patient of CIDP showing bilaterally symmetrical thickened lumbar nerve roots with hyperintense signal in (b) (red arrows).
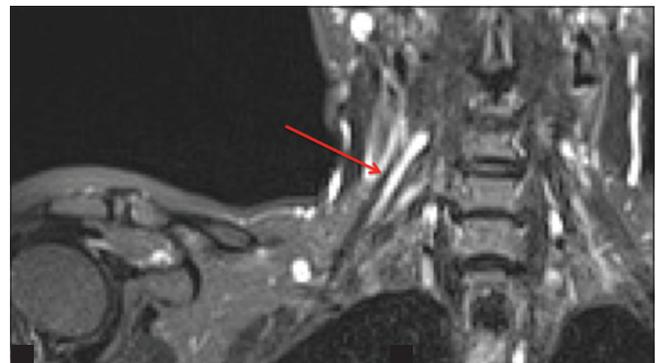

Figure 15: Coronal 3D STIR SPACE image in a patient with Parsonage-Turner syndrome showing mildly enlarged and hyperintense right C5 and C6 spinal nerves (red arrows).

former while these changes are seen at entrapment sites in the latter.[14]

Mass lesions

Common benign tumors which arise from the nerve sheath include schwannomas and neurofibromas. In schwannomas, growth occurs within the epineurium and they appear as eccentric mass lesions which displace fascicles. This enables surgical resection without functional deficit. However, neurofibromas tend to incorporate the nerve, so nerve grafting is needed after excision to prevent functional deficit.[8,33] Schwannomas and the localized type of neurofibromas are commonly single. Other types of neurofibromas include the diffuse and plexiform neurofibromas and the latter is considered pathognomonic for neurofibromatosis type 1.[34]

Benign peripheral nerve sheath tumors (PNSTs) appear as well-defined fusiform mass lesions in US and MRI. In lesions involving larger nerves, the nerve can be seen entering into and exiting from the mass indicating the origin of the mass. On US, the lesion appears hypoechoic with internal vascularity and on MRI, the lesion demonstrates signal intensity similar to muscle on T1W images and appears hyperintense on T2W images [Figures 16 and 17]. Other useful imaging signs described for these tumors include "target sign," "split-fat sign," and the "fascicular sign."[34,35]

Diffuse neurofibromas show plaque such as infiltrative or mixed patterns and involve the skin, subcutaneous fat and deep fascia. They appear iso to mildly hyperintense to muscle on T1W images and hyperintense on T2W images with intense post-contrast enhancement [Figure 18a and b].[36]

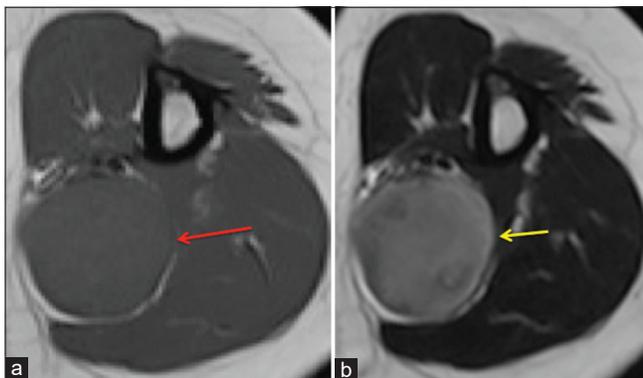The possibility of a malignant PNST arises with increase in lesion size-more than 5 cm, ill-defined margins, heterogenous echotexture, signal intensity with necrosis, and infiltration of adjacent structures [Figure 19a and b]. Using information from both conventional and functional MRI, Demehri *et al.* suggested that a malignant PNST was unlikely if the average tumor diameter was <4.2 cm and it showed a minimum apparent diffusion coefficient value of $\geq 1.0 \times 10^{-3}$ mm^2/s.[37]

A neural fibrolipomatous hamartoma is a benign lesion where there is extensive fatty infiltration in the connective tissue around the fascicles along with fibrotic changes in the perineurium and epineurium.[38] The majority of cases are seen in the median nerve but involvement of other nerves such as radial, ulnar, peroneal as well as brachial plexus has

Figure 17: Sagittal T2W image (a) and coronal STIR image (b) of the same patient as Figure 16 showing continuity of the mass with the ulnar nerve (red arrows).

Figure 16: In a proven case of ulnar nerve schwannoma, axial T1W image (a) shows a well defined ovoid mass lesion in the medial aspect of upper left arm which is isointense to muscle (red arrow) and in axial T2W image (b) the mass appears heterogenously hyperintense (yellow arrow).

Figure 18: Sagittal pre-contrast T1W image (a) and post-contrast T1W image (b) in a young girl with Neurofibromatosis type 1 showing an avidly enhancing mass lesion in the skin, subcutaneous fat plane and deep fascia (yellow arrows) which was proven to be a diffuse neurofibroma.

been reported. US shows an enlarged nerve with abundant echogenic fatty tissue separating the hypoechoic fascicles [Figure 20a and b].[33] MRI reveals an enlarged nerve with thickened hypointense fascicles on T1W and T2W images surrounded by extensive fat which is hyperintense on T1W images and hypointense on T2W images [Figure 21a and b]. This appearance of neural fibrolipomatous hamartoma has been likened to that of a coaxial cable in axial images and is not seen in other neural disorders.[39]

Both US and MRI enable accurate visualization and facilitate surgical planning of intraneural ganglion cysts. These cysts arise due to extension of joint fluid into an articular nerve branch following capsular damage. The common peroneal nerve is a common site where fluid extends along the epineurium from the proximal tibio-fibular joint.[40] According to their location, intraneural ganglion cysts can be classified as intrafascicular cysts, and extrafascicular or epineural cysts. Surgical resection of the extrafascicular cysts is easier as the nerve fascicles are spared.[41] On US, ganglion cysts can appear as anechoic multiloculated fluid collections or as heterogeneous hypoechoic lesions adjacent to nerves and in MRI, they demonstrate T1 hypointense and T2 hyperintense signal [Figure 22].[8,35]

Morton's neuroma is a not actually a neuroma but represents perineural fibrosis occurring in a plantar digital nerve due to chronic nerve compression against the intermetatarsal ligament, commonly seen in the second and third intermetatarsal spaces.[35] US shows a well-defined hypoechoic mass lesion in the intermetatarsal space [Figure 23]. On T1W MR images, the lesion appears hypointense to adjacent fat and on T2W images, it appears hypointense to mildly hyperintense.[35,42]
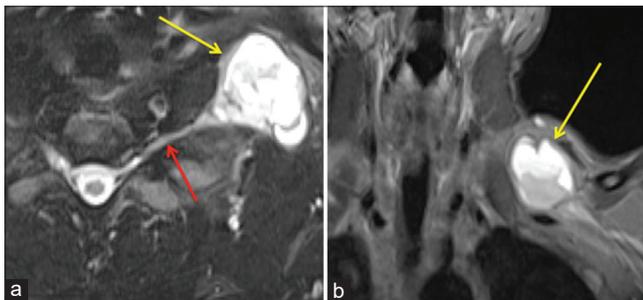

Figure 19: Axial T2W fat saturated image (a) and Coronal 3D STIR SPACE image (b) in a patient with proven malignant PNST showing a lobulated heterogenous mass lesion (yellow arrows) involving the left C6 spinal nerve (red arrow) and upper trunk.
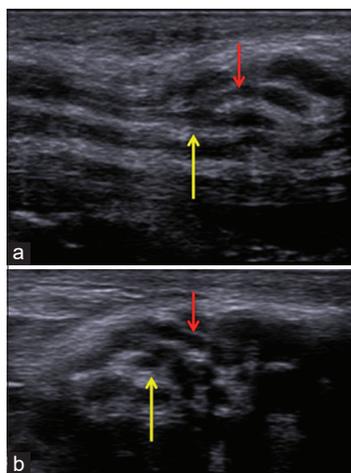

Figure 21: Axial T1W image (a) and Sagittal T1W image (b) of the same patient as Figure 20 showing the grossly enlarged median nerve with hypointense fascicles (red arrows) surrounded by fat (yellow arrow), consistent with fibrolipomatous hamartoma.

Figure 20: Longitudinal axis (a) and transverse axis (b) US images showing a grossly enlarged median nerve in distal forearm and hand with hypoechoic fascicles (red arrows) surrounded by fat (yellow arrows), suggestive of fibrolipomatous hamartoma.
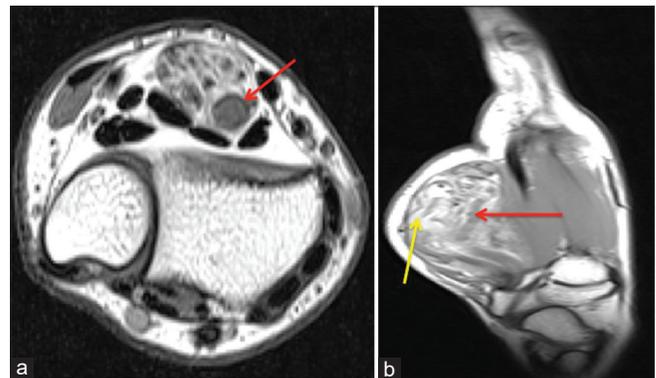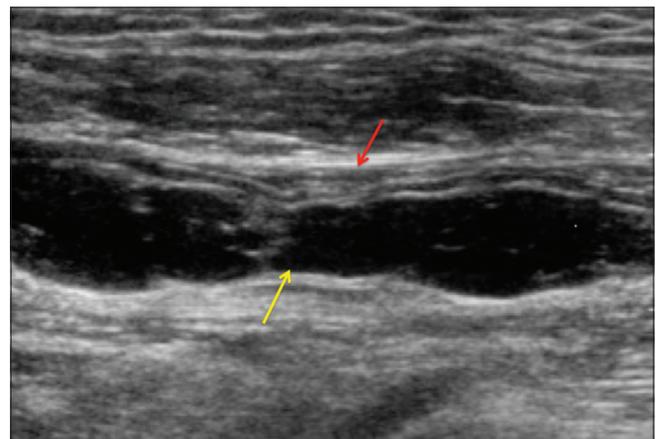

Figure 22: Longitudinal axis US image in a patient with intraneural extrafascicular or epineural ganglion cyst showing an elongated cystic lesion (yellow arrow) along the ulnar nerve (red arrow) in proximal forearm.
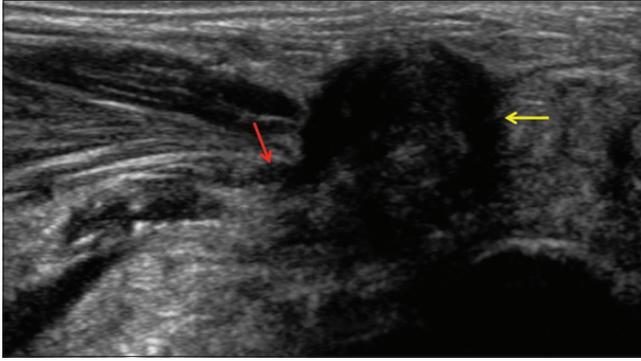
Figure 23: US image in a patient with Morton's neuroma showing a well defined hypoechoic mass lesion in the right second intermetatarsal space (yellow arrow) which is in continuity with the plantar digital nerve (red arrow).

CONCLUSION

Both US and MRI are excellent modalities for imaging of the peripheral nerves. They are able to delineate the site of disease, assess its severity, identify the cause of neuropathy and also monitor response to therapy. Hence, they have enabled timely diagnosis and management of these patients and improved their quality of life. US with its easy availability, cost effectiveness and good spatial resolution can be used as the preliminary modality to evaluate these patients. MRI with its superior contrast resolution and ability to assess deep seated nerves can be used in cases where US results are inadequate or equivocal and when additional information about the adjacent osseous, vascular, and soft-tissue structures is necessary.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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