IMAGING TECHNIQUES FOR PERIPHERAL NERVE COMPRESSIONS

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INTRODUCTION

The development of ultrasonography (US) and magnetic resonance imaging (MRI), which provide high-resolution images of soft tissues, has made it possible to apply diagnostic imaging to the study of peripheral nerves. Thus, the imaging diagnosis of compressive neuropathies has developed significantly in the last 15 years, allowing the evaluation of millimeter-sized nerves. We will review the role of imaging methods in compressive neuropathies, demonstrating their main applications.

IMAGING TECHNIQUES

MRI

MR neurography enables visualization of the peripheral nerve anatomy, contours, fascicular arrangement, signal, and caliber, as well as alterations of these features[1]. In neuropathies, the nerve remains isointense on T1-weighted images but is hyperintense relative to muscle on fluid-sensitive sequences due to increased endoneurial free water. The nerve may appear fusiform or present focal thickening that is usually proximal or at the level of compression, although nerve compression may not necessarily demonstrate morphologic or signal changes, despite clinical evidence of neuropathy. The injured nerve may also present distortion of the normal fascicular architecture (Figure 1) [2].

Signal abnormalities in denervated muscles may be demonstrated. In acute denervation, prolongation of T2 relaxation times can occur as early as 4 days after nerve injury and present as high-signal intensity on fluid-sensitive sequences (Figure 2). Chronic denervation may lead to atrophy and fat replacement of the muscles, optimally seen on T1-weighted images (Figure 3) [3].

Ultrasound

On US, it is possible to see hypoechoic fascicles surrounded by hyperechoic joint tissue and collagen (epineurium). The set of fascicles has another thin layer that surrounds them, also hyperechoic, which consists of the perineurium. On the longitudinal plane, a wavy appearance is observed, with multiple parallel hypoechoic bands (fascicles/bundles) separated by hyperechoic lines (perineurium) (Figure 4).

US can be used to detect and demonstrate the site and cause of compression. The main US findings are thickening of the nerves in the fibrous tunnels and an abrupt change in caliber, in addition to hypoechogenicity and loss of the fascicular pattern (Figure 5). In a dynamic examination, there is a reduction in sliding movement in some cases, and eventually, comparison with the corresponding contralateral nerve can help in detecting more subtle signs[4].

However, it must be remembered that a normal nerve appearance does not exclude the diagnosis of neuropathy.

COMPRESSIVE NEUROPATHIES

There are anatomical regions in which segments of peripheral nerves are vulnerable or predisposed to becoming trapped or suffering chronic compression. Neural compression occurs especially in osseofibrous tunnels, but it can occur at points where the peripheral nerve passes

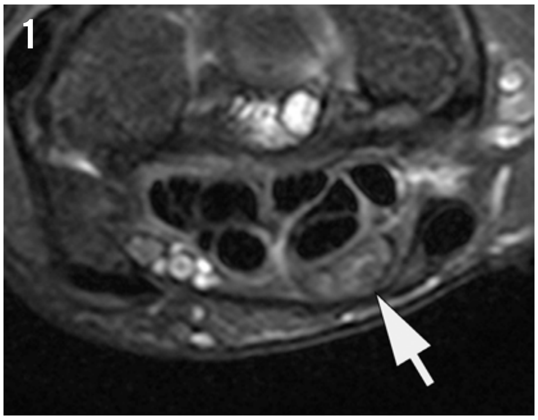
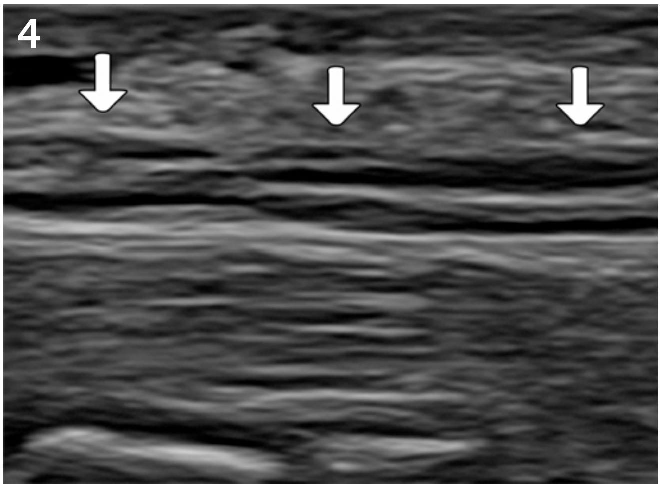


Figure 1: Neuropathy of the median nerve. Axial T2-weighted fat-suppressed image of the wrist depicts thickening of the median nerve, slightly increased signal, and loss of the normal fascicular pattern (arrow).

Figure 2: Acute muscle denervation. Axial T2-weighted fat-suppressed image of the leg shows edema of the extensor muscles (arrow), related to a fibular nerve compression.

Figure 3: Chronic muscle denervation. Axial T1-weighted image of the elbow shows fatty atrophy of the supinator muscle (arrow), related to posterior interosseous nerve compression.



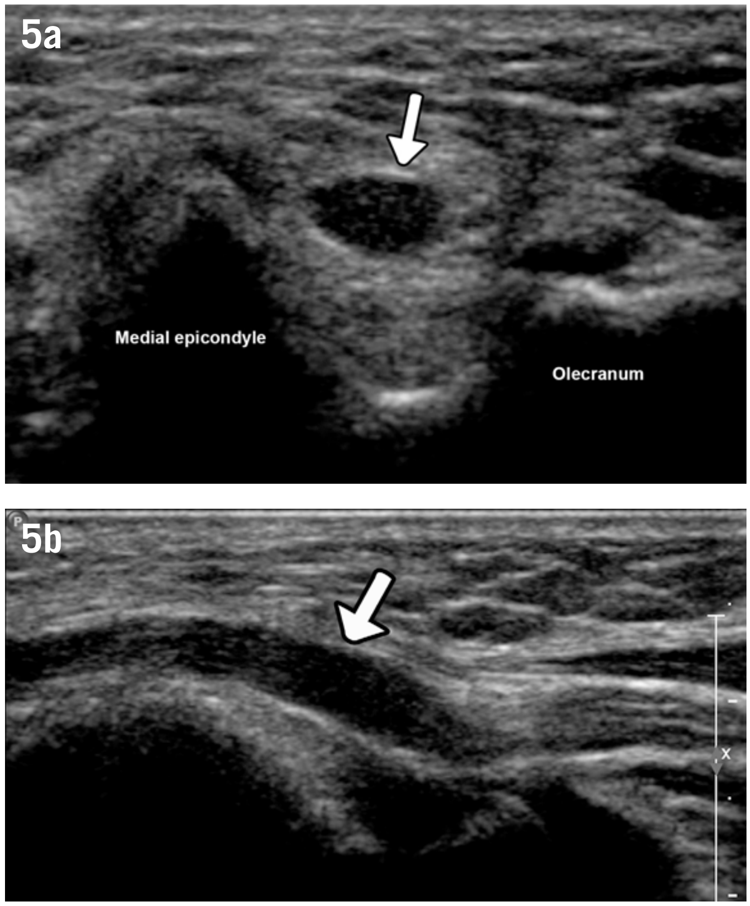


Figure 4: Normal nerve on ultrasound. Longitudinal US image of the median nerve (arrows). Nerve fascicles (hypoechoic bands) are separated by the perineurium (hyperechoic lines).

Figure 5: Neuropathy – US. (a) Transverse US image of the elbow showing an enlarged and hypoechogenic ulnar nerve (arrow). (b) Longitudinal US image demonstrates the ulnar nerve thickening, and hypoechogenicity with loss of fibrillar pattern, indicating a neuropathy.

between muscles or through a band of fibrous tissue.

In changes caused by chronic compression, damage to the nerve occurs progressively or intermittently, sometimes with periods of remission and exacerbation. As a result of repeated trauma or chronic ischemia, fibrosis can occur within and around neural fascicles. In more serious cases, the nerve fibers may be destroyed, and the neural trunk may be replaced by fibrosis if surgical decompression is not performed. The diagnosis of compression neuropathies is traditionally made based on clinical history findings, physical examination, and, at times, electrodiagnostic studies, including electromyography, nerve conduction studies, and somatosensory evoked potentials. US and MRI have frequently been used to complement the investigation of these neural compressions, although they are not always able to directly demonstrate the cause of compression. When using these two imaging methods, knowledge of the basic anatomy of peripheral nerves and innervation territories is essential. The relative advantage of US is that it allows

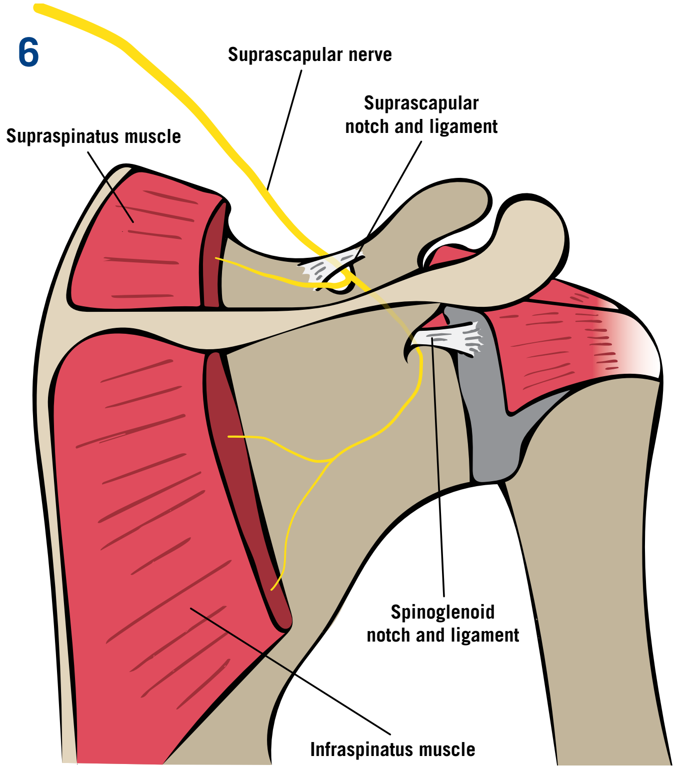
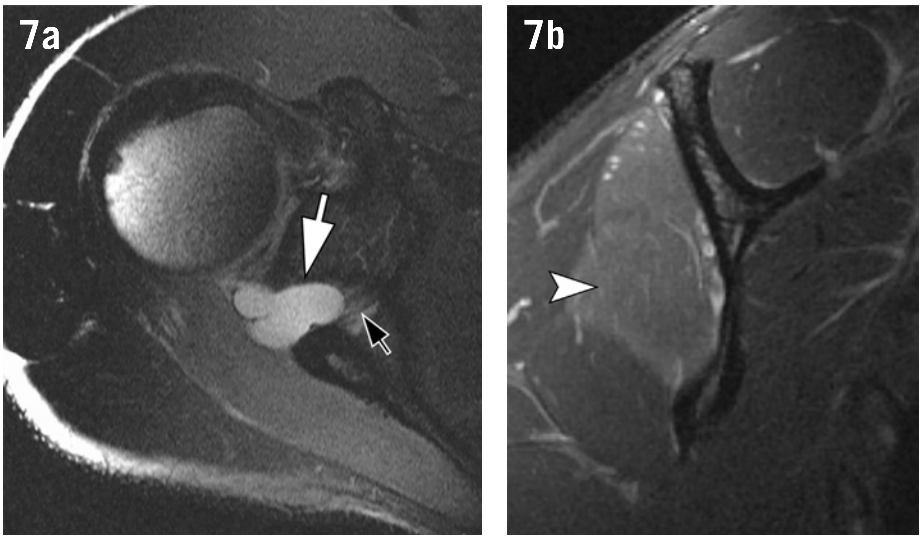
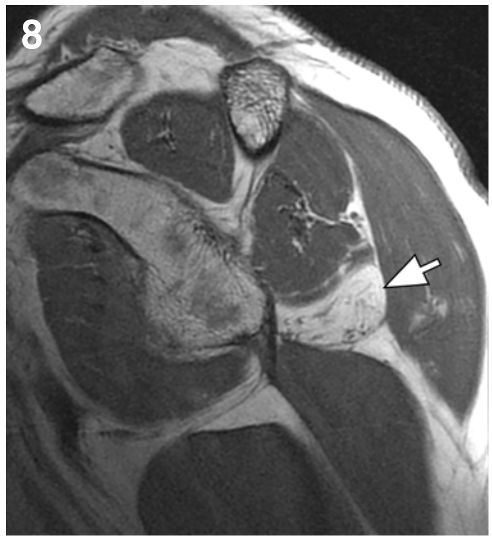


Figure 6: Suprascapular nerve anatomy.

Figure 7: Suprascapular nerve compression. (a) Axial T2-weighted image of the shoulder. There is a paralabral cyst at the spinoglenoid notch (white arrow) with compression of the suprascapular nerve (black arrow). (b) Sagittal T2-weighted image with fat suppression shows denervation with edema at the infraspinatus muscle (arrowhead).

Figure 8: Quadrilateral space syndrome. Sagittal T1-weighted image of the shoulder. Complete fatty atrophy of the teres minor muscle (arrow).





examination of the entire limb or a large part of the limb relatively quickly, as long as a radiologist is trained to evaluate peripheral nerves. More recently, the possibility of imaging tests, particularly via MRI, to identify signs of muscle denervation in the specific territory of a given nerve or branch has been emphasized. MRI has greater sensitivity in identifying muscle changes and has the advantage of being noninvasive compared to electromyography.

SPECIFIC COMPRESSIVE NEUROPATHIES

Suprascapular Nerve

The most common cause of suprascapular nerve injury is nerve entrapment in the suprascapular and/or spinoglenoid notch[5].

The suprascapular nerve runs across the superior border of the scapula into the suprascapular notch, under the scapular superior transverse ligament (or suprascapular ligament). The nerve then runs posteriorly, supplies motor branches to the supraspinatus muscle, and enters the spinoglenoid notch under the scapular inferior transverse ligament (or spinoglenoid ligament), supplying motor branches to the infraspinatus muscle (Figure 6).

MRI is useful in evaluating the course of the nerve and patterns of muscle denervation. Entrapment of the nerve in the suprascapular notch, beneath the supraspinatus muscle, may lead to edema and/or atrophy of both the supraspinatus and infraspinatus muscles. More distal entrapment in the spinoglenoid notch will result in selective denervation of the infraspinatus (Figure 7).[6] Visualization of the superior transverse ligament and its relationship to the nerve is also possible.

Axillary Nerve

Quadrilateral space syndrome (QSS) is a rare condition caused by compression of the axillary nerve and the posterior circumflex artery in the quadrilateral space. The clinical manifestations of this condition may be confusing, and MR is useful in its diagnosis.

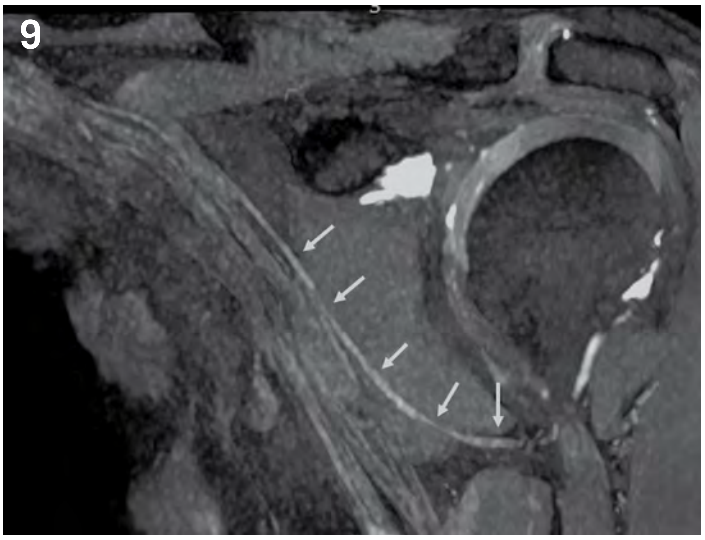


Figure 9: MR neurography of a normal Axillary nerve. 3D MIP reconstruction of a 3D steady-state MR sequence of the axillary nerve (arrows).

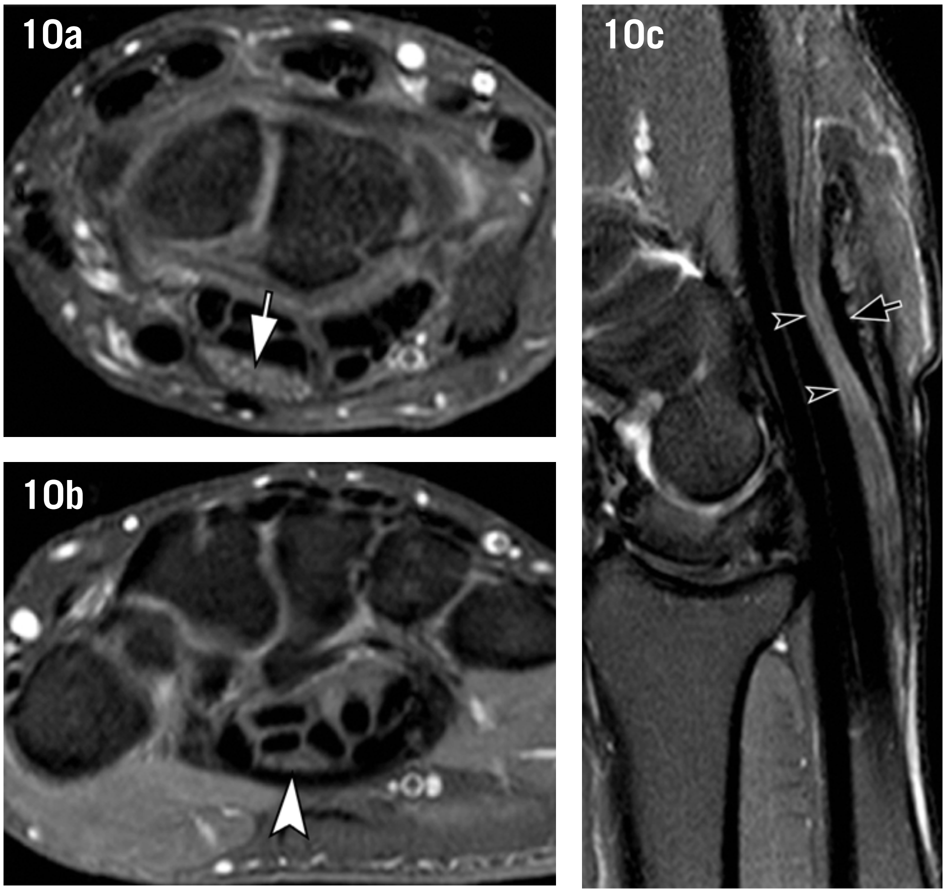


Figure 10: Carpal tunnel syndrome. Axial T2-weighted fat-suppressed images of the wrist at the levels of the pisiform (a) and the distal aspect of the carpal tunnel (b). Sagittal T2-weighted fat-suppressed image of the wrist shows the longitudinal axis of the median nerve (c). There is proximal enlargement (white arrow) and distal flattening (white arrowhead) of the median nerve. Note the increased signal and decrease in size with an "hourglass" appearance of the median nerve at the middle and distal aspects of the carpal tunnel (black arrowheads). There is also a thickening of the flexor retinaculum (black arrow).

Quadrilateral space compression may be static or dynamic. MR findings of QSS include increased teres minor and deltoid muscle signal intensity (on T2-weighted images) and/or fatty atrophy (on T1-weighted images) (Figure 8). Isolated teres minor atrophy can be seen in 3% of all routine MR studies and may be associated with other conditions[7]. MR angiography can also be useful in diagnosing QSS and demonstrating occlusion of the posterior circumflex artery during abduction and external rotation of the arm[8]. Direct visualization of the axillary nerve is possible with new MR neurography techniques (Figure 9).

Median Nerve

Lacertus syndrome is caused by compression of the median nerve at the level of the elbow, usually underneath the lacertus fibrosus, between the superficial (humeral) and deep (ulnar) heads of the pronator teres muscle or at the origin of the flexor digitorum superficialis muscle. The MR findings of lacertus syndrome are related to space-occupying lesions along the course of the nerve and, especially, signal abnormalities and/or atrophy in the flexor pronator muscle group. Recently, intrinsic MR alterations within the median nerve in entrapment syndromes have been described with the use of high-resolution sequences[9].

Carpal tunnel syndrome (CTS) is the most common compressive neuropathy of the upper extremity, with a prevalence of 3% in the general population[10]. MRI is accurate in 90% of CTS cases and predicts surgical benefits for these patients[11]. The most specific MR signs of CTS are proximal median nerve enlargement, flattening of the median nerve in the carpal tunnel, volar bowing of the flexor retinaculum, and T2 hypersignal in distal median nerve branches (Figure 10). Isolated T2 hypersignal of the median nerve within the carpal tunnel has been reported to have a lower specificity[12]. Recently, diffusion tensor imaging has been reported in various studies as a potential tool in the diagnosis and evaluation of CTS treated conservatively[13]. Quantitative analysis is possible in CTS, and fractional anisotropy values of the nerve below 0.5 are considered abnormal[14]. MR neurography also plays an important role in the postsurgical evaluation of CTS by detecting incomplete flexor retinaculum release and signal alterations within the nerve (Figure 11).

Several quantitative criteria can be measured in imaging exams and that have been described in the literature to aid in the diagnosis of CTS, but the most commonly

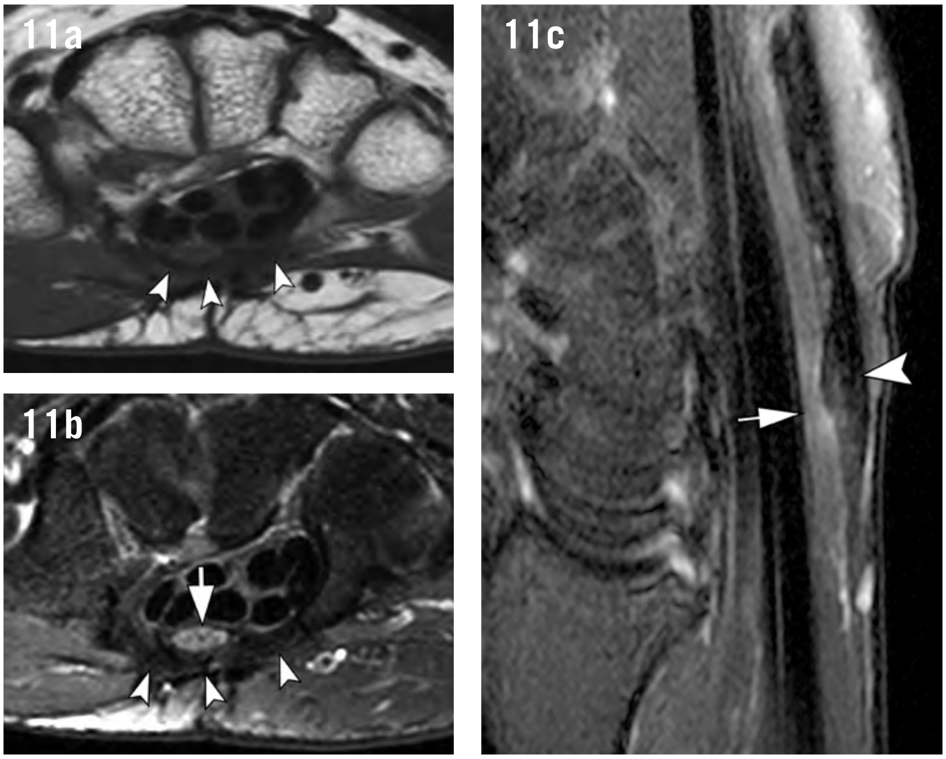


Figure 11: Post-operative carpal tunnel syndrome. Axial (a) T1-weighted and (b) T2-weighted fat-suppressed images of the wrist at the level of the distal carpal tunnel. Sagittal T2-weighted fat-suppressed image of the wrist shows the longitudinal axis of the median nerve (c). There is an incomplete flexor retinaculum release with fibrous tissue and thickening (arrowheads). The median nerve is flattened with increased signal (arrows).

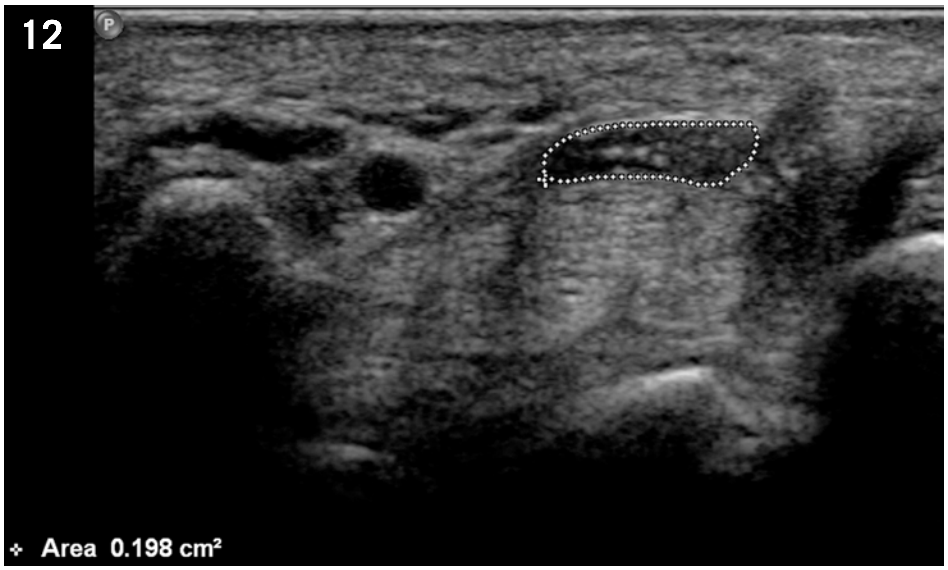


Figure 12: Increased median nerve cross-sectional area on US (19.8mm2), at the proximal aspect of the carpal tunnel.

used criterion is the cross-sectional area of the median nerve, particularly in the US literature (Figure 12).

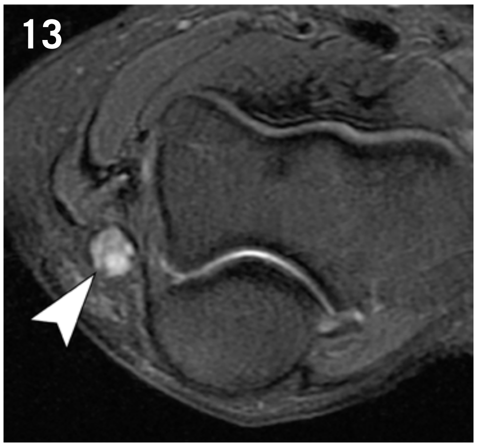
Most authors suggest that the upper limit of normality of the median nerve is between 9 and 12 mm^2. The value of 15 mm^2 has been suggested by some authors as the upper limit of normality for the cross-sectional area of the median nerve, serving to differentiate mild from severe cases of the disease[15].

Ulnar Nerve

Ulnar nerve compression is the most common neuropathy of the elbow and is secondary to dynamic or anatomic factors. In the elbow, the most common compression site is the cubital tunnel, where compression occurs as a result of decreased volume during elbow flexion. The MR findings include increased signal intensity on T2-weighted images, thickening of the nerve (Figure 13), and obliteration of fat tissue surrounding the nerve on T1-weighted images.

Ulnar nerve subluxation is a common feature and is present in up to 16% of asymptomatic individuals. In a minority of cases, it may cause compressive neuropathy. Subluxation can be seen on routine MRI; however, elbow flexion allows better visualization of nerve dislocation (Figure 14)[16]. It is easier to identify underlying instability of the nerve dynamically, and US is a suitable method for studying this condition and possible snapping syndromes (Figure 15)[17]. It is advisable to use dynamic flexion and extension maneuvers and maneuvers to evaluate flexion against resistance, which increases the chances of making the diagnosis.

Ulnar nerve compression can occur at the wrist level. Within Guyon's canal, the ulnar nerve divides into superficial sensory and deep motor branches. On MR, the normal anatomy is well depicted on T1-weighted



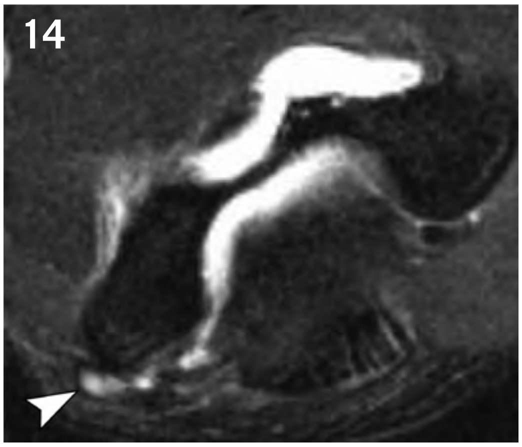


Figure 13: Ulnar neuropathy. Axial T2-weighted image with fat saturation. Thickening and increased signal of the ulnar nerve with loss of the regular fascicular pattern (arrowhead).

Figure 14: Ulnar nerve subluxation on MR. Axial T2-weighted with fat suppression images of the elbow demonstrates the ulnar nerve at the apex of the medial epicondyle (arrowhead), indicating subluxation. There is ulnar neuropathy associated, with increased signal and thickening of the nerve.

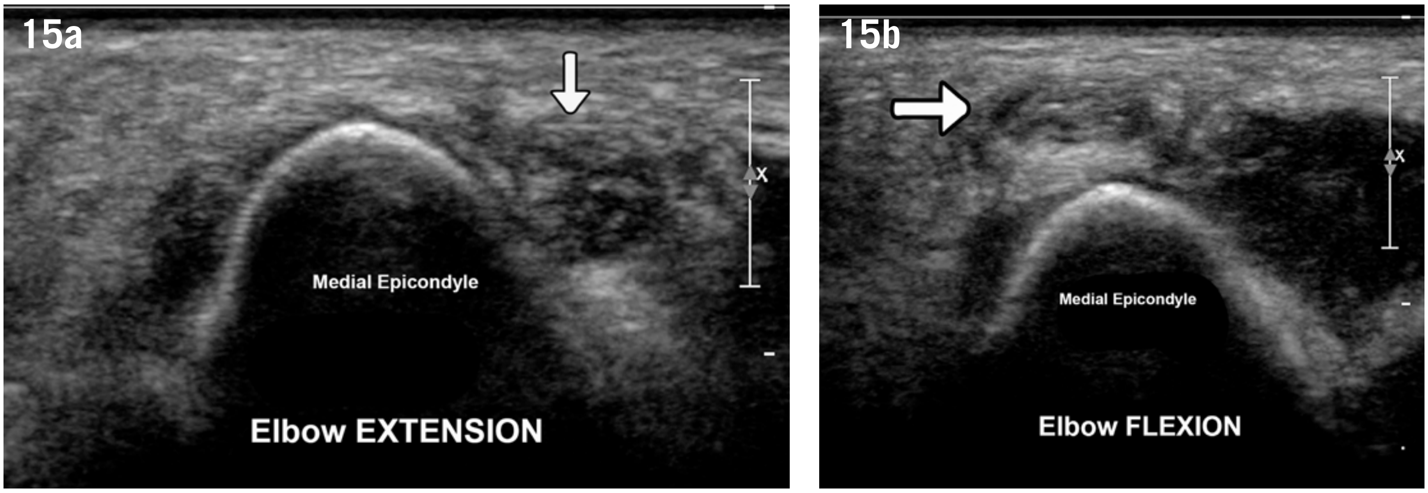


Figure 15: Ulnar nerve subluxation on US. (a) Transverse US image of the extended elbow. The ulnar nerve is within the cubital tunnel (arrow), posterior to the medial epicondyle. (b) With elbow flexion, the ulnar migrates to the apex of the medial epicondyle (arrow), indicating subluxation.

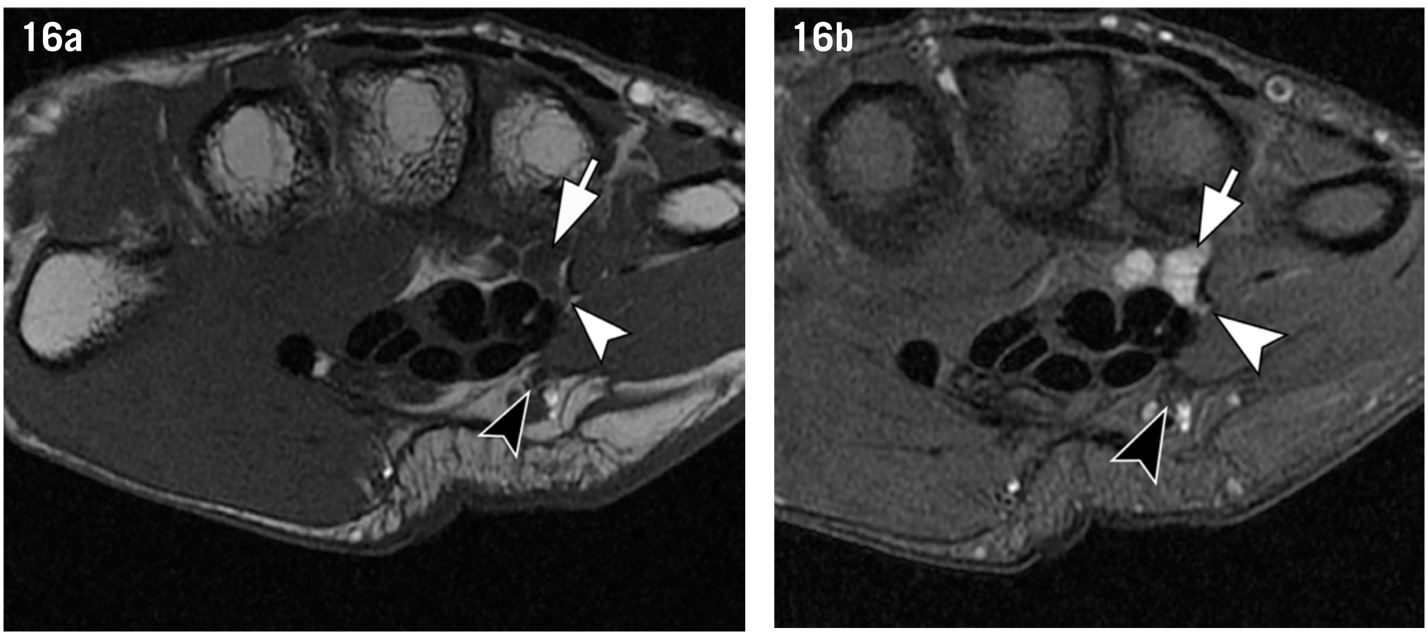
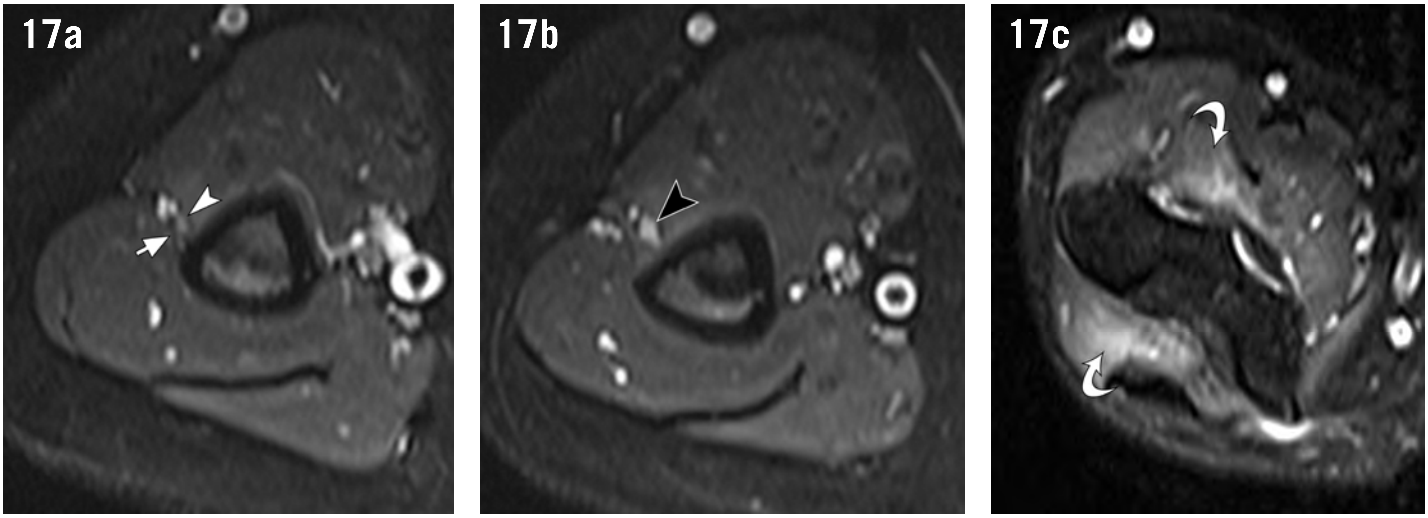


Figure 16: Ulnar nerve entrapment at the wrist. Axial T1-weighted (a) and T2-weighted fat-suppressed (b) images of the wrist. There is a cyst (arrow) compressing the deep branch of the ulnar nerve (white arrowhead). The superficial branch of the ulnar nerve is normal (black arrowhead).



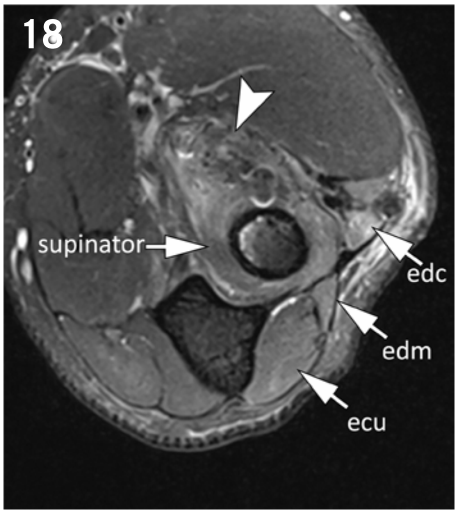


Figure 17: Radial nerve compression. Axial T2-weighted fat-suppressed images at the level of the humeral spiral groove (a and b) and the level of the elbow joint (c). In (a), the ulnar nerve has normal size and signal (white arrowhead) and is starting to cross the lateral intermuscular septum (white arrow). At a slightly more distal image, there is increased signal and thickening of the radial nerve (black arrowhead). There is denervation edema of the brachialis and supinator muscles.

Figure 18: Posterior interosseous nerve entrapment. Axial T2-weighted image with fat saturation demonstrates postoperative scar tissue at the anterolateral aspect of the elbow (arrowhead) with obliteration of the posterior interosseous nerve. There is denervation muscle edema of the supinator, extensor carpi ulnaris (ecu) , extensor digitorum minimi (edm), and extensor digitorum communis (edc) (arrows).

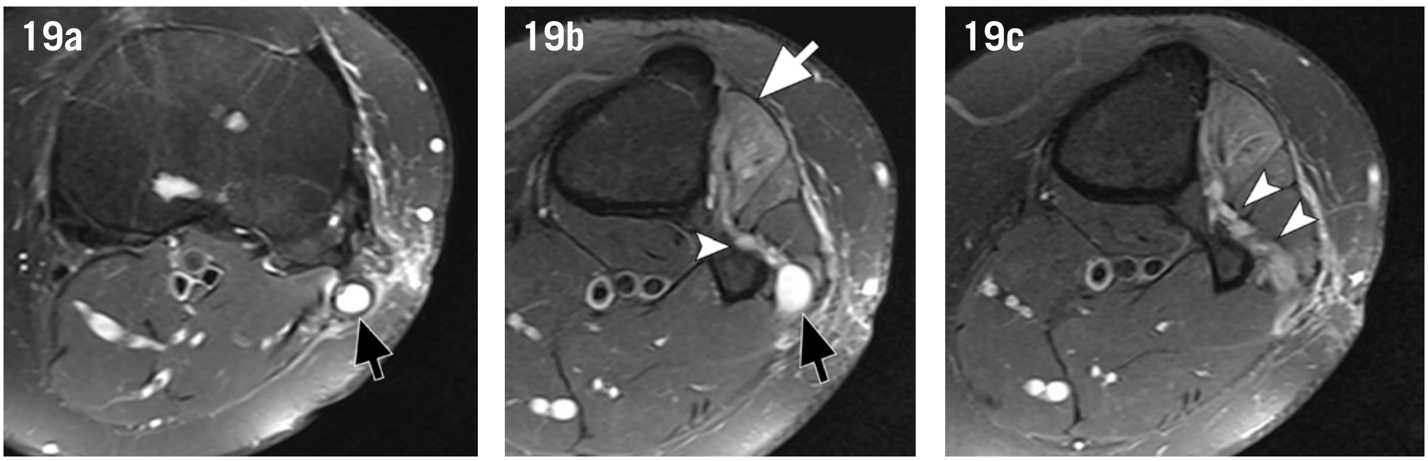


Figure 19: Axial T2-weighted consecutive images (a, b, and c) of the left knee with fat suppression. There is a cyst within the common peroneal nerve (black arrows), originating from the proximal tibiofibular joint through its articular nerve branch (arrowheads). There is denervation edema within the extensor muscles (white arrow).

> **Knowledge of new and available imaging techniques is essential to perform state-of-the-art MR and US examinations.**

images, and bifurcation of the superficial and deep nerve branches is adequately seen. MRI is useful in detecting mass lesions along the course of the ulnar nerve branches (Figure 16). Ulnar nerve fascicular pattern and caliber alterations are better visualized on US.

Radial Nerve

Radial nerve entrapment is a lesser common type of compression and frequently associated with trauma. In the arm, the radial nerve can be compressed at the humeral spiral groove as it crosses the lateral intermuscular septum, where it enters the anterior compartment of the arm. With 3D volumetric sequences, MR neurography can depict radial nerve thickening in the lateral intermuscular septum, as well as caliber and signal abnormalities (Figure 17)[18,19]. At the level of the elbow joint, the radial nerve bifurcates into the sensory branch of the radial nerve (SBRN), and the posterior interosseous nerve (PIN), a pure motor branch. The PIN passes under the arcade of Frohse, a fibrous arch present in 35% of individuals and formed by the proximal thickened edge of the superficial head of the supinator muscle, which is the most common site of compression of the PIN[20]. Compression of the PIN may lead to a denervation pattern in the muscles innervated by the PIN, namely, the supinator, extensor digitorum communis, extensor digitorum minimi, and extensor carpi ulnaris (Figure 18).

Common Peroneal Nerve

The peroneal and tibial divisions of the sciatic nerve usually split at the level of the popliteal fossa to form the common peroneal and tibial nerves. The common peroneal nerve is more commonly compressed as it courses by the fibular neck due to its more superficial location. Intraneural ganglia can develop from the proximal tibiofibular joint into the articular branch of the common peroneal nerve. MR neurography and US enable visualization of nerve abnormalities such as thickening and T2 hypersignal/hypoechogenicity[21,22] (Figure 19).

SUMMARY

MR neurography and high-resolution US are excellent techniques for the evaluation of peripheral nerves. Knowledge of currently available techniques is essential to perform state-of-the-art MR and US examinations. To provide an accurate diagnosis, physicians must also be familiar with the basic clinical aspects of nerve entrapment and, especially, with anatomic and pathologic aspects related to the nerves.

References
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