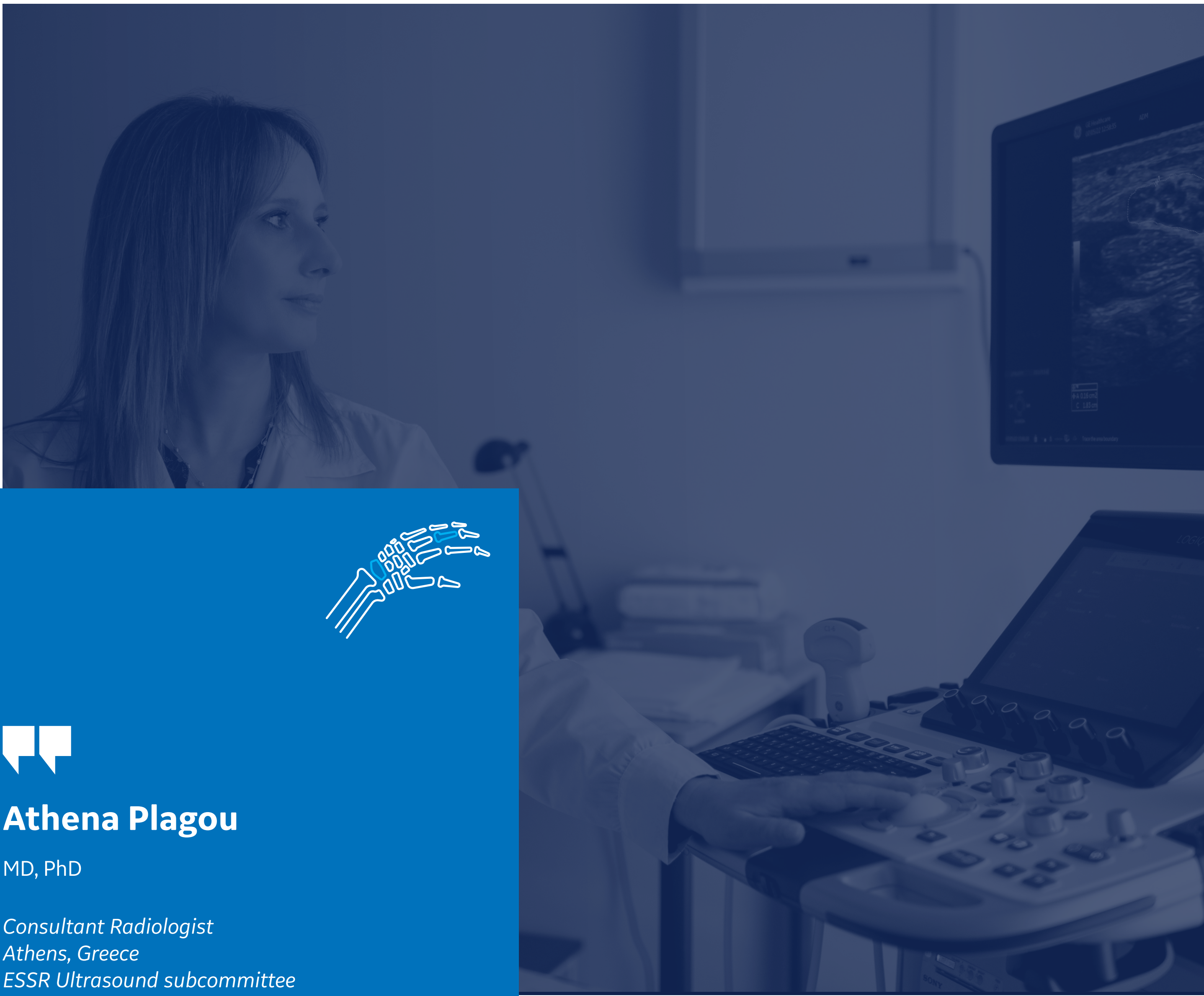


Athena Plagou

MD, PhD

Consultant Radiologist
Athens, Greece
ESSR Ultrasound subcommittee chairperson

The role of **High Frequency Ultrasound** in the Diagnosis of Peripheral Nerve Pathology

gehealthcare.com

Introduction

Traditionally, nerves have been examined by clinical tests and electrodiagnostic testing. However, this approach has limitations as electrodiagnostic tests are not conclusive in the acute phase of nerve injury and cannot provide information about the exact localisation and extent of a nerve lesion or entrapment. Moreover, changes in nerve structure, anatomic variants and surrounding abnormalities impeding the nerve cannot be detected using the traditional method. **Imaging modalities such as MRI and Ultrasound (US) can provide this important information.** MRI, with a wide field of view is more useful in the assessment of deep-lying nerves (i.e intrapelvic location), while US has a higher spatial resolution for superficial nerves. US can be performed at the bedside of the patient and an experienced operator can quickly explore extended anatomical areas (ie the entire course of a peripheral nerve from the neck to the fingers) and compare with the other side, using dynamic manoeuvres to detect pathology with high sensitivity. Ultrasound was found to modify the diagnosis and therapy in a significant percentage of patients with nerve trauma [1]. Importantly, latest technology has progressed with high frequency probes and increased spatial resolution giving the opportunity to trained practitioners to scan quickly and efficiently even the smallest branches of peripheral nerves and not only contribute significantly to an accurate diagnosis but also provide guidance for interventional procedures or surgery.

Latest technologies for nerve studies in Ultrasound

The latest GE improvements in B-mode and the extended capabilities of vascular flow modes increase the accuracy of the Ultrasound diagnosis. The software development leads to a high-level quality of diagnostic confidence for smallest branches of nerves and vessels.

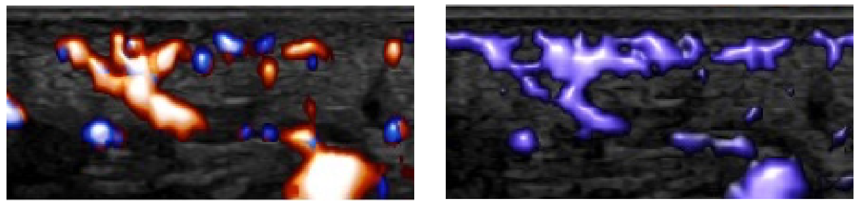
The introduction of the new cSound™ Imageformer clearly improve the image's spatial resolution in musculoskeletal with a focus at each pixel. The new levels of Speckle Reduction Imaging deliver high flexibility into the speckle noise reduction, contributing to an excellent contrast resolution of the image. This helps to better differentiate the smallest structures within the nerves and any potential pathologies related.

The new L6-24D high frequency probe provides great clinical achievements in musculoskeletal investigations. Its small footprint allows high-resolution imaging at relatively superficial location, and may detect and evaluate traumatic, inflammatory, infective, neoplastic, and compressive pathologies of the peripheral nerves. It contributes to an excellent fibre and border continuity (visible at 2-3 mm) than the previous linear probes. It also enhances the contrast resolution for nerves studies and the definition of the bone surface.

Beyond the new morphological depiction of the nerves in Ultrasound, latest flow modes will provide the clinician with a high-definition and visualisation of tiny vessels with a near 3D look.

The new Micro Vascular Imaging (MVI) combined with Radiantflow™ technology allows:

- a clearer definition of the vessels,
- an easier display of interconnecting smaller vessels; detecting more vascularity than with Colour Doppler or Power Doppler,
- a better detection of subtle abnormalities
- a better assessment of the inflammation in wrist and finger
- an improvement in the visualisation of a foreign body



Flow in finger. Comparison of conventional flow presentation with PDI (left) and with MVI (right).

MVI shows more small branches and slow flow with excellent continuity.

Clinical Cases

01

CASE 01. Median Nerve at the level of the Carpal Tunnel– Anatomy

Normal appearances of the median nerve in the carpal tunnel in short and long axis views- Measurements

IMAGES

The median nerve in the carpal tunnel in **short axis view** (circuscribed area) is clearly demonstrated in image 1. We can recognise the typical honeycomb appearance of the peripheral nerve in short axis view with multiple rounded hypoechoic areas that correspond to the nerve fascicles in a hyperechoic background that corresponds to the perineurium (surrounding connective tissue).

Deep to the median nerve, the flexor tendons are visualised in transverse view (blue arrows)

The hypoechoic, linear structure (yellow arrows) corresponds to the roof of the carpal tunnel which is the flexor retinaculum.

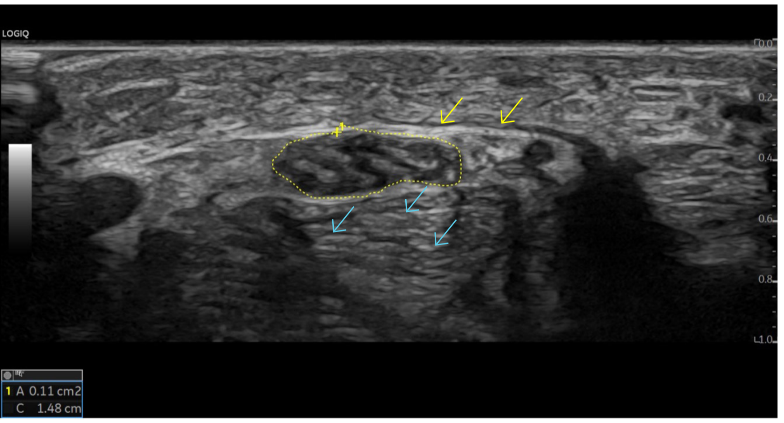


Image 1

The normal appearance of the median nerve in **long axis view** (image 2, arrows) is a striated appearance composed of multiple parallel hypoechoic and hyperechoic bands corresponding to nerve fascicles and surrounding connective tissue (perineurium)

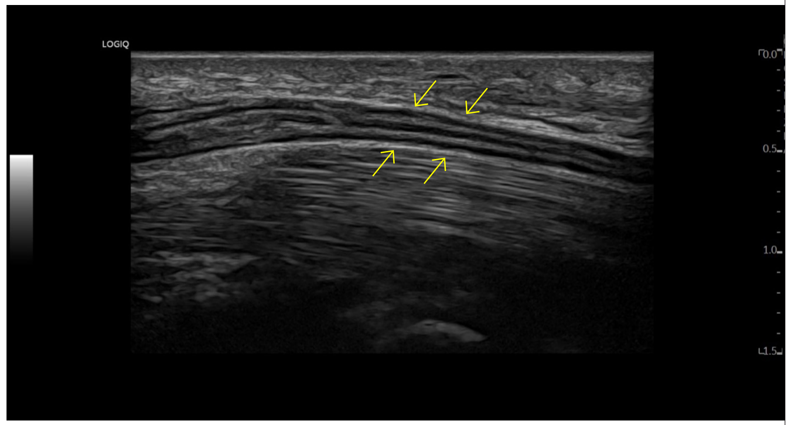


Image 2

In order to evaluate the swelling of the median nerve in the carpal tunnel it is useful to make the following measurements:

The largest cross-sectional area (CSA) of the median nerve **at the level of the carpal tunnel** (IMAGE 4 circle) is compared to the CSA **at the level of pronator quadratus muscle** (red arrows) (IMAGE 3 circle). If there is an increase in the area of the nerve at the level of the carpal tunnel compared to the area measured at the level of pronator quadratus it is a sign of nerve compression (carpal tunnel syndrome) [2]. In this case of a healthy individual, the CSA of the nerve at both levels is practically the same.

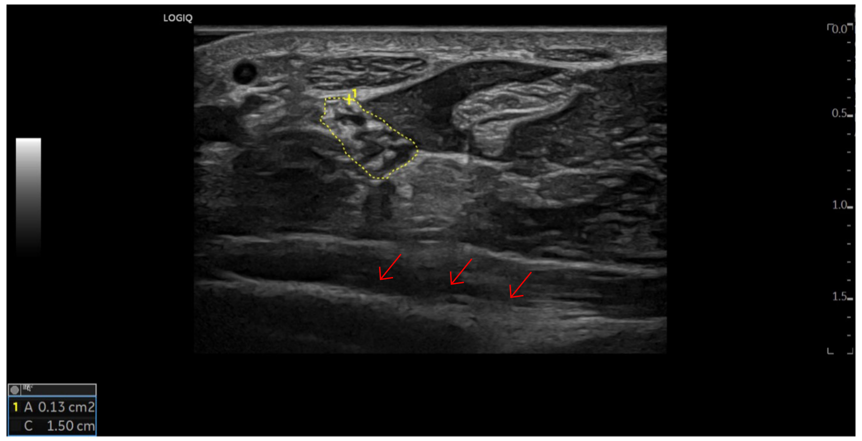


Image 3

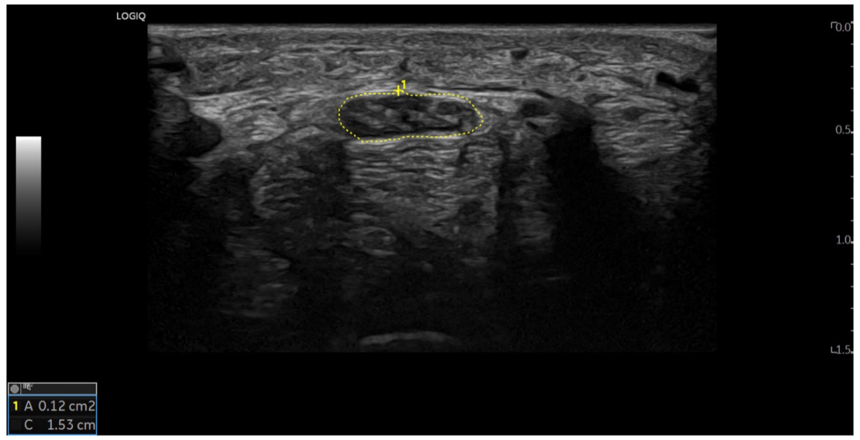


Image 4

02

CASE 02. Median Nerve - Carpal Tunnel Syndrome

PATIENT'S HISTORY

Middle – aged woman with history of rheumatoid arthritis presented with clinical signs of carpal tunnel syndrome (CTS): numbness and tingling in the hand and fingers and weakness of the thumb. Ultrasound scan was performed to confirm clinical suspicion of CTS and exclude other pathology (ie tenosynovitis of flexor tendons)

IMAGES

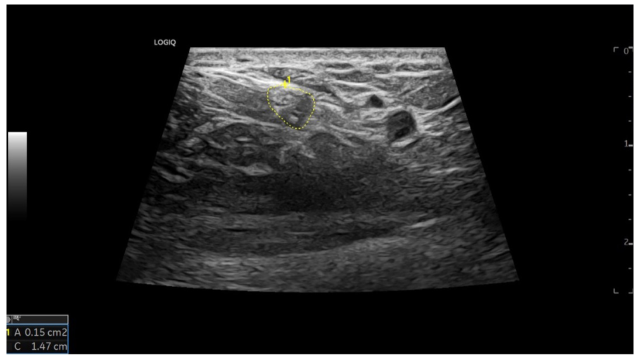


Image 1a

Short axis view at the level of pronator quadratus muscle and measurement of the cross sectional area (CSA) of the median nerve

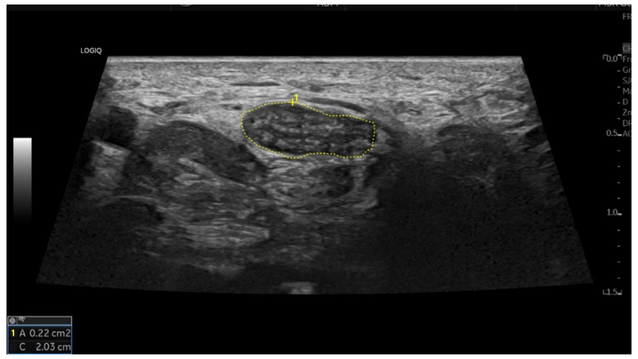


Image 1b

Short axis view at the level of the carpal tunnel and measurement of the CSA of the median nerve reveals significant enlargement of the median nerve in the carpal tunnel

Images 2a-2b

Short axis view of the median nerve in the carpal tunnel.

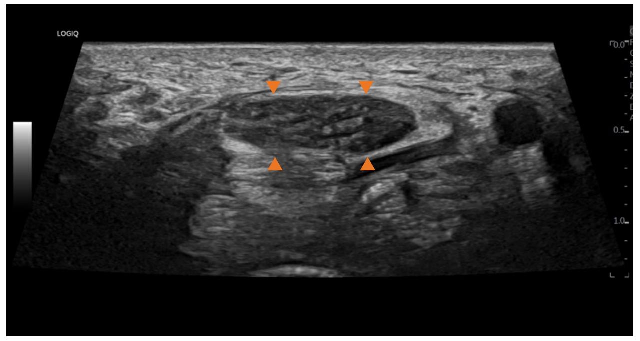


Image 2a

Notice the increased dimensions, decreased echogenicity of the median nerve and loss of the normal honeycomb appearance (arrowheads)

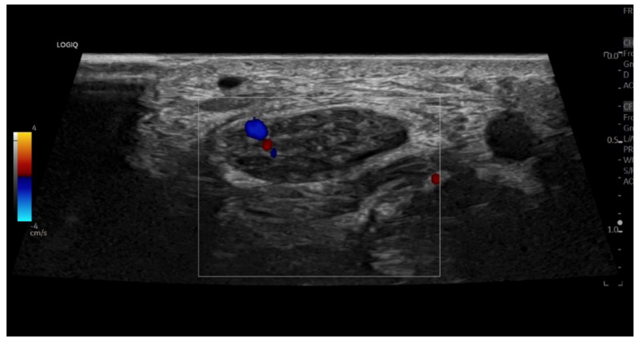


Image 2b

Colour Doppler study reveals increased vascularity in the nerve

Images 3a-3b-3c

Long axis view of the median nerve in the carpal tunnel.

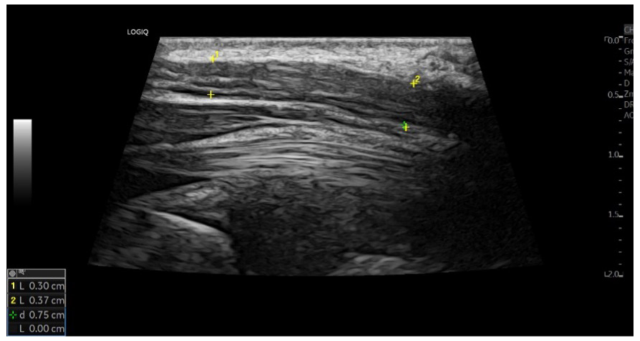
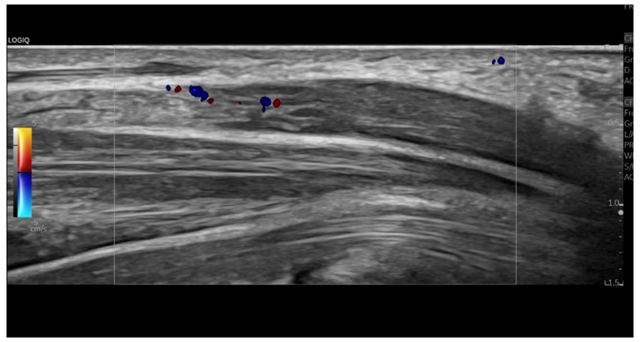


Image 3a

Increase in the diameter of the median nerve in the carpal tunnel (cursors) and loss of the normal striated echostructure. The decreased echogenicity and loss of striated pattern at the level of the carpal tunnel is sign of significant nerve oedema



Images 3b

Use of colour Doppler reveals increased vascularity in the nerve

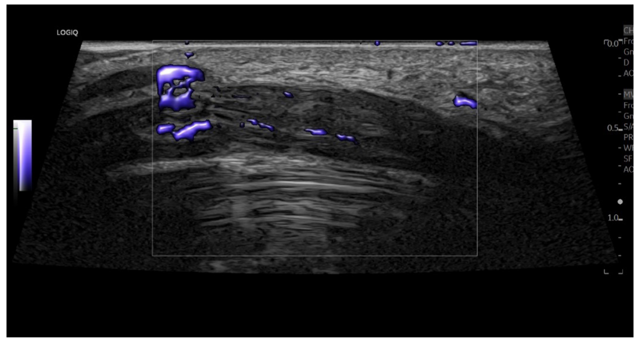


Image 3c

Use of MVI reveals even more vascularity

DIAGNOSIS

Ultrasound scan of the carpal tunnel with short and long axis views reveales significant increase in the CSA of the median nerve, change in the normal echogenicity of the nerve and increased vascularity. Comparison of the CSA of the nerve at the levels of pronator quadratus muscle and the carpal tunnel reveals significant increase of the CSA in the carpal tunnel syndrome confirming the clinical diagnosis. No other pathology was encountered in the carpal tunnel.

DISCUSSION

The most important factor when performing US scans of peripheral nerves is to be familiar with the normal appearance of the nerves. The normal echostructure of peripheral nerves in short axis views is the honeycomb appearance and in long axis views the striated appearance. These details in echostructure can now be easily recognized with the aid of high frequency optimal US technology (B mode).

Changes in normal echostructure such as decreased echogenity and loss of the honeycomb and striated appearances are strong indicators of nerve oedema (CTS) due to compression.

The second crucial indicator of CTS is the increase in the CSA of the median nerve in the carpal tunnel. Measurements of the CSA of the median nerve inside the carpal tunnel and comparing the difference of the CSA outside the carpal tunnel yields high levels of specificity and sensitivity of CTS diagnosis [2].

A third indicator of compression neuropathy is increased vascularity. Recent studies [3,4] have shown that severity of CTS strongly correlates with colour Doppler sonography findings. Techniques that are more sensitive in depicting increased vascularity such as MVI offer valuable information for the diagnosis and classification of a compression neuropathy as mild, moderate or severe.

CASE 03. Median Nerve in the Carpal Tunnel- Anatomical Variations

PATIENT'S HISTORY

Young female patient with complaints of wrist pain was scanned in the wrist area to exclude seronegative rheumatoid arthritis or other pathology. The ultrasound scan revealed no signs of fluid collection or synovial proliferation in the examined joints and tendons. No other pathological findings were encountered. Scanning of the carpal tunnel revealed anatomical variation.

IMAGES

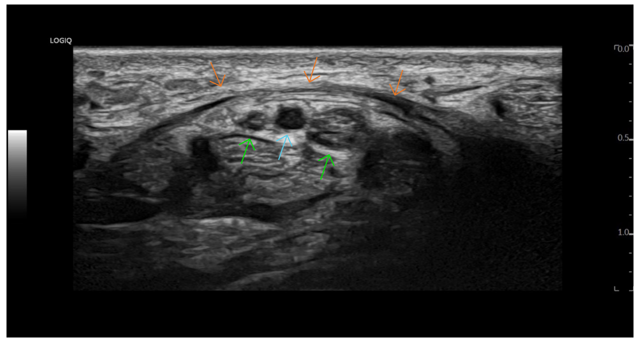


Image 1a

Transverse scan over the carpal tunnel. The roof of the carpal tunnel (flexor retinaculum) is clearly visualised (orange arrows). In the anatomical area of the medial nerve, two structures with nerve morphology (green arrows) and a tubular structure with vessel morphology (blue arrow) are visualised.

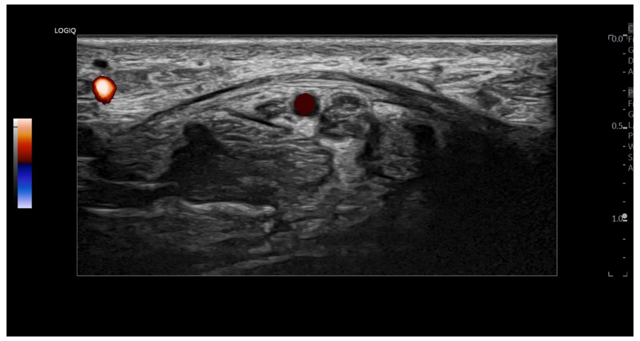


Image 1b

Transverse scan over the carpal tunnel - colour Doppler study.

The use of colour Doppler proves that the tubular structure between the nerve branches corresponds to a vessel.

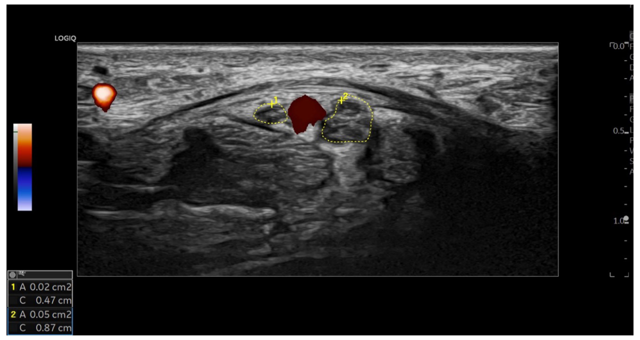


Image 1c

Transverse scan over the carpal tunnel and measurements of the cross-sectional area (CSA) of the nerve fascicles (circles). The total CSA is within normal limits and is consistent with the history of the patient who presents no signs of carpal tunnel syndrome.

DIAGNOSIS

Bifid median nerve and persistent median artery is an anatomical variation in the carpal tunnel. In this case it was an incidental finding in a patient scanned in the wrist area without symptoms of CTS.

DISCUSSION

The most common anatomical variation in the carpal tunnel, which can be detected with Ultrasound, is the bifurcation of the median nerve proximal to the transverse carpal ligament (bifid median nerve) [5,6].

The two nerve fascicles run parallel in the carpal tunnel and may have similar dimensions or different sizes, one fascicle being prevalent over the other.

The bifid median nerve is frequently accompanied by the persistent median artery (7). The median artery is an embryological remnant that is present in 1.2% to 23% of the population and is normally obliterated after birth.

The persistent median artery is located between the two branches of the bifid median nerve; occasionally, the median artery can flank a nonbifid nerve [8,9].

The median artery has a superficial course as it approaches the transverse carpal ligament and thus can be injured during carpal tunnel release.

Identification of a persistent median artery with an ultrasound scan and use of colour Doppler is important to avoid problems during carpal tunnel release.

CASE 04. Trauma - Neuroma Interdigital nerve

PATIENT'S HISTORY

Middle aged, female patient with history of penetrating trauma in the middle phalanx of the index finger caused by a knife. Patient trauma was sutured at the ER of a tertiary referral center. The patient complained of hypoesthesia at the ulnar side of the proximal phalanx. The patient was referred for an Ultrasound scan of the index finger.

IMAGES

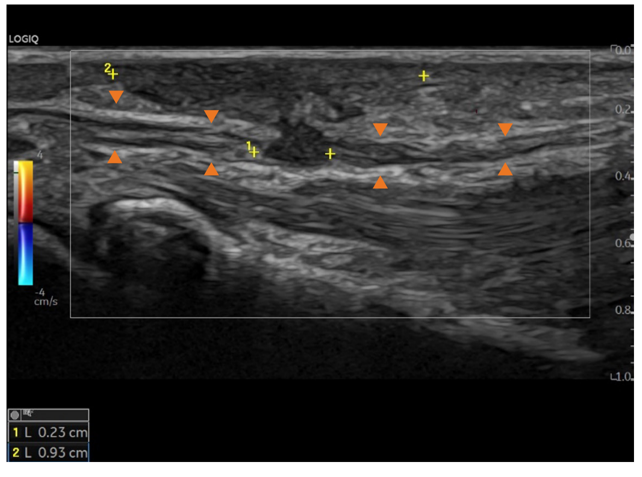


Image 1a

The index finger was scanned with the hockey stick (L6-24D) probe on the area of the wound where it was sutured. Sutures had been removed and it had healed on the day of the examination. Scar tissue was evident on the skin on the ulnar side of the middle phalanx and the probe was placed on this area. On the long axis view in the subcutaneous, soft tissue layer a hypoechoic area is recognised (superficial cursors). The area has the morphology of scar tissue. In the colour Doppler study there is no increased vascularity. Deep to the scar tissue a hypoechoic nodule is seen (deep cursor) measuring 2,5 mm. It is continuous with a linear tubular structure that has the appearances of a small peripheral nerve.

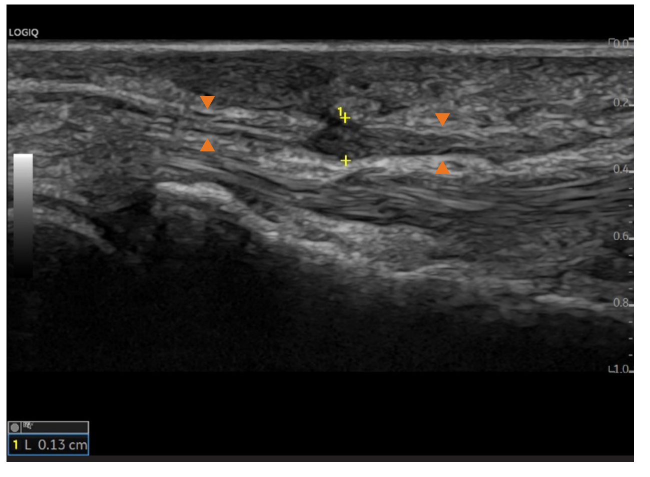


Image 1b

Long axis scan at the same area (gray scale imaging). The hypoechoic structure (between cursors) has the appearance of a neuroma. Its continuation with the nerve fibres of a small sized peripheral nerve (arrowheads) is evident.

Image 2a-2b-2c

Short axis scans at the level of the wound (neuroma). Scanning was performed in short axis covering the area of the wound as well as the areas cranially and caudally.

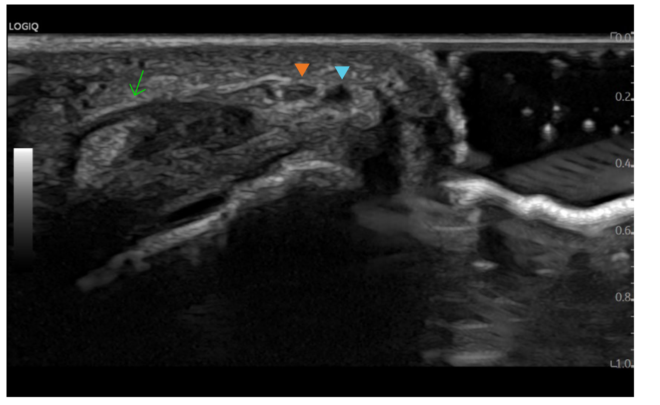


Image 2a

Short axis scan cranial to the wound (neuroma) reveals the following structures: The flexor tendons of the index are located centrally (green arrow). Slight lateral translation of the hockey-stick probe reveals the characteristic honeycomb nerve morphology of the ulnar digital nerve (orange arrowhead) and the adjacent blood vessel (blue arrowhead).

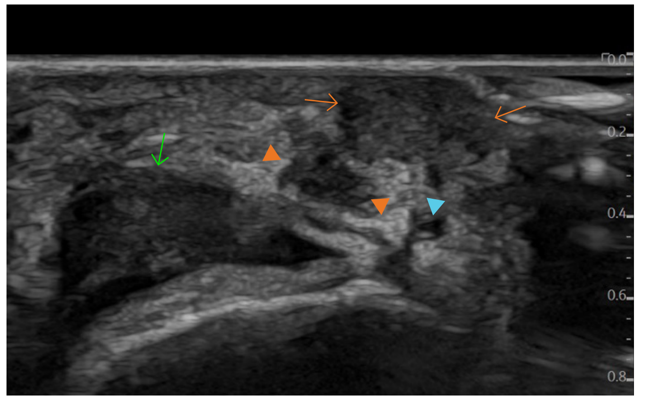
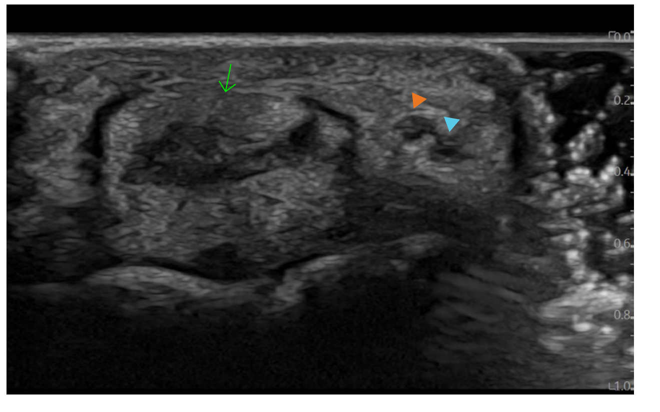


Image 2b

Short axis scan at the level of the scar reveals a superficial hypoechoic area (orange arrows) which corresponds to the scar tissue and a hypoechoic nodule at the anatomical area of the ulnar digital nerve (orange arrowheads) with the morphology of a neuroma. Adjacent blood vessel (blue arrowhead), flexor tendons (green arrow).



Images 2c

Short axis scan caudally to the scar area reveals normal echostructure of the ulnar digital nerve (orange arrowhead). Adjacent blood vessel (blue arrowhead), flexor tendons (green arrow).

DIAGNOSIS

The symptom of hypoesthesia is consistent with nerve injury. The ulnar digital nerve was examined with Ultrasound using a high frequency hockey- stick probe. Both long axis and short axis scans revealed continuity of the nerve and presence of a traumatic neuroma which represents a disordered, hyperplastic growth response to nerve injury. The findings are consistent with axonotmesis.

DISCUSSION

Nerve injuries are broadly classified in terms of neurapraxia, axonotmesis, and neurotmesis. In neurapraxia, there may be clinical signs of hypoesthesia or anesthesia for a short time, but the nerve has normal morphology. In axonotmesis there is a disruption of the internal architecture of the nerve involving some or all axonal groups, but the external continuity of the nerve is maintained. Neurotmesis is complete disruption of the axon and supporting connective tissue structures [10]. Imaging can confirm clinical suspicion and most importantly provide accurate classification of nerve injury which is crucial for early decision of surgical repair if necessary. In penetrating wounds, Ultrasound is able to measure the extent of injured fascicles with accuracy. Ultrasound scans with high end systems and high frequency probes can clearly demonstrate pathology in even the smallest nerve branches like digital nerves [11,12].

Conclusion

Nerve imaging with high frequency ultrasound provides detailed information both about nerve morphology and surrounding structures. Clinical and electrodiagnostic tests alone cannot shed light to the extent and classification of a lesion, surrounding pathology and anatomy features of the examined nerves. Anatomic variations, extent of compression and concomitant pathology can significantly influence decision making about treatment and surgery. US guided interventions around even the smallest nerve branches are now feasible thanks to the high spatial resolution offered by new high end US systems and high frequency probes. Surgery planning and outcome is dependent on the anatomic details provided beforehand by a state-of-the art Ultrasound scan. Technology achievements can be beneficial to patient care and treatment in the hands of well-trained practitioners. Training and awareness of new US possibilities on nerve imaging is a challenge and an important goal for the near future.

REFERENCES

1. Padua, L.; di Pasquale, A.; Liotta, G.; Granata, G.; Pazzaglia, C.; Erra, C.; Briani, C.; Coraci, D.; de Franco, P.; Antonini, G.; et al. Ultrasound as a useful tool in the diagnosis and management of traumatic nerve lesions. Clin. Neurophysiol. 2013, 124, 1237–1243.
2. Klauser AS et al. Carpal Tunnel Syndrome Assessment with US: Value of Additional Cross-sectional Area Measurements of the Median Nerve in Patients versus Healthy Volunteers.. Radiology 2009 Jan;250(1):171-7
3. Mallouhi A et al. Predictors of carpal tunnel syndrome: accuracy of gray-scale and color Doppler sonography. AJR 2006; 186:1240–1245
4. Mohammadi A et al Correlation Between the Severity of Carpal Tunnel Syndrome and Color Doppler Sonography Findings. AJR 2012;198: 181-184
5. Mitchell I, Chesney A, Seal S et al (2009) Anatomical variations of the carpal tunnel structures. Can J Plast Surg 17:3–7
6. Gervasio A et al M (2020) Carpal tunnel sonography J Ultrasound 23:337–347
7. Peetrons P (2013) Carpal Tunnel Syndrome. Semin Musculoskelet Radiol 2013;17:28–33.
8. Olave E, Prates JC, Gabrielli C, Pardi P. Median artery and superficial palmar branch of the radial artery in the carpal tunnel. Scand J Plast Reconstr Surg Hand Surg 1997;31:13-6.
9. Barfred T, Hojlund AP, Bertheussen K. Median artery in carpal tunnel syndrome. J Hand Surg [Am] 1985;10:864-7
10. Umans H, Kessler J, de la Lama M, Magge K, Liebling R, Negron J. Sonographic assessment of volar digital nerve injury in the context of penetrating trauma. AJR. 2010;194:1310–3.
11. Renna R, Coraci D, De Franco P, Erra C, Ceruso M, Padua L. Ultrasound study is useful to discriminate between axonotmesis and neurotmesis also in very small nerves: a case of sensory digital ulnar branch study. Med Ultrason. 2012;14:352–4.
12. Yoshimi E et al. Ultrasound features of traumatic digital nerve injuries of the hand with surgical confirmation. Skeletal Radiol. 2021 Sep;50(9):1791-1800.

gehealthcare.com

Athena Plagou, MD, PhD

Dr. Athena Plagou is Consultant Radiologist in Athens, Greece.

Since 2019, Dr Plagou is the Chairperson of ESSR Ultrasound SubCommittee.

She has a well-known expertise in Imaging for Musculoskeletal and Rheumatic Diseases.

She has been working on several publications, guidelines and recommendations at European Level, defining the role and spectrum of Ultrasound features in cases of inflammatory arthritis, sports injuries and peripheral nerve pathology in the adult.

gehealthcare.com