

Peripheral nerve ultrasound II: upper extremity entrapment neuropathies

Ultrasonido de nervios periféricos II: neuropatías por atrapamiento de extremidad superior

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Abstract

In the first part of this article, the anatomy and histology of peripheral nerves are discussed, emphasizing the importance of the correlation with their imaging appearance. The normal appearance of a nerve and the ultrasound exploration technique are presented. In the second part, the ultrasonographic study of upper extremity entrapment neuropathies is reviewed.

Keywords: Peripheral nerves. Ultrasound. Neuropathies. Entrapment.

Resumen

En la primera parte de este artículo se discute la anatomía e histología de los nervios periféricos, enfatizando la importancia de la correlación con su aspecto imagenológico. Se presenta el aspecto normal de un nervio y la técnica de exploración con ultrasonido. En la segunda parte se revisa el estudio ultrasonográfico de las neuropatías por atrapamiento de la extremidad superior.

Palabras clave: Nervios periféricos. Ultrasonido. Neuropatías. Atrapamiento.

Entrapment neuropathies

These correspond to a group of focal neuropathies related to the compression of a peripheral nerve causing paresthesia, pain, and in more advanced stages, loss of nerve function. Although the diagnosis of most entrapment neuropathies is based on the clinical symptoms, physical examination, and electrophysiological tests, ultrasound (US) has a significant role in verifying clinical suspicion. The main value of imaging is the evaluation of difficult or atypical cases, or when a mass or demonstrable anatomical cause is suspected that explains the symptoms. Anyone can suffer from

a neuropathy compression, but certain groups of individuals are more predisposed, such as athletes, musicians and laborers¹.

Nerve entrapment from extrinsic causes can occur anywhere in the body, however it is more common in anatomical sites where the nerves pass through rigid, inextensible osteofibrous tunnels, or beneath a prominent or abnormal band of a muscle, supernumerary muscles, bands of connective tissue, abnormal vascular structures or bony prominences, especially if these anatomical regions are subjected to repetitive stress or overuse². They can also be compressed by the presence of a tumoral mass, cysts, fluid collections, etc.

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Date of reception: 19-06-2022

Date of acceptance: 19-10-2022

DOI: 10.24875/RCHRADE.M23000024

Available online: 21-06-2023

Rev Chil Radiol (Engl. ed.). 2022;28(4):132-151

www.resochradi.com

The most common symptoms depending on the degree of compression and time of evolution are paresthesias, motor involvement and trophic changes in the skin. The onset of symptoms is usually gradual, although it can also have a sudden onset after acute traumatic events (for example, after the application of a tourniquet to inhibit bleeding or due to extrinsic compression after the use of a compression bandage or a closed cast)³.

From a pathophysiological point of view, nerve compression can occur acutely or develop chronically⁴. A short compression time causes slowing and conduction failure at the compression site, while the segment distal to this point retains its normal function. These conduction disturbances are often called «neuropraxia» and tend to resolve completely over a variable time. Classic examples of this situation are «Saturday night radial palsy», in which the radial nerve is compressed in the radial canal of the humerus for a limited time, and the “crossed-leg fibular palsy”, in which the same occurs with the fibular trunk compressed in the head of the fibula¹.

If this focal compression is prolonged over time, there is ischemia, edema⁴, distortion of the nerve architecture, damage to the myelin sheath and Wallerian degeneration (corresponding to axonal damage), thus compromising the nerve fibers². In this case, there is a persistent nerve deficiency secondary to the alteration of the axoplasm (cytoplasm of the axon) even after compression relief.

In the early stages, the symptoms are usually intermittent, or are partially alleviated with exercise, due to the recovery of intraneural circulation and drainage of the intraneural edema. But if the cause of the compression continues, the sustained edema produces fibrotic changes in the epineurium and thickening of this covering, contributing to the chronic compression of the fascicles. This interferes with the intraneural microvascular supply causing ischemia, venous congestion, and edema. There is increased pressure and a micro-compartment syndrome sets in.

Myelin damage and axonal degeneration, also induced by fibrosis, in the final stage lead to conduction block and atrophy of the innervated muscles.

Animal studies have shown that increased nerve volume is associated with inflammation, demyelination, remyelination, and fibrosis⁵.

In 1973, Upton and McComas introduced the “double crush” theory, that there could be a double entrapment. They proposed that compression of a nerve at a proximal point compromised axoplasmic flow, which would make the nerve more susceptible to lesion at a more distal location. For example, a patient with cervical

radiculopathy or thoracic outlet syndrome is more likely to have carpal tunnel syndrome.

In 2004, Lundborg described the reverse double crush syndrome, in which compression at a distal site predisposes to a proximal lesion, since it would decrease the flow of neurotrophic substances back to the body of the neuron.

Both theories suggest that nerve entrapment affects axoplasmic transport, making other areas of the nerve more susceptible to entrapment^{4,6-8}.

Ultrasound in entrapment neuropathies

In nerve entrapment syndromes, US may demonstrate changes in both nerve shape and echostructure, the most common being sudden flattening, with focal reduction in the cross-sectional area at the point of compression (notch sign), and thickening proximal to the compression level (Fig. 1A).

As a secondary finding, dynamic examination may show a decrease in the usual gliding movement of the nerve, but this last sign is subjective and difficult to quantify with US⁵.

The cross-sectional area of the nerve before compression and in the area of compression has also been considered as an indication of entrapment.

The echostructure may become uniformly hypoechoic, with loss of the fascicular (honeycomb) pattern at and proximal to the compression site (Fig. 1B).

In general, hypoechogenic changes occur gradually and become more severe as the nerve approaches the compression site.

These changes derive from the edema of the individual fascicles and from the reduction in the echogenicity of the perineurium and endoneurium, associated with vasocongestion (Fig. 1C).

The external covering of the nerve (epineurium), which is normally not defined and forms part of a continuum with the perineurium and surrounding fat, becomes clear and well delineated⁹, there is hypertrophy of the epineurium (Fig. 1D).

In cases of chronic entrapment, it is possible to find hyperechogenic points in the thickness of the nerve in the axial section, that represent fibrotic changes. Similarly, there may be hypervascularization on Doppler study¹⁰ (Fig. 1 E and F).

Based on ultrasound evaluation, entrapment neuropathies can be divided into three groups:

- Compression of large nerves, such as median, ulnar, radial, sciatic, tibial, etc., that is, nerves that are easily represented with US at the compression site. In this

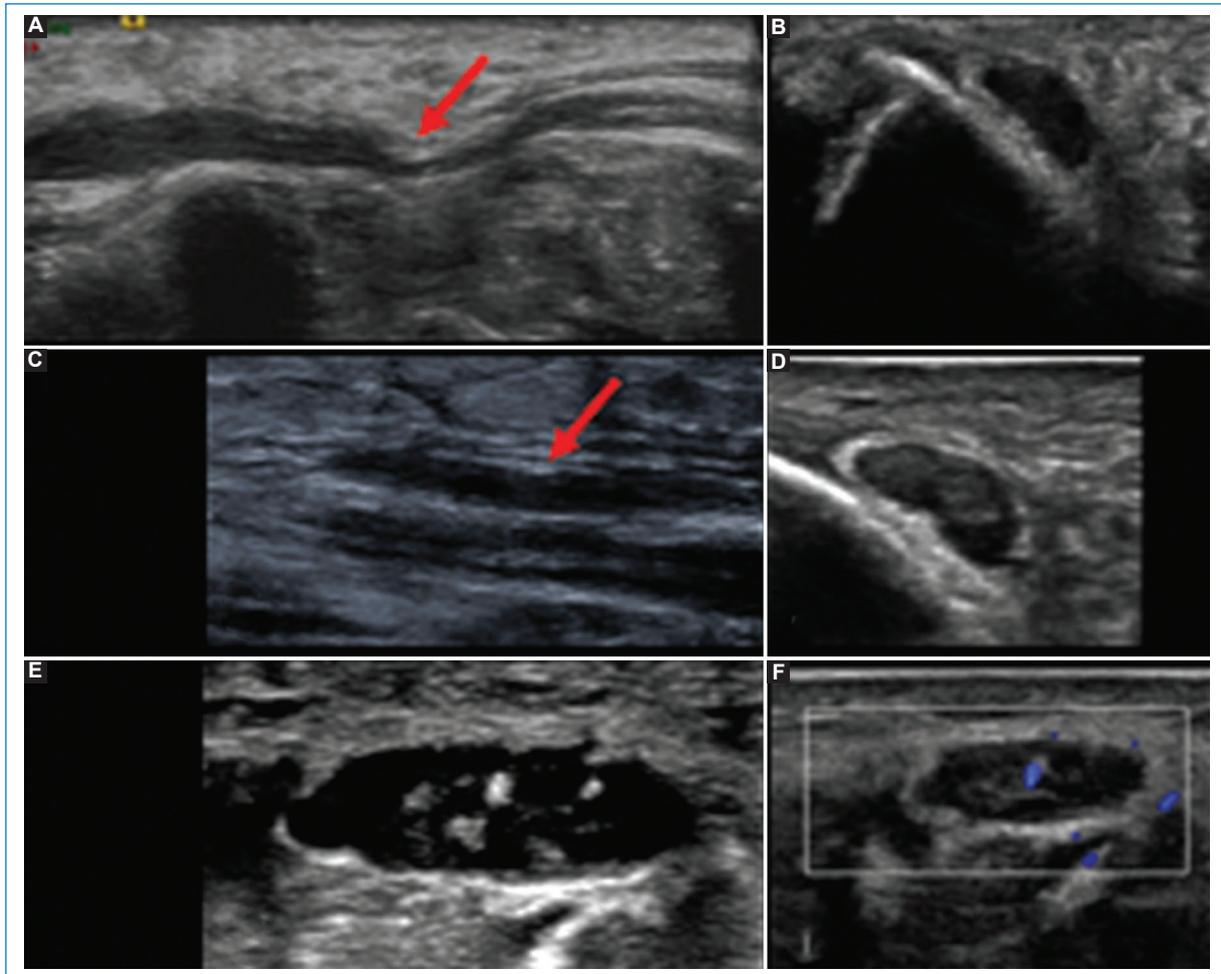


Figure 1. Ultrasound signs of neuropathy. **A:** notch sign on longitudinal slice. **B:** loss of the fascicular honeycomb pattern on cross-sectional slice. **C:** diffuse reduction in echogenicity of the endoneurium and perineurium on longitudinal slice. **D:** hypertrophy of the epineurium on cross-sectional slice. **E:** hyperechogenic points representing fibrotic changes in chronic entrapment on cross-sectional slice. **F:** hypervascularization in chronic entrapment on cross-sectional slice.

group, the diagnosis is based on the analysis of recognition of normal echographic patterns and on quantitative measurements. These explorations can be carried out with conventional equipment.

- Compression of small nerves, such as posterior interosseous, musculocutaneous, sural, plantar, etc. In these cases, equipment with high frequency transducers is required. Diagnosis is based on analysis of patterns and morphology, since quantitative measurements are not possible due to the small caliber of the nerve.
- Compression of nerves not detectable with US because they are very small, have a very deep course or are hidden by bone structures. In these cases, US can only evaluate the muscles innervated by the nerve studied for signs of denervation.

In the first two groups there are many compression sites that can be studied with US in the upper and lower

extremities, and whatever the site involved may be, the signs described above are found to a greater or lesser degree and are practically pathognomonic of compressive neuropathy.

Compression sites in the upper extremity that can be studied with US are reviewed below.

It is essential for the radiologist to know the anatomy, etiopathogenesis and clinical presentation of compressive neuropathies for a correct diagnosis¹¹.

Upper extremity

Brachial plexus

The anatomy of the brachial plexus is variable. It can even vary from one side to the other in the same patient. It comprises the ventral rami of the C5 to T1 roots which

exit the junctional foramina and enter a groove between the anterior and medial scalene muscles. Towards the periphery the superior, middle and inferior trunks are formed. The C5 and C6 rami unite to form the superior trunk near the medial border of the middle scalene. The C7 ramus forms the middle trunk, and the C8 and T1 rami unite to form the inferior trunk¹².

Each trunk separates into anterior and posterior divisions as it travels behind the middle third of the clavicle through the interscalene groove.

The divisions combine to form lateral, posterior, and medial cords that are named according to their position relative to the axillary artery.

The lateral cord is formed from the anterior divisions of the superior and middle trunks.

The posterior cord is formed from the posterior divisions of the three trunks.

The medial cord is formed from the anterior division of the anterior trunk. Finally, the terminal branches emerge from the cords¹².

The musculocutaneous nerve and the lateral portion of the median nerve arise from the lateral cord. The radial and axillary nerves from the posterior cord. The ulnar nerve and medial portion of the median arise from the medial cord (Fig. 2).

There are several key anatomical cues to simplify assessment of the brachial plexus (Fig. 3). The transverse processes of the cervical spine have an anterior and a posterior tubercle between which the nerve roots emerge as they exit the spinal canal. In the middle and lower vertebrae these anterior and posterior processes are of similar size, however, in C7 the posterior process is much larger than the anterior, which is easy to recognize with US. More distally the plexus can be identified in the interscalene groove, where the middle scalene muscle lies just posterior to the anterior scalene. In the periclavicular region, the nerves of the brachial plexus form a cranial “hood” and posterior to the subclavian artery¹³.

Clinically, the relevant spaces in the trajectory of the brachial plexus are^{12,14}:

- Interscalene triangle: limited by the first rib that forms the base of said triangle and by the anterior and middle scalene muscles (Fig. 4). In the inferior part of the triangle the subclavian artery passes and the inferior trunk of the brachial plexus passes behind the artery. Neurovascular compression usually occurs in this space, caused more frequently by anatomical variants, either of the rib or of the insertions of the scalenes.
- Costoclavicular space: located distal to the Interscalene triangle (Fig. 5) limited anteriorly by the inferior

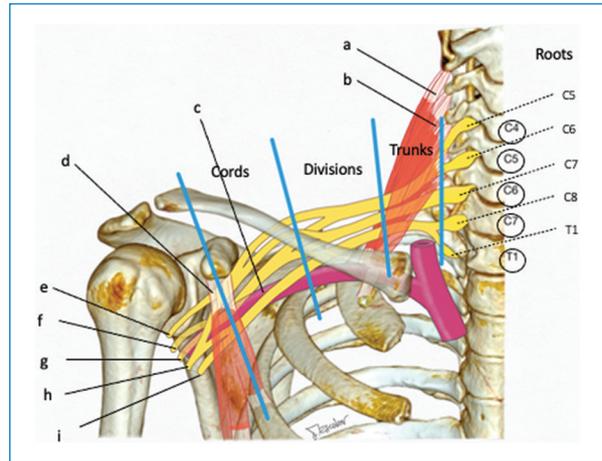


Figure 2. Anatomy of the brachial plexus. **A:** middle scalene muscle. **B:** anterior scalene muscle. **C:** axillary artery. **D:** pectoralis minor muscle. **E:** musculocutaneous nerve. **F:** axillary nerve. **G:** radial nerve. **H:** median nerve. **I:** ulnar nerve.

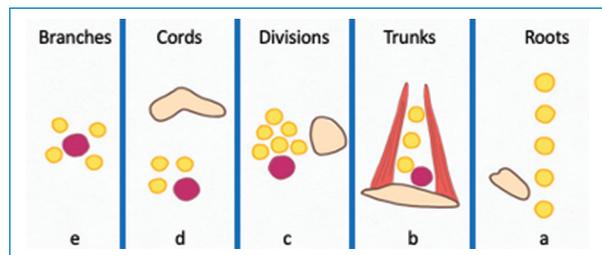


Figure 3. Anatomy of the brachial plexus on the sagittal plane with its anatomical references. **A:** roots in relation to first rib. **B:** trunks in an interscalene triangle in relation to the subclavian artery and on the first rib. **C:** divisions in the retroclavicular region in relation to the subclavian artery. **D:** cords in the infracoracoid region in relation to the axillary artery. **E:** terminal rami in the proximal arm in relation to the axillary artery.

- half of the clavicle, subclavian muscle and costoclavicular ligament. Posteriorly and medially limited by the first rib and the insertion of the anterior and middle scalene. Compression in this space is generally secondary to acquired morphological changes of the clavicle and/or first rib, changes in the scalene muscles, or secondary to trauma. Crossing down the clavicle the cords enter the retropectoralis minor space (Fig. 6).
- Retropectoral minor space (subcoracoid tunnel): during arm elevation, the cords may rest tightly against the pectoralis minor, which may predispose to compression, especially in short, stocky men, causing tingling and weakness in the hands during hyperabduction.

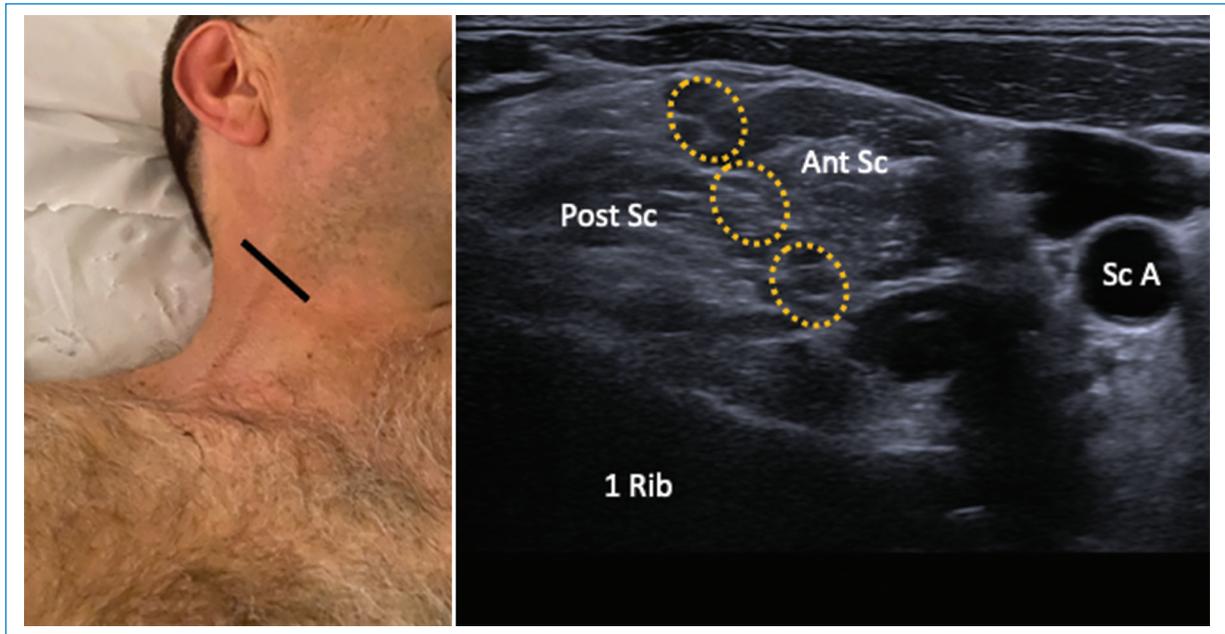


Figure 4. Roots of the brachial plexus. The transducer position is indicated by a black bar. Interscalene triangle: delimited by the first rib that forms the base of the triangle and by the anterior and middle scalene muscles. A Sc: subclavian artery; Esc Med: medium scalene; Esc Ant: anterior scalene.

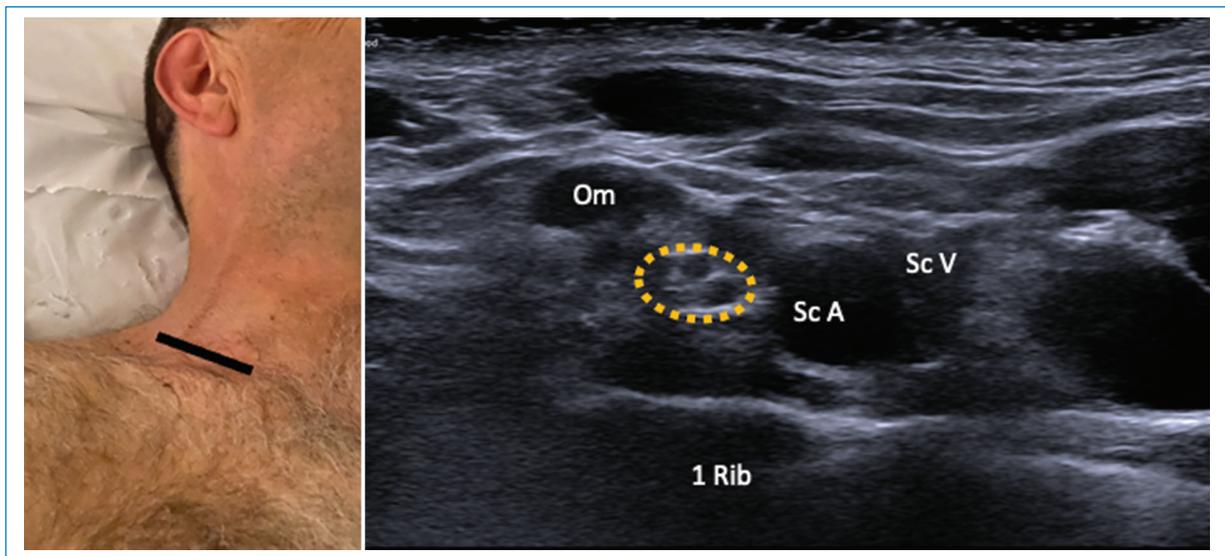


Figure 5. Divisions of the brachial plexus. The transducer position is indicated by a black bar. A Sc: subclavian artery; Om: omohyoid; V Sc: subclavian vein.

Thoracic outlet syndrome involves the brachial plexus and subclavian artery or vein in these three anatomical sites susceptible to compression.

Brachial plexopathy generally manifests with pain, paresthesias¹⁵ and muscle weakness on the affected side¹⁵.

Magnetic resonance imaging (MRI) is generally preferred to study the plexus because of its deep location and complex anatomy. It allows the comparative study with the contralateral side in a reproducible way and also includes the evaluation of muscle planes. US, however,

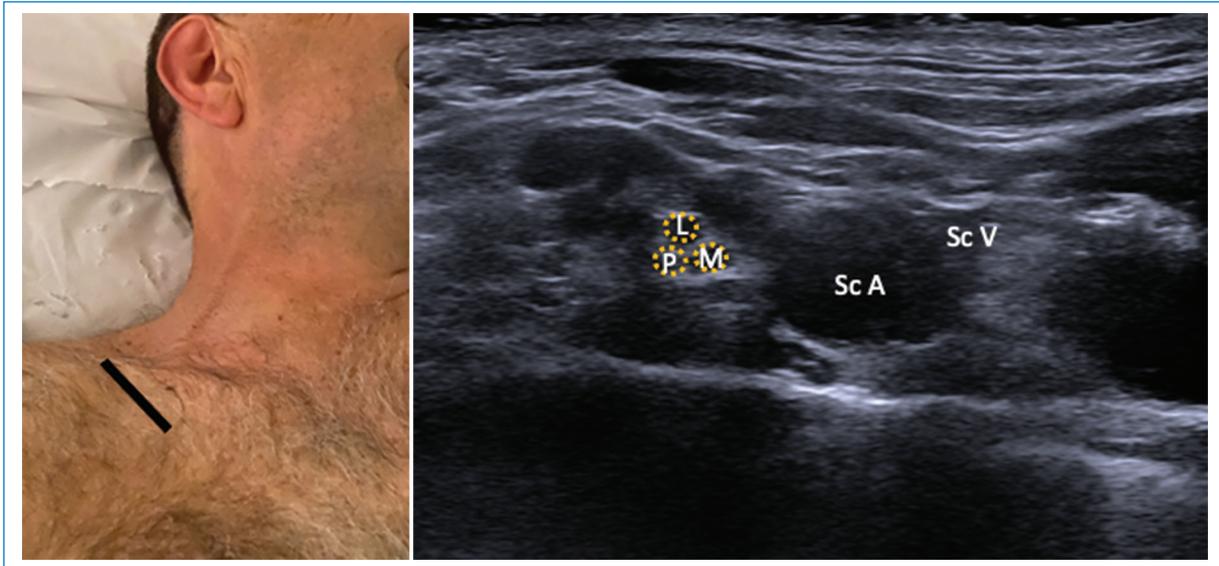


Figure 6. Brachial plexus cords. Infraclavicular region. The transducer position is indicated by a black bar. A Sc: subclavian artery; L: lateral cord; M: medial cord; P: posterior cord; V Sc: subclavian vein.

has an important role in patients with contraindications for MRI, especially to assess distally from the trunks, and in suspected thoracic outlet syndrome due to the possibility of performing dynamic maneuvers during the examination.

Suprascapular nerve

It has sensory and motor branches from the superior trunk of the brachial plexus (C5-C6) and provides motor innervation to the supraspinatus and infraspinatus muscles. From its origin in the brachial plexus it runs through the posterior triangle of the neck and then lateralizes down the trapezius toward the suprascapular notch, where it passes under the suprascapular ligament together with the suprascapular vessels; here the nerve gives off two branches, supraspinatus and infraspinatus. In about half the population, the infraspinatus nerve passes through a separate posteroinferior tunnel covered by the spinoglenoid ligament¹⁵. When the nerve is compressed in the suprascapular notch, there is denervation of the supraspinatus and infraspinatus muscle, and if the compression occurs in the spinoglenoid notch, only the infraspinatus muscle is involved². The most frequent cause of compression is a ganglion originating from a posterior labral lesion¹⁶. Another cause is the practice of activities with the limb above the head or sports activities that determine repetitive traction (volleyball)¹⁵.

For US scanning, the transducer is positioned transversely to the posterior surface of the scapula to show

in its space lateral to the scapulohumeral joint, adjacent to the glenoid labrum. By moving the probe distally or proximally, a characteristic depression or indentation is found in the posterior contour of the scapular surface, the suprascapular notch, which is delimited medially by the spine of the scapula and laterally by the edge of the glenoid fossa. At the base is the suprascapular artery, on the medial side of which the suprascapular nerve passes. The artery passes over the superior transverse scapular ligament and under the inferior one, while the nerve passes under both ligaments, attaching to the bony surface of the supraspinatus and then to the infraspinatus fossa.

US can demonstrate the presence of a ganglion or other space-occupying expansive lesion¹⁷ in the notch that explains the symptoms, but it is not possible to define the characteristics of the nerve, due to its small diameter¹⁸ (Fig. 7).

Spinal accessory nerve

The spinal accessory nerve (SAN) is the 11th spinal nerve; it has a long shallow course on the neck, making it vulnerable to lesions or entrapment. Traditionally it was thought that it was an exclusively motor nerve, however, anatomical studies have confirmed that it also has a sensory component. It innervates the sternocleidomastoid and the trapezius⁸. Chronic entrapment or compartment syndrome of the trapezius can cause chronic painful weakness.

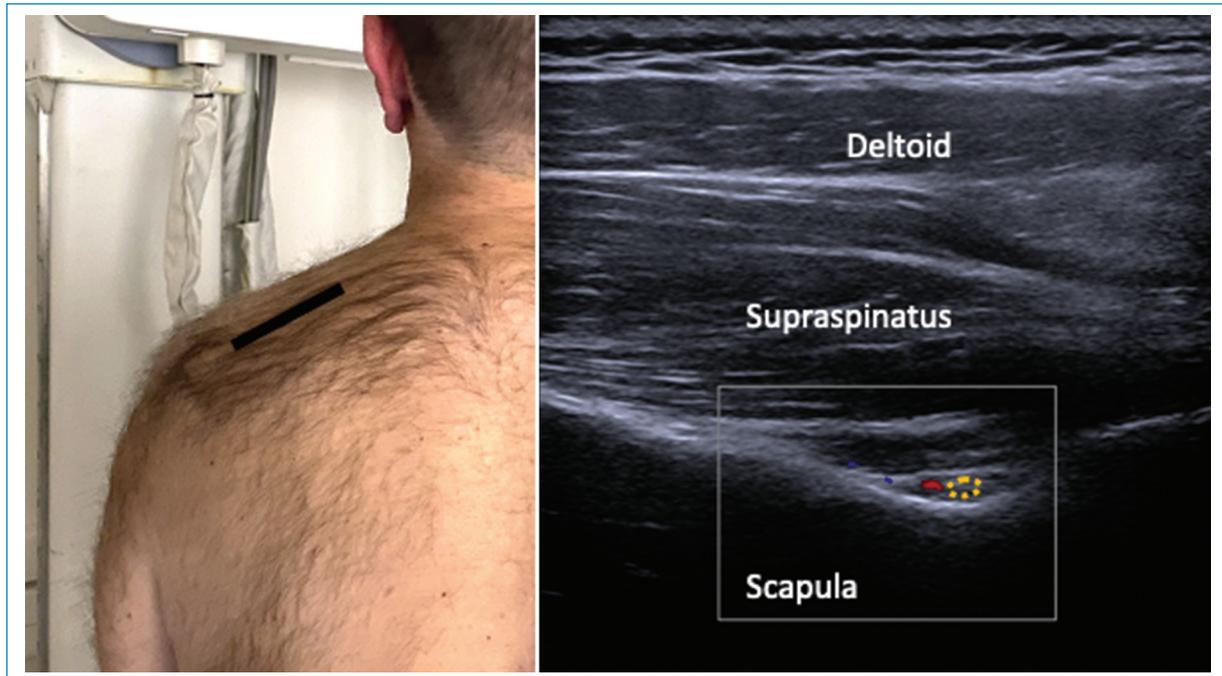


Figure 7. Suprascapular nerve. The transducer position is indicated by a black bar transverse to the posterior aspect of the scapula. Located in the suprascapular notch adjacent to the suprascapular artery (red), under the transverse scapular ligament.

SAN palsy presents with isolated atrophy of the trapezius and sternocleidomastoid (dropped shoulder syndrome), shoulder pain, and neck pain.

Pain has been attributed to entrapment, either caused by the aforementioned chronic compartment syndrome, or by a higher level entrapment lesion secondary to trauma. Post-traumatic adhesions between the nerve and the underlying fascia have been described.

The nerve can be examined on US with high-frequency transducers. It descends from the jugular foramen to the posterior triangle of the neck. This anatomical space is limited, in its superior aspect by the confluence between the sternocleidomastoid and the trapezium, by the trapezium from behind and by the clavicle in its inferior aspect.

Ultrasonographically, it is located at the posterior lateral border of the sternocleidomastoid, where it enters the posterior triangle of the neck¹³ (Fig. 8).

Axillary nerve

It originates from the posterior cord of the brachial plexus. Proximally it passes below the coracoid process and by the anterior surface of the subscapularis muscle. It then turns to the inferior aspect of the scapulohumeral joint and crosses the quadrilateral space passing through

the posterolateral aspect of the surgical neck of the humerus where it divides into anterior and posterior rami. The quadrilateral space is delimited laterally by the medial aspect of the humerus¹⁵, medially by the long head of the triceps, above by the teres minor muscle, and below by the teres major muscle^{19,20}.

The sites of entrapment are the quadrilateral space and the lower zone of the scapulohumeral joint. Impingement can occur during exercise or when the arm is held in prolonged abduction and external rotation, for example, while sleeping.

In the quadrilateral syndrome, the axillary nerve is compressed by traumatic or atraumatic causes¹⁴. It can be secondary to tumors, perilabral cysts, fibrous bands, osteophytes, etc.

The posterior circumflex artery that accompanies the axillary nerve is seen with color Doppler and is the anatomical reference to locate the nerve with US. The transducer is placed in the axillary fossa (parallel to the posterior axillary line) or on the posterior surface of the scapula at the level of the surgical neck of the humerus, parallel to the long axis of the arm, where the inferior border of the teres minor muscle with the adjacent posterior circumflex artery is found. The nerve runs perpendicular to the long axis of the humerus and parallel to the artery. The second protocol (from the

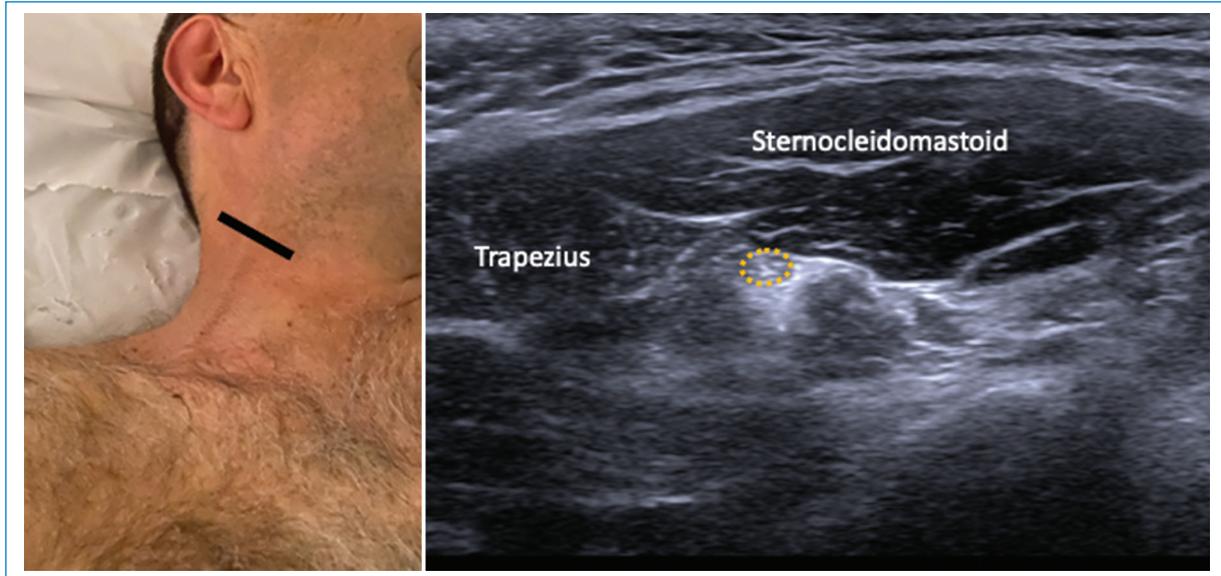


Figure 8. Spinal accessory nerve. The transducer position is indicated by a black bar. Located in the posterior triangle of the neck, between the lateral border of the sternocleidomastoid muscle (SCM) and the medial border of the trapezius.

posterior surface of the scapula) is more comfortable for the patient, since there is no need to abduct the limb²¹ (Fig. 9 A-D).

Musculocutaneous nerve

The musculocutaneous nerve is the fourth largest nerve in the upper extremity¹⁰. It corresponds to one of the terminal branches of the lateral cord of the brachial plexus. It generally receives fibers from the C5 and C6 roots. It is a mixed sensory and motor nerve that provides motor innervation to the coracobrachialis, brachialis, and biceps brachii muscles before piercing the antebrachial fascia. It has anatomical variations such as receiving a contribution from C7 or communicating with the median nerve. In some cases, it may be absent⁵.

After emerging from the lateral cord, the nerve pierces the coracobrachialis muscle, where it can become trapped¹⁴. It is susceptible to traction lesions, resulting in weakness of the biceps brachii and brachialis muscles, as well as difficulty in flexing the elbow.

Distally, the nerve runs between the biceps brachii and coracobrachialis muscle.

On US it is located at the emergence between these muscles and is then located lateral to the biceps brachii tendon, proximal to the elbow crease. It passes through the antebrachial fascia to enter the subcutaneous cellular tissue. The musculocutaneous nerve emerges here

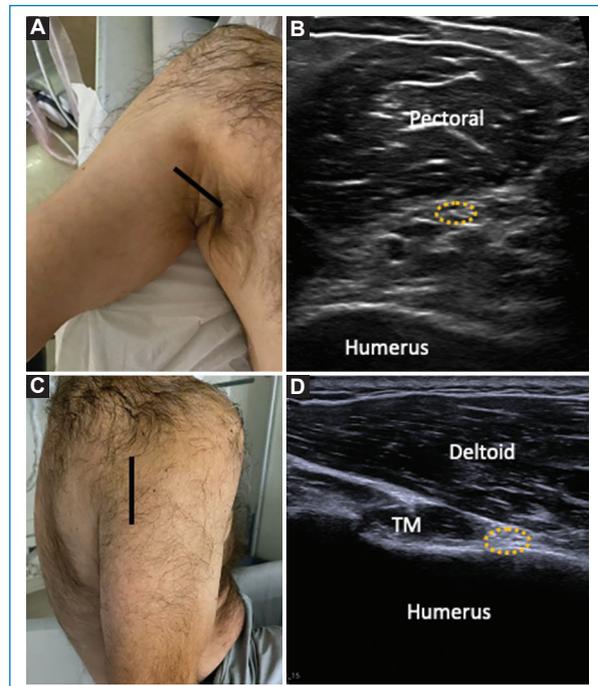


Figure 9. Axillary nerve. **A:** the position of the transducer is indicated by a black bar in the axillary fossa (parallel to the posterior axillary line). **B:** the nerve is located behind the pectoralis major and coracobrachialis muscle. **C:** transducer position is indicated by a black bar on the posterior surface of the scapula in the surgical neck of the humerus, parallel to the long axis of the humerus (humero) and the posterior circumflex artery. **D:** the nerve is located perpendicular to the long axis of the humerus. TM: teres minor

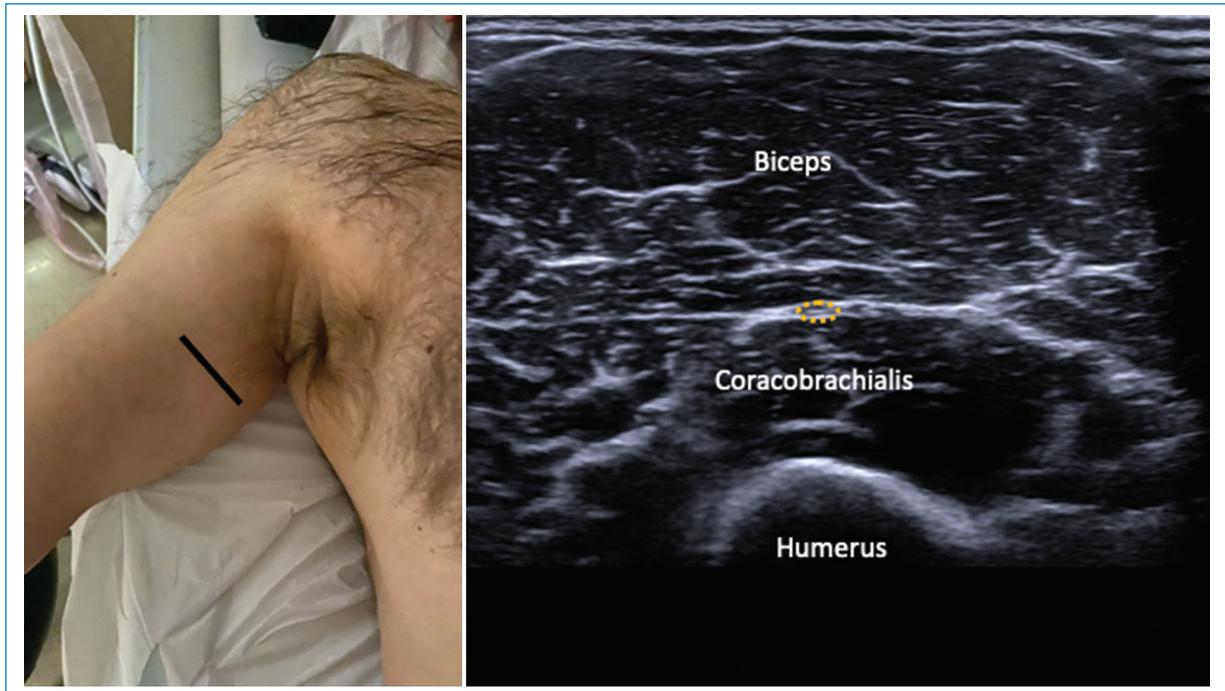


Figure 10. Musculocutaneous nerve. The transducer position is indicated by a black bar. The nerve is located between the biceps brachii and coracobrachialis muscles.

as antebrachial lateral cutaneous nerve. At this point of emergence, in the cubital fossa, the nerve is susceptible to entrapment⁶ (Fig. 10).

Radial nerve

The radial nerve leaves the posterior division of the brachial plexus (C5-T1). It is a sensory motor nerve. It innervates the triceps, supinator longus (brachioradialis), and brevis muscles, extensors carpi radialis, extensor carpi ulnaris, extensor digitorum communis, extensor digitorum proprius, abductor pollicis longus, extensor pollicis brevis and longus, and extensor indicis proprius.

Leaving the plexus, it enters the posterior compartment of the arm, distal to the teres major muscle. The nerve is identified lateral to the long head of the triceps. It continues down between the medial and lateral heads. It courses from medial to lateral through the radial canal of the humerus²².

It advances distally and crosses anteriorly, proximal to the elbow joint. It exits the arm between the brachioradialis and brachialis muscles anterior to the lateral epicondyle. Upon entering the forearm, it divides into a superficial sensory branch that courses in the forearm and a deep motor branch that enters the radial tunnel²³ (Fig. 11).

The motor branch, when it leaves the radial tunnel, runs between the superficial and deep supinator muscles, and when it leaves the posterior face of the supinator muscle, it takes the name of the posterior interosseous nerve (Fig. 12). After leaving the supinator it descends on the dorsal surface of the interosseous membrane dividing into small branches that extend to the extensor muscles of the forearm and terminate on the dorsal aspect of the wrist supplying dorsal carpal proprioception. The superficial branch runs deep to the brachioradialis muscle with the radial artery and provides sensory innervation to the hand.

In the armpit the radial nerve can be compressed by the use of crutches.

The radial canal is the most frequent site of compression, either due to a stabilized humeral fracture with osteosynthesis material or due to "Saturday night palsy"²² which refers to the temporary compression of the radial nerve in the torsion canal; the cause is usually falling asleep with the arm dangling or compressed by the weight of the body¹⁰.

Compression of the motor branch at the elbow can cause radial tunnel syndrome or posterior interosseous syndrome (also called supinator syndrome). It is not known why one syndrome occurs and not the other.

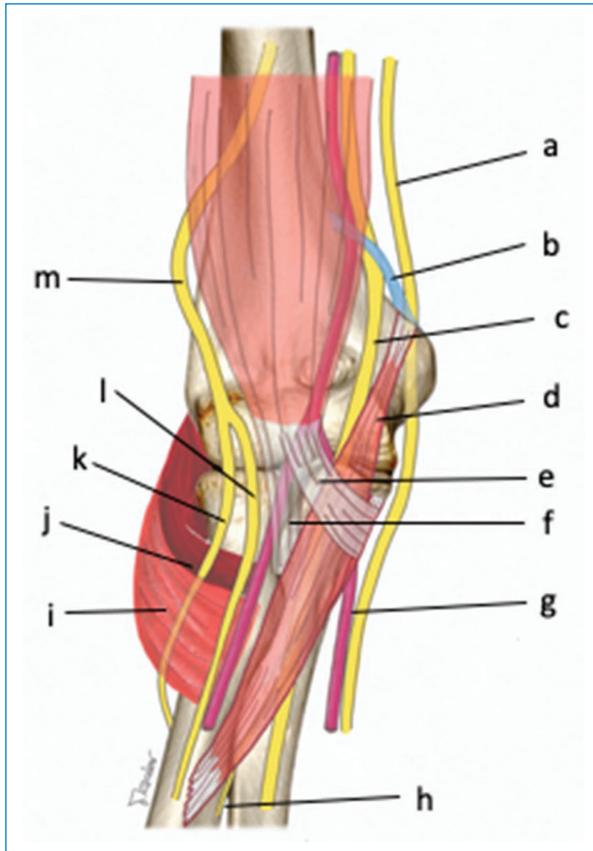


Figure 11. **A:** ulnar nerve. **B:** Sthruther's ligament. **C:** median nerve. **D:** pronator teres muscle. **E:** lacertus fibrous. **F:** biceps brachii tendon. **G:** ulnar artery. **H:** anterior interosseous nerve of the median nerve. **I:** supinator muscle. **J:** arcade of Frohse. **K:** deep branch of the radial nerve. **L:** superficial branch of the radial nerve. **M:** radial nerve.

Proximal sensory branch compression is uncommon and may mimic radial tunnel syndrome. Superficial radial entrapment can occur in the forearm or wrist, producing Wartenberg syndrome¹⁰.

Radial Tunnel Syndrome-Supinator Syndrome

Compression of the motor branch in the elbow can produce, as already mentioned, radial tunnel syndrome or posterior interosseus syndrome (also called supinator syndrome)²⁴.

Radial tunnel syndrome is characterized clinically by tenderness and pain on the lateral aspect of the proximal forearm that mimics lateral epicondylitis, with or without motor weakness.

Supinator syndrome is clinically different. It most frequently presents as paralysis of the extensor muscles of the forearm⁹.

The radial tunnel is an anatomic space that extends from the radiocapitellar joint to the proximal aspect of the supinator muscle.

There are five points where the nerve can become trapped in the tunnel. The most common compression site is the arcade of Frohse (Fig. 11), which represents a thickened tendinous proximal end of the superficial head of the supinator present in approximately 50% of the population. This thickening is generally acquired, secondary to repetitive pronation and supination movements²⁵.

Another rare compression can be caused by the crossing of branches of the recurrent radial artery^{10,22} (anatomical variant), the so-called Leash of Henry²⁵.

Also, compression can occur as a consequence of masses, cysts, bicipitoradial bursitis, etc.

US shows an increase in volume of the posterior interosseous nerve at the compression site, with or without reduced echogenicity in the fascicles. The normal cross-sectional area of the radial nerve has been estimated at 7.2 mm² in the humeral shaft, 6.2 mm² in the intermuscular septum, and 2.3 mm² in the supinator area¹⁰ (Fig. 13). In the authors' experience, measurements alone do not make the diagnosis. It is the morphological and ultrasound characteristics of the nerve that make it possible to consider compression with greater certainty.

WARTENBERG SYNDROME OR CHEIRALGIA PARAESTHETICA¹³, ALSO CALLED «HANDCUFF NEUROPATHY»²⁶

The superficial sensory branch runs through the subcutaneous tissue 5-10 cm proximal to the radial styloid close to the cephalic vein (Fig. 15).

Its entrapment is characterized by pain and paresthesias on the dorsal radial surface of the forearm, with radiation to the dorsum of the thumb, index, and middle fingers.

Some physical activities that require pronation of the forearm with simultaneous flexion and ulnar deviation of the hand predispose to compression of the superficial branch of the radial nerve between the brachioradialis muscle and the extensor carpi radialis. On US it is not difficult to identify this branch in the deep subcutaneous cellular tissue, proximal to the radial styloid (Fig. 16).

It can be seen in association with De Quervains tenosynovitis or decompressive surgery of the first extensor compartment. Other possible causes are venous cannulation, distal radius fracture, use of compression bandages, jewelry, or wristwatch.

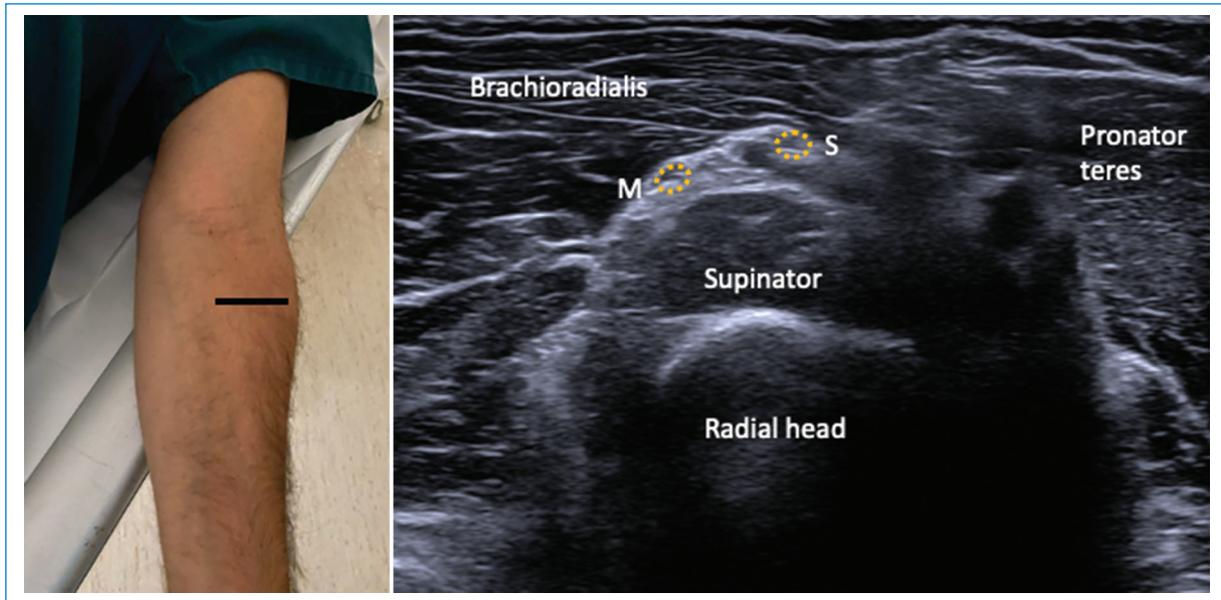


Figure 12. Radial nerve. The transducer position is indicated by a black bar. Location in the forearm of the division of the radial nerve into a superficial sensory branch and a deep motor branch or posterior interosseous nerve (PIN).

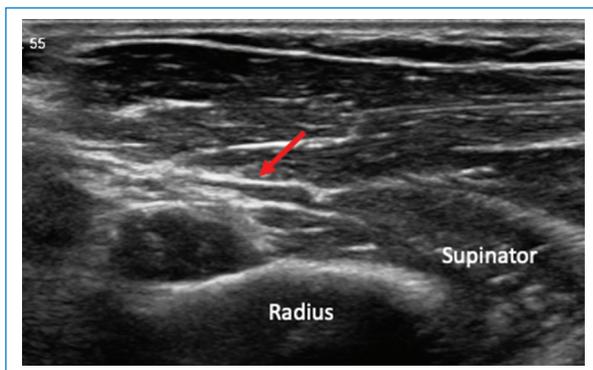


Figure 13. Compression of the posterior interosseous nerve (PIN). A change in nerve caliber is observed at the compression site (red arrow) with increased proximal volume and decreased echogenicity of the fascicles.

Median nerve

It is formed by the union of the medial (C5 to C7) and lateral (C8 to D1) divisions of the brachial plexus. It is a mixed nerve, located in relation to the lower edge of the pectoralis minor²¹. It advances up the arm next to the brachial artery.

At the distal end of the humerus there is an anatomical variant, the supracondylar process, which consists of a bone spur arising on the anteromedial aspect of the distal third of the humerus and oriented towards the elbow. It is associated with the Struthers ligament (Fig. 11) which runs from the tip of said process to the

epitrochlea determining a foramen through which the median nerve and the brachial artery pass.

At the elbow, the nerve follows to the cubital fossa medial to the biceps tendon and passes to the forearm between the two heads of the pronator teres (Fig. 17). In the forearm it is positioned below the flexor digitorum superficialis and above the flexor digitorum profundus (Fig. 18). In the forearm, it innervates the pronator teres, palmaris major, and flexor digitorum superficialis.

Then, it gives off the branch of the interosseus that lies between the flexor digitorum profundus and the flexor pollicis longus, which it innervates. It also innervates the pronator quadratus.

Just before entering the carpal tunnel, the main trunk of the median gives off the palmar cutaneous branch (Fig. 19). Upon exiting the tunnel, it innervates the abductor brevis, the flexor pollicis brevis, and the I and II lumbricals.

Median nerve entrapment at the elbow presents in two different ways:

- Pronator syndrome: patients present pain and paresthesias mimicking carpal tunnel syndrome.
- Anterior interosseous nerve syndrome (Kiloh-Nevin syndrome): in which patients have only motor symptoms.

Pronator syndrome

It presents clinically with pain and paresthesias in the volar aspect of the elbow, forearm, and hand affecting

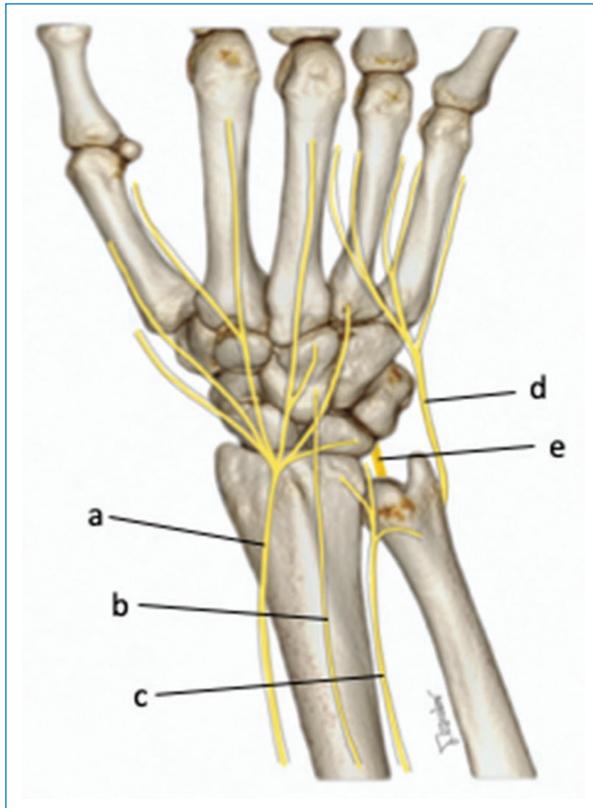


Figure 14. **A:** superficial branch of the radial nerve. **B:** posterior interosseous nerve of the radial nerve. **C:** posterior cutaneous nerve of the radial nerve. **D:** ulnar nerve. **E:** dorsal branch of the ulnar nerve.

the first, second, and third fingers, as well as the radial half of the ring finger.

The median nerve can get caught in four places around the elbow:

- At the level of the distal humerus by Struthers' ligament: the ligament extends from the supracondylar process to the medial epicondyle. The bone spur and ligament can be easily identified on US, however examination always requires radiographic verification.
- At the level of the proximal elbow by an aponeurosis of thickened biceps brachii, due to trauma, overuse of the biceps, due to bicipitoradial bursitis, or formation of a hematoma after intravenous or brachial artery puncture.
- At the level of the elbow joint, between the two heads of the round pronator muscle (superficial and deep). Compression may be associated with trauma with hematoma, pronator teres hypertrophy, or congenital anomalies. Other causes at this level of compression can be tumors (hemangiomas, lipomas) or degenerative or traumatic bone extrusions.

- At the level of the proximal forearm. It is the most common site of compression, usually from a thickened proximal edge of the flexor digitorum superficialis muscle or a fibrous band between the pronator teres and flexor digitorum superficialis.

Anterior interosseous nerve

Its entrapment determines the Kiloh-Nevin syndrome. It is a very small nerve that corresponds to the main motor branch of the median nerve in the forearm. It originates from the median trunk, just distal to the pronator teres (Fig. 11) and innervates the flexor pollicis longus, pronator quadratus, and flexor digitorum profundus muscles. It presents clinically as a motor deficit, which typically consists of weakness or inability to join the thumb and index finger, which translates into involvement of the flexor pollicis longus, flexor digitorum profundus, and pronator quadratus muscles. The severity of the symptoms depends on the degree of nerve compression.

The most common causes are the presence of bruises or masses of another nature in the course of the nerve. It can also be due to an interosseous artery of higher caliber. Less frequent is its occurrence in the context of Parsonage-Turner syndrome or acute brachial neuritis²⁸.

Because it is a small nerve and its location deep, its evaluation with US is difficult. Locating the interosseous artery in front of the interosseous membrane gives us an idea of the position of the nerve.

In cases of chronic entrapment, it is possible to detect changes due to muscle atrophy in the muscles innervated by the flexor pollicis longus¹³.

Median nerve entrapment at the wrist presents as carpal tunnel syndrome, which is the most common entrapment neuropathy. Consists in compression of the median nerve as it passes through the carpal tunnel²⁹ (Fig. 14).

Prevalence is 2% in the adult population. Women are affected three to five times more often than men. It is bilateral in up to 50% of cases.

The median nerve provides sensory and motor innervation to the thumb, index, middle finger, and radial half of the ring finger.

Clinically, patients present with a history of nocturnal pain, clumsiness, and tingling in said distribution³⁰. Sensory loss usually precedes motor deficit. On physical examination, there may be atrophy of the thenar eminence.

The cause of the entrapment is idiopathic in most cases³¹, however in some cases it is possible to

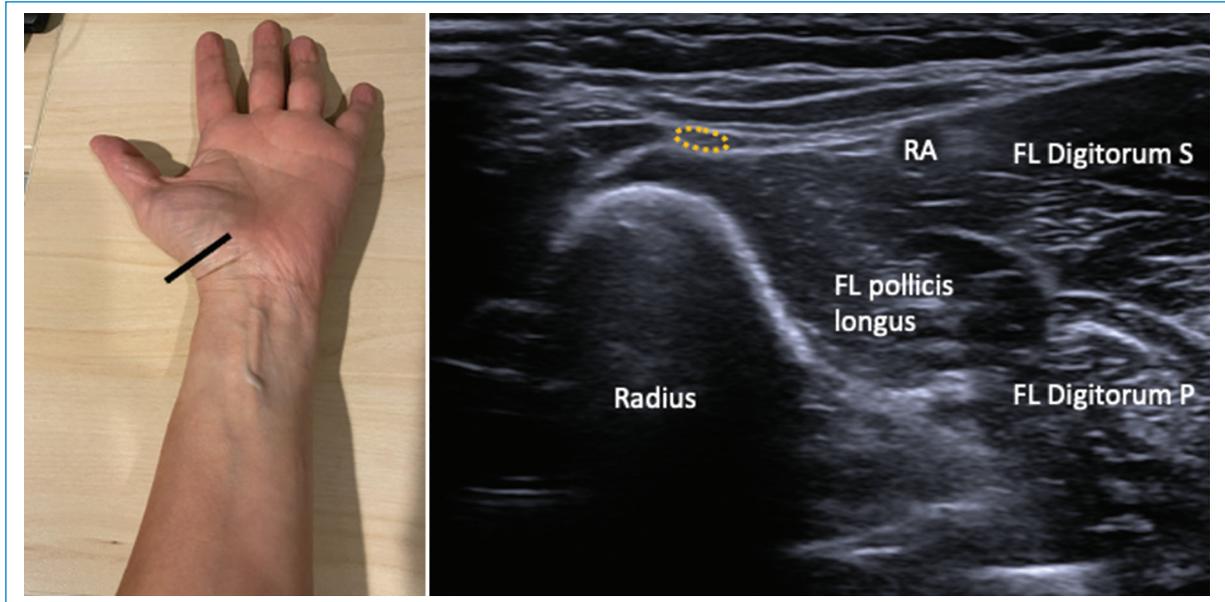


Figure 15. Superficial sensory branch of the radial (radio) nerve. The transducer position is indicated by a black bar. Located in the subcutaneous tissue proximal to the radial styloid. AR: radial artery; FL: flexor pollicis longus.

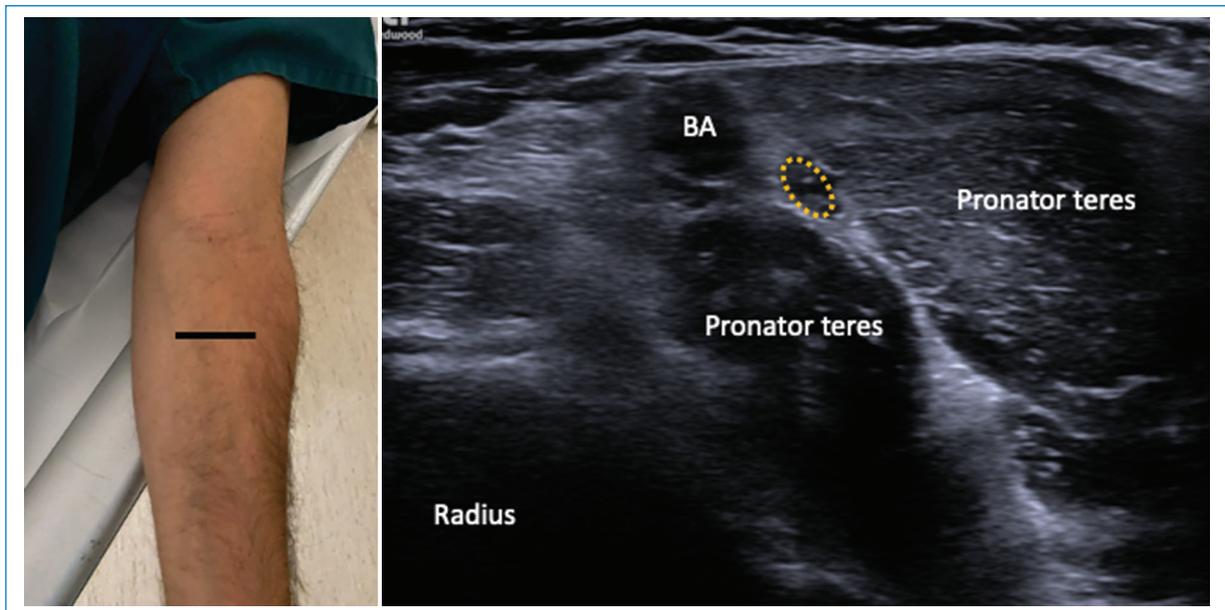


Figure 16. Median nerve. The transducer position is indicated by a black bar. Location of the nerve in the forearm between the two heads of the pronator teres. AB: brachial artery.

demonstrate the cause of the compression, such as osteoarthritis or increased tunnel content due to ganglions, accessory muscles, overuse or inflammatory tenosynovitis, amyloid deposits or gout, etc. There are conditions that decrease the size of the carpal tunnel that can cause

neuropathy: pregnancy, obesity, rheumatoid arthritis, diabetes, hypothyroidism, acromegaly³².

US is an accurate tool for the diagnosis of carpal tunnel syndrome and provides additional information on the severity³³ of the compression³⁴.

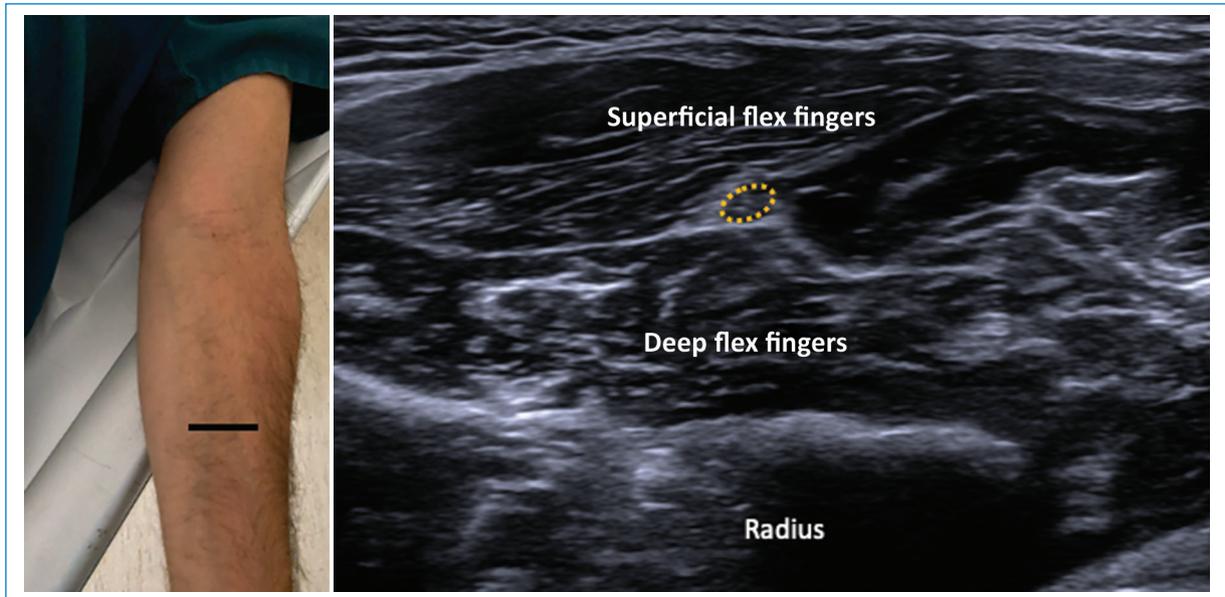


Figure 17. Median nerve. The transducer position is indicated by a black bar. Location on the forearm between the superficial and deep flexors of the fingers.

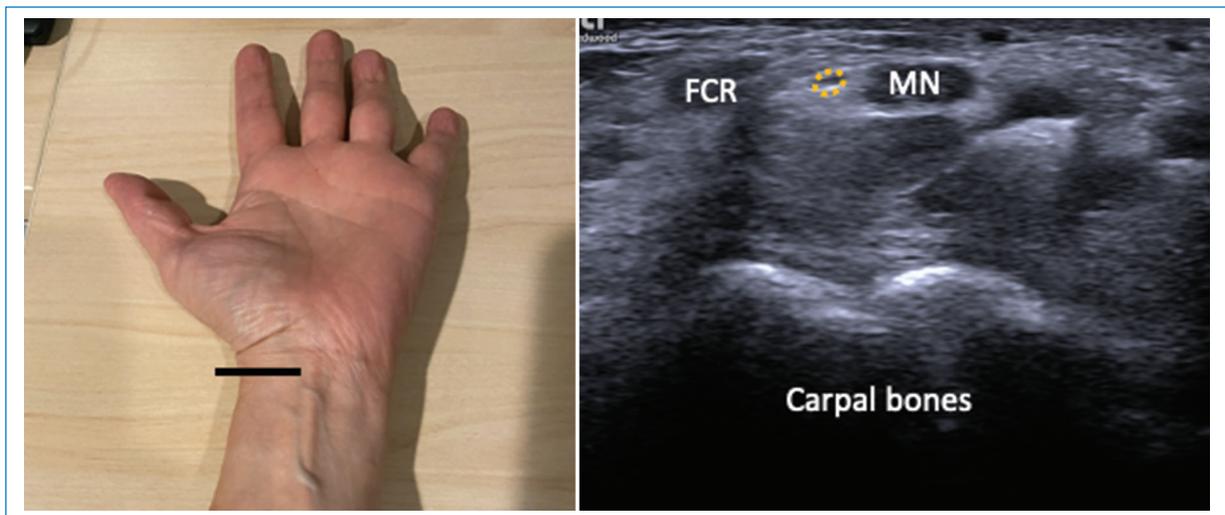


Figure 18. Cutaneous-palmar branch of the median nerve. The transducer position is indicated by a black bar. This branch arises from the radial side of the median nerve (NM), proximal to the flexor retinaculum, adjacent to the flexor carpi radialis (FRC).

The diagnosis using US is made based on the following findings¹⁰:

- Increased caliber of the nerve. It is evaluated by comparing the difference in cross-sectional area at two points (delta value): at the level of the carpal tunnel and at the level of the pronator quadratus in the distal forearm. If the difference is greater than

2 mm², it is considered an entrapment criterion. Based on this delta value, the severity of entrapment is defined as: slight, between 2 and 6 mm²; moderate, between 6 and 9 mm², and severe, greater than 9 mm².

In the authors' experience, the difference of the cross-sectional area between two points contributes

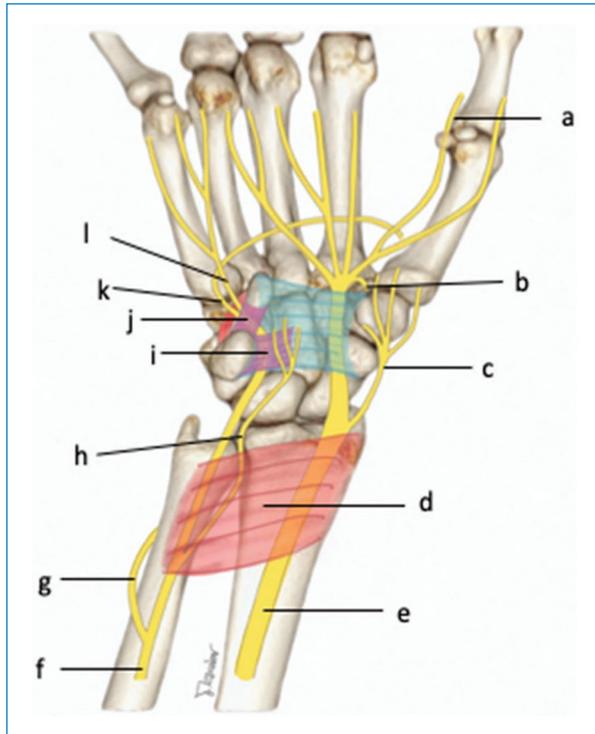


Figure 19. **A:** ulnar digital nerve of the thumb. **B:** recurrent thenar nerve of the median nerve. **C:** palmar cutaneous branch of the median nerve. **D:** pronator quadratus muscle. **E:** median nerve. **F:** ulnar nerve. **G:** dorsal branch of the ulnar nerve. **H:** palmar cutaneous branch of the ulnar nerve. **I:** volar carpal ligament. **J:** pisohamate ligament. **K:** deep branch of the ulnar (motor) nerve. **L:** superficial branch of the ulnar (sensory).

more to the diagnosis than the absolute average value in a single slice.

The evaluation should cover the entire course of the nerve in the carpal tunnel, because occasionally the area of greatest caliber is distal to the carpal tunnel instead of proximal; this feature is known as the “reversed notch” sign.

A bifid median nerve is a possible variant of nerve anatomy that may be present with a persistent median artery. The nerve can be partially or completely bifid or even trifid. In this case, to estimate the diameter of the nerve, the areas of the lateral and medial branches of the nerve must be added, and a new delta cutoff value of 4 mm² instead of 2 mm² applied.

- Distal flattening of the median nerve.
- Bulging of the flexor retinaculum (> 2 mm above the line that joins the hamate-pisiform bones to the trapezium-scaphoid bones) (Fig. 20).

PALMAR CUTANEOUS NERVE OR PALMAR CUTANEOUS BRANCH OF THE MEDIAN NERVE

This branch exits from the median nerve, proximal to the flexor retinaculum, adjacent to the flexor carpi radialis tendon (Fig. 14). It is a sensitive nerve. Neuropathy of this nerve is characterized by sensory deficits in the palmar triangle and the thenar eminence³⁵. It is generally found in patients undergoing surgery for carpal tunnel syndrome, ganglion resection, or penetrating trauma¹⁰. The most common findings are hypoechoic enlargement of the nerve, post-surgical and/or post-traumatic changes (scar-neuroma). To identify this branch, it is recommended to locate the median nerve in the forearm and continue distally until before the retinaculum where it emerges on the radial side¹³ (Fig. 19).

RECURRENT THENAR BRANCH OF THE MEDIAN NERVE

It exits the median nerve, distal to the retinaculum, and supplies motor innervation to the superficial head of the flexor pollicis brevis and adductor pollicis brevis, the opponens pollicis, and in some cases the first dorsal interosseus (Fig. 14). To identify this nerve, it is recommended to locate the median nerve in the tunnel. The recurrent branch arises most of the time distal to the retinaculum, from the palmar or radial aspect of the median¹³ (Fig. 21).

It can be injured after a surgical procedure due to carpal tunnel syndrome or the presence of ganglions. It usually produces a loss of the musculature of the thenar eminence and reduced opposition of the thumb. This nerve is known as the “million-dollar nerve”, since its iatrogenic lesion has generated large financial compensation³⁶.

ULNAR DIGITAL NERVE OF THE THUMB (BOWLER’S THUMB)

This sensory branch, the median nerve branch¹³ (Fig. 14) innervates the ulnar aspect of the thumb. To identify this nerve, it is recommended to first locate the flexor pollicis longus tendon at the first metacarpophalangeal joint and move the transducer slightly towards the tendon (Fig. 22).

Its repetitive compression produces perineural fibrosis that causes pain and paresthesias. There may also be difficulty in clenching or making a fist, especially pincer movements involving the thumb. Bowlers are susceptible to this pathology from repetitive abduction of the thumb or compression of the thumb when throwing the ball.

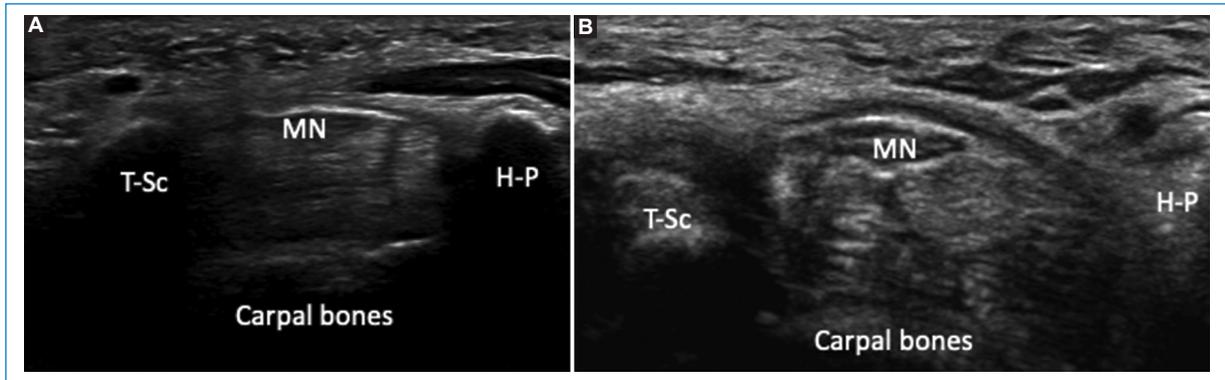


Figure 20. **A:** normal flexor retinaculum. **B:** bulging flexor retinaculum. More than 2 mm above the line that joins the hamate-pisiform bones (G-P) to the trapezium-scapoid (T-E). MN: median nerve.

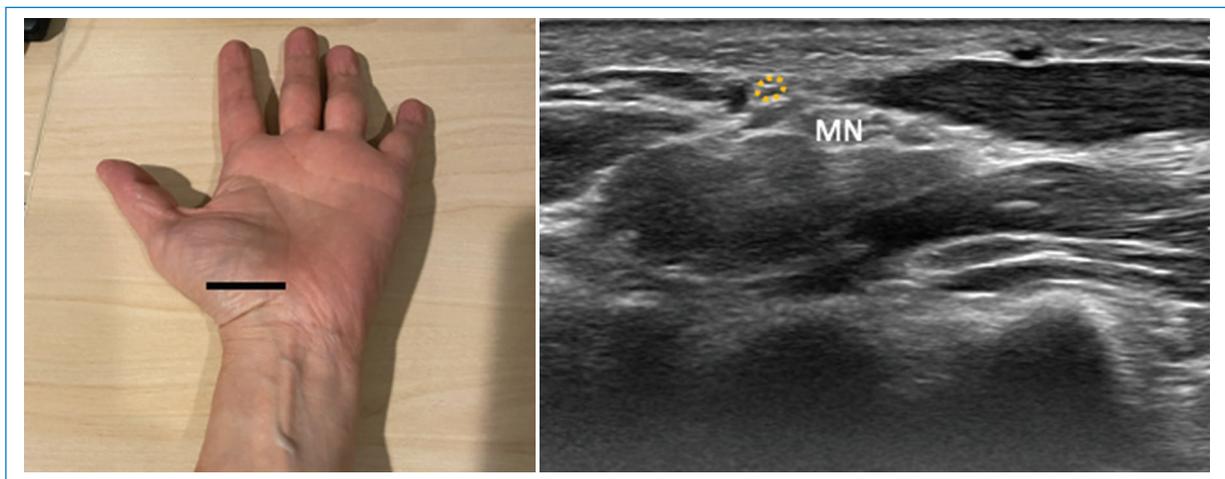


Figure 21. Recurrent thenar branch of the median nerve (NM). The transducer position is indicated by a black bar. It arises from the radial palmar aspect of the median nerve, distal to the flexor retinaculum.

Ulnar nerve

It is a mixed nerve originating from the medial chord of the brachial plexus. Roots from C8 to T1 contribute to its formation. It descends on the posteromedial side of the humerus, together with the median nerve and the brachial artery (Fig. 11), passing through the ulnar canal, which is formed by the medial epicondyle, the olecranon and a fibrous roof or Osborne ligament³⁷ (Fig. 23).

Upon reaching the elbow, it gives off the first branches to the flexor carpi ulnaris muscle. It enters the flexor compartment of the forearm via the heads of the flexor carpi ulnaris and runs medial to the ulna. It then descends along with the ulnar artery deep to the flexor digitorum profundus. It enters the palm of the hand

through Guyon's canal or cubital tunnel, formed in part by the pisiform and the hook of the hamate (Fig. 14).

Compression of the ulnar nerve is the second most frequent entrapment of the upper extremity³².

It can occur in the elbow, cubital tunnel syndrome, and in the wrist, Guyon's canal syndrome.

CUBITAL TUNNEL SYNDROME

Ulnar neuropathy at the elbow is more common in men. The nerve is compressed in the cubital tunnel, an osteofibrous tunnel formed by: the olecranon process laterally, the medial epicondyle medially, the articular capsule and posterior band of the collateral ligament on the anterior aspect, and Osborne's retinaculum (including the arcuate ligament) in the posterior aspect.

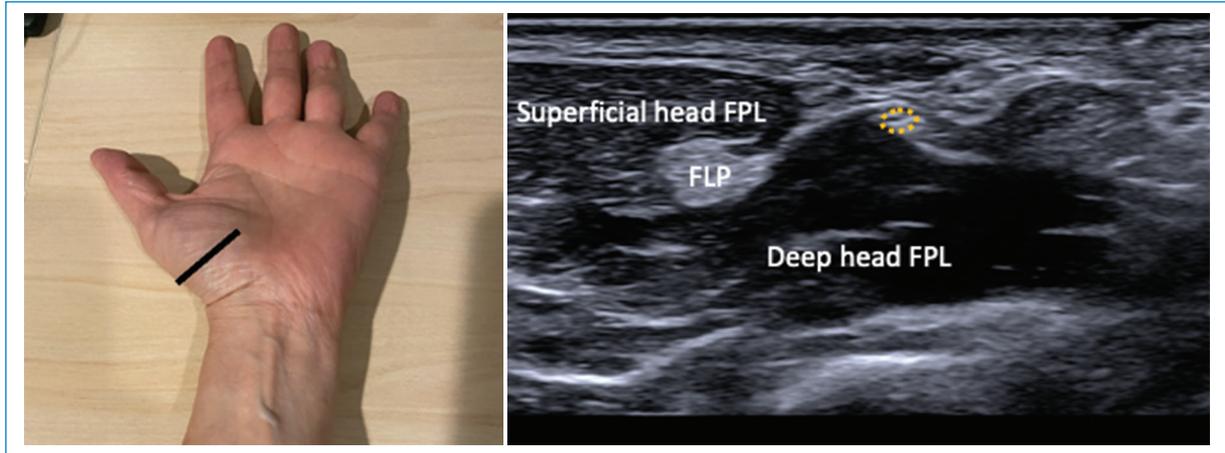


Figure 22. Ulnar digital nerve of the thumb. The transducer position is indicated by a black bar. It arises from the median nerve, to locate it is recommended to first locate the flexor pollicis longus tendon at the first metacarpophalangeal joint and move the transducer slightly towards the tendon. FLP: flexor pollicis longus.

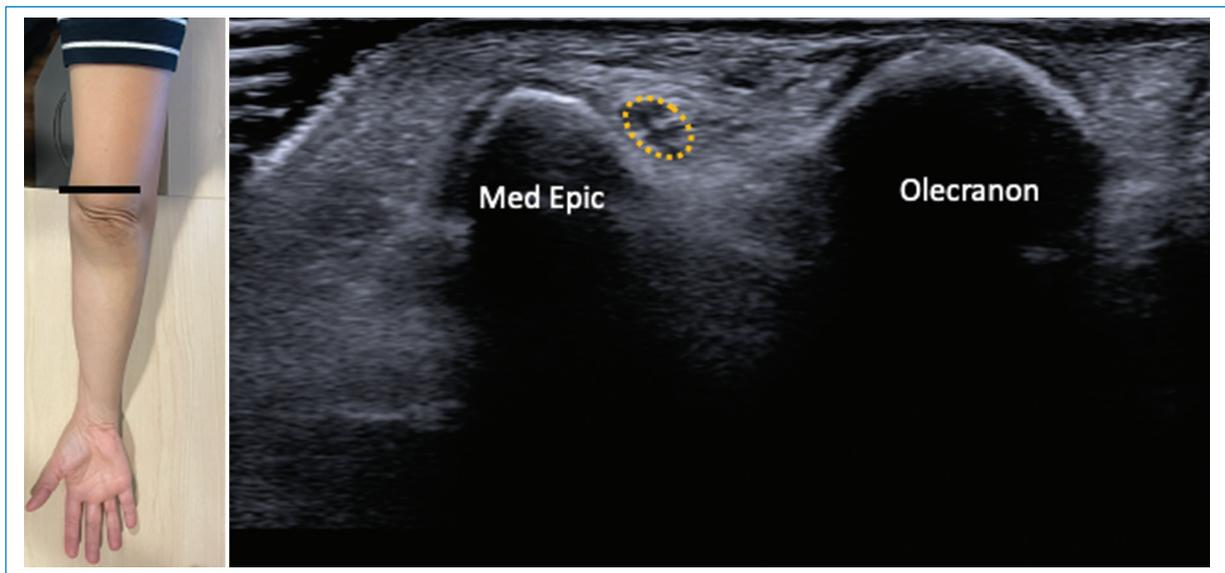


Figure 23. Ulnar nerve in ulnar canal. The transducer position is indicated by a black bar. Ulnar nerve in the ulnar canal formed by the medial epicondyle (Epic. med.), olecranon and Osborne's ligament.

Said retinaculum exerts a static pressure on the nerve. Elbow flexion increases pressure inside the tunnel.

Patients at risk for elbow flexion-induced ulnar neuropathy include truck drivers (resting their flexed elbow on an open window) and cell phone users. Elbow trauma can also cause ulnar neuropathy, usually late in relation to fracture. Another risk group are patients with dislocation of the nerve during elbow flexion³⁸. The causes of nerve dislocation are: absence of retinaculum, shallow epicondylar groove, and laxity of the arcuate ligament³⁹.

Clinically, these patients consult for pain, paresthesias, and weakness on the ulnar side of the hand (fourth and fifth fingers)²². In mild cases, patients describe intermittent symptoms that may be caused by prolonged elbow flexion. Other symptoms are weakness to take hold of things or difficulty buttoning. Crossing the fingers can also be difficult due to the involvement of the interosseous muscles³².

After carpal tunnel syndrome, it is the most common entrapment neuropathy³⁸.

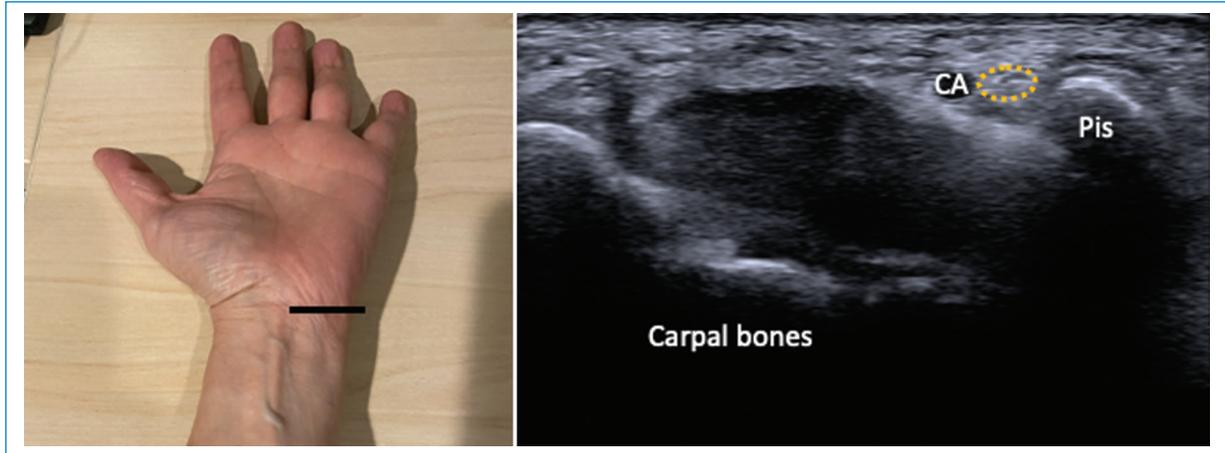


Figure 24. Ulnar nerve in Guyon's canal. The transducer position is indicated by a black bar. Ulnar nerve in Guyon's canal formed in part by the pisiform (Pis) and the hook of the hamate. AC: ulnar artery.

On US we found an increase in the caliber of the nerve in the tunnel, with decreased echogenicity and loss of the honeycomb pattern. It must be taken into account that the nerve normally increases its diameter slightly in the medial epicondyle and this should not be confused with pathology²⁸.

The average normal area of the nerve in a cross-sectional slice is 10 mm², however there are individual differences. Two measurements are then made: the first in the area where the nerve is most voluminous (generally at the level of the epicondyle) and the second more proximal at the level of the head of the medial triceps. A difference between the area of the nerve at the level of the ulna and the humerus > 1.4 mm² is considered a positive value when associated with structural changes of the nerve¹⁰. Comparison with the contralateral side may be useful⁴⁰.

Dynamic US during flexion and extension is a real-time diagnostic method for assessing transient dislocation and can visualize both the nerve and the medial head of the triceps, but may need to be performed during resisted flexion and extension to show abnormal motion of the nerve. There may be another compression site distal to the elbow, in the flexor carpi ulnaris.

The role of US is also to exclude external compression by loose bodies, osteophytes, bone fragments arising from the elbow joint, space-occupying lesions such as tumors or hematomas, synovitis, and accessory muscles (epitrochlear anconeus).

GUYON'S CANAL SYNDROME

Guyon's canal is an oblique osteofibrous tunnel 4 cm long, delimited by the pisiform bone (medial) and by the

hook of the hamate (lateral). The deep limit is determined by the flexor retinaculum and its roof by the superficial volar carpal ligament. Its content is: ulnar nerve, ulnar artery and vein (Fig. 24). The nerve divides within the canal and gives off a superficial sensory branch and two or three deep motor branches.

Its compression initially produces paresthesias and then motor disturbances in the ring and little fingers, as well as weakness in the palmar muscles.

Extrinsic compression of the canal can be caused by the handlebars in cyclists, tennis rackets, or in golfers. It has been called the «cyclist's palsy»²⁶.

Another form of extrinsic compression is hammer syndrome due to repetitive trauma over the hypothenar area against the hook of the hamate²⁷.

On US we found an increase in the caliber of the nerve that should be measured at two points: a proximal one, in the radioulnar joint, and a distal one, in the site of the greatest caliber of the nerve in the canal.

One should look for a space-occupying lesion: varicose veins, ulnar artery pseudoaneurysm, lipoma, ganglion. Other possible causes of compression are thrombosis or aneurysm of the superficial palmar branch of the ulnar artery and the presence of the accessory abductor digiti minimi muscle.

PALMAR (CUTANEOUS) BRANCH OF THE ULNAR NERVE

It arises from the ulnar nerve in the distal forearm, approximately 5 cm proximal to the wrist (Fig. 14). It can be found in Guyon's canal, between the pisiform and

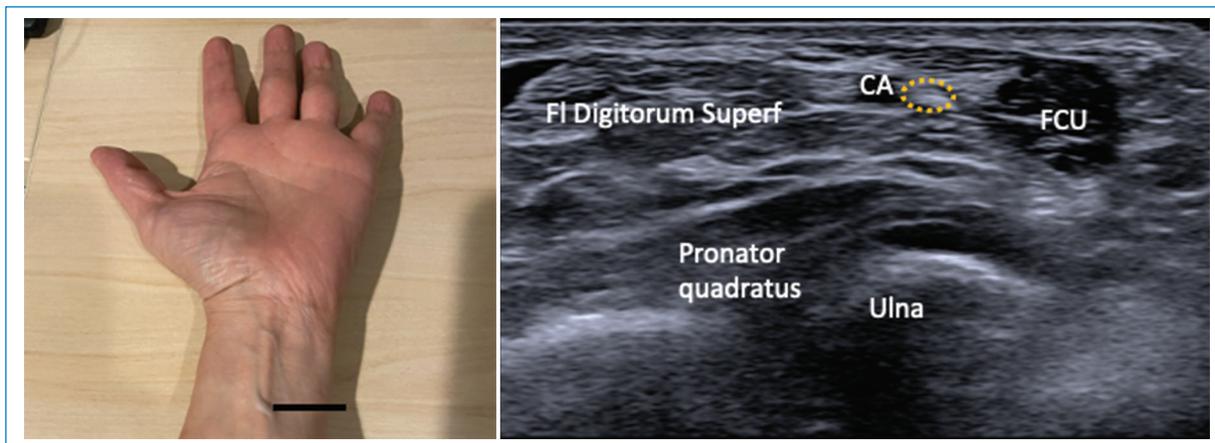


Figure 25. Palmar branch of the ulnar nerve. The transducer position is indicated by a black bar. It arises from the ulnar nerve in the distal forearm, approximately 5 cm proximal to the wrist, between the flexor muscles. FI: flexor digitorum superficialis; AC: ulnar artery; FCC: flexor carpi ulnaris.

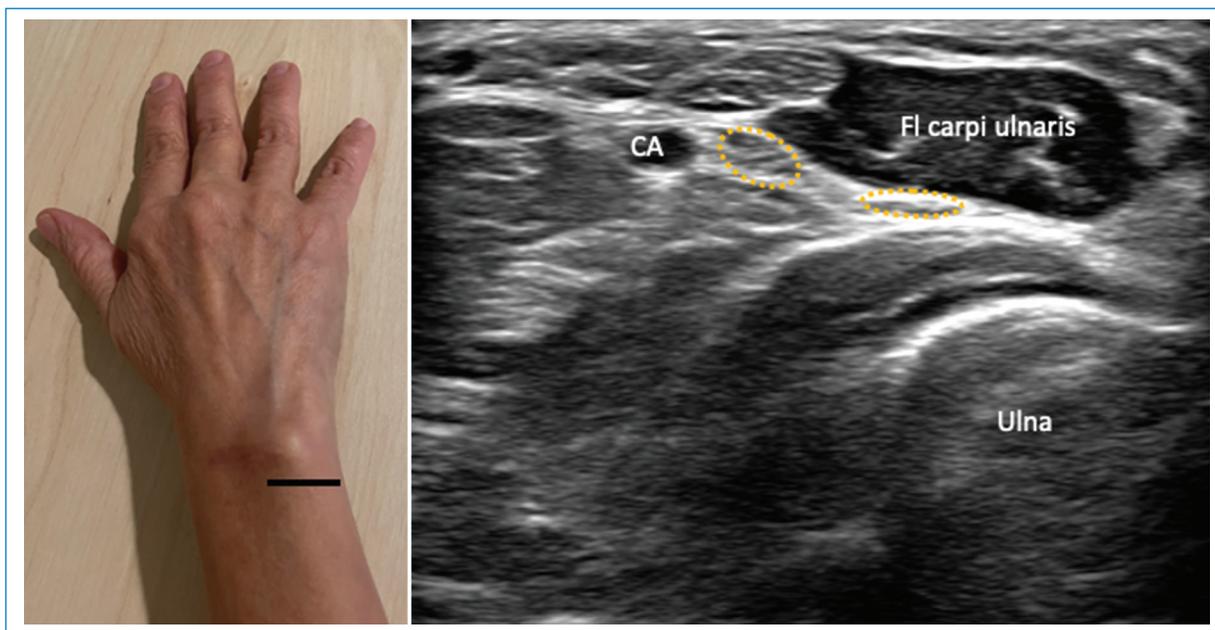


Figure 26. Dorsal branch of the ulnar nerve. The transducer position is indicated by a black bar. It emerges from the ulnar nerve in the distal forearm. It is recommended to follow the ulnar nerve in the forearm, adjacent to the ulna in the deep plane of the flexor carpi ulnaris, identifying the dorsal branch that arises medially and runs along the medial aspect of the ulna. AC: ulnar artery.

ulnar artery, where it gives off superficial sensory branches and deep motor branches. This nerve may be compressed by ganglions or cysts of the pisotriquetral joint or other intercarpal joints. Less frequent are vascular compressions. The symptoms of this neuropathy are motor, sensory or mixed depending on the level of compression¹³ (Fig. 25).

DORSAL BRANCH OF THE ULNAR NERVE

This branch also arises on the distal forearm, providing sensory innervation to the dorsum of the little finger and the dorsal and ulnar aspects of the ring finger (Figs. 14 and 15). To identify this nerve, it is recommended to follow the ulnar nerve in the forearm, adjacent to the ulna,

in the deep plane of the flexor carpi ulnaris (Fig. 26). The nerve is then followed distally, identifying the dorsal branch that arises medially and runs along the medial aspect of the ulna¹³. This neuropathy can be found in cases of fractures or ulnar osteotomies.

Conclusion

Most entrapment neuropathies are treatable and reversible if diagnosed early. Imaging diagnosis plays an important role. US, in expert hands and with adequate equipment, is the study technique of choice. The radiologist must know the anatomy, the study technique of each nerve in particular, the etiopathogenesis and the clinical presentation for a correct interpretation.

Funding

The authors declare that they have not received any source of funding.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical disclosures

Protection of people and animals. The authors declare that no experiments were carried out on humans or animals for this research.

Data confidentiality. The authors declare that this article does not contain data on patients.

Right to privacy and informed consent. The authors declare that no patient data appears in this article.

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