Ultrasound of the Ulnar Nerve: A Pictorial Review

Part 1: Normal Ultrasound Findings

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This is the first of a two-part article in which we focus on the ultrasound (US) appearance of the normal ulnar nerve (UN) and its main branches. The detailed US anatomy of the UN course is presented with high-resolution US images obtained with the latest-generation US machines and transducers.

Key Words—cubital tunnel; entrapment; Guyon; Struthers arcade; ulnar nerve

The ulnar nerve (UN) is the terminal branch of the medial cord of the brachial plexus, with contribution from the ventral rami of C8 and T1 nerve roots; it may also have additional contribution from C7.[1] UN entrapment at the elbow is the second most common clinically relevant compression neuropathy in the upper extremity, after carpal tunnel syndrome.[1,2] Other locations of UN pathology are less frequent, but should be kept in mind by clinicians when evaluating patients with suspected ulnar neuropathy.

Ultrasound (US) is currently an established imaging modality with which to demonstrate normal nerves and their pathological conditions. Recent transducers allow acquisition of exquisite details of nerves and surrounding structures, particularly when superficial. In trained hands, the entire course of a nerve at a limb can be quickly followed to focus on where an alteration is depicted.[3–10] Moreover, according to a recent international expert consensus, investigations of clinically suspected ulnar neuropathy at the elbow should include a US study.[11] This is the first of a two-part article in which we review the normal anatomy and course of the UN, focusing on possible compressive sites. The main nerve divisions are detailed as well. In literature, we have not found a recent article that reviews in depth the US appearance of the normal and pathological UN. The aim of this two-part article is to help sonologists in recognizing normal findings related to UN course and distinguish them from pathological cases, which will be discussed in Part 2. We describe our US technique to locate and follow the nerve at the upper extremity, with high-resolution US images obtained with the latest-generation US machines and transducers. Since musculoskeletal US currently involves more and various healthcare providers, this article is not intended only for radiologists, but also to for other clinicians interested in fine anatomical details that can be depicted at US and which may be relevant to demonstrate pathological conditions. The IRB waived the necessity to obtain informed consent for this study.

Video online at jultrasoundmed.org

Supplemental material online at jultrasoundmed.org

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Abbreviations

CSA, cross sectional area; DBUN, deep branch of the ulnar nerve; FCU, flexor carpi ulnaris; IBL, internal brachial ligament; MIMS, medial intermuscular septum; pbUCL, posterior band of the ulnar collateral ligament; SBUN, superficial branch of the ulnar nerve; UA, ulnar artery; UN, ulnar nerve; US, ultraosund

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General Considerations and US Requisites for UN Evaluation

Recent multifrequency probes up to 14 to 15 MHz enable a good demonstration of the UN and its main branches. Nevertheless, since the UN is superficial almost along its entire course, higher-frequency transducers (≥17 MHz) are advised to allow a more detailed examination.

Similar to the US evaluation of other nerves, recognizing the location of the UN at a certain level allows even novices to follow it for a long tract using the so-called elevator technique, tracking the nerve proximally and distally by axial sonograms.[12,13] The normal fascicular structure of nerves with hypoechoic fascicles surrounded by a hyperechoic background, with the honeycomb appearance on short axis sonograms, has been well described in the literature, and therefore, will be only briefly mentioned in this article.[14,15]

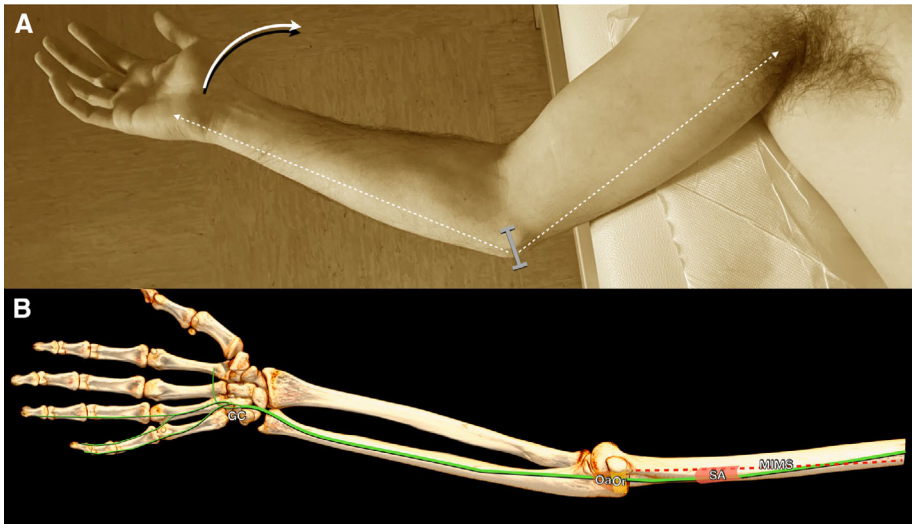
To study the course of the UN, we prefer to have the patient supine with the arm abducted at around 75°–90°, the elbow slightly flexed and the hand supinated (Figure 1). Other possible techniques with which to study the nerve are described in Figure 2. We prefer to start the US examination at the elbow at the level of the cubital tunnel. The medial epicondyle and the olecranon process are palpable, so that the UN is easily demonstrated on the short axis between these two bony landmarks (Figure 1). The UN can then be followed both proximally and distally; the detailed anatomy and US anatomy of the UN will be discussed later.

Color Doppler is used to locate and differentiate vessels from the UN, and can be useful at the cubital tunnel[16] and to distinguish the small distal branches.[17] When pathological changes are depicted, long-axis sonograms are acquired. In doubtful cases, a comparison with the contralateral limb might be helpful. US findings always need correlation with clinical data and mostly with electrodiagnostic tests.

It should be noted that to help the novice in detecting normal nerves, some machines have implemented automatic nerve tracking, based on artificial intelligence.[18]

Moreover, recent microvascular imaging techniques may also be used to demonstrate vessels near the UN; these techinques seem promising for the depiction of intraneural blood flow in case of entrapment neuropathy.[19] However, further studies are needed to define their role in the evaluation of normal nerves.[20]

Figure 1. Patient positioning to study the UN. **A**. Suggested position to demonstrate the UN. The patient lies supine with the arm abducted. The forearm lies off the examination bed, it is supinated as much as possible. We suggest starting the examination at the elbow: the transducer (gray line) is placed between the medial epicondyle and the olecranon. The forearm is progressively flexed (curved arrow) to evaluate for possible dynamic changes of the UN. Then, the nerve can be followed proximally and distally. **B**. The course of the UN (green) is schematized with the main described location of entrapment. From proximal to distal, MIMS indicates the medial intermuscular septum; SA, Struthers' arcade; Or and Oa, Osborne retinaculum and arcade; GC, Guyon's canal.



Finally, elastography seems to be a potential tool with which to demonstrate UN neuropathy; again its role in the evaluation of the normal UN needs to be further defined.[21]

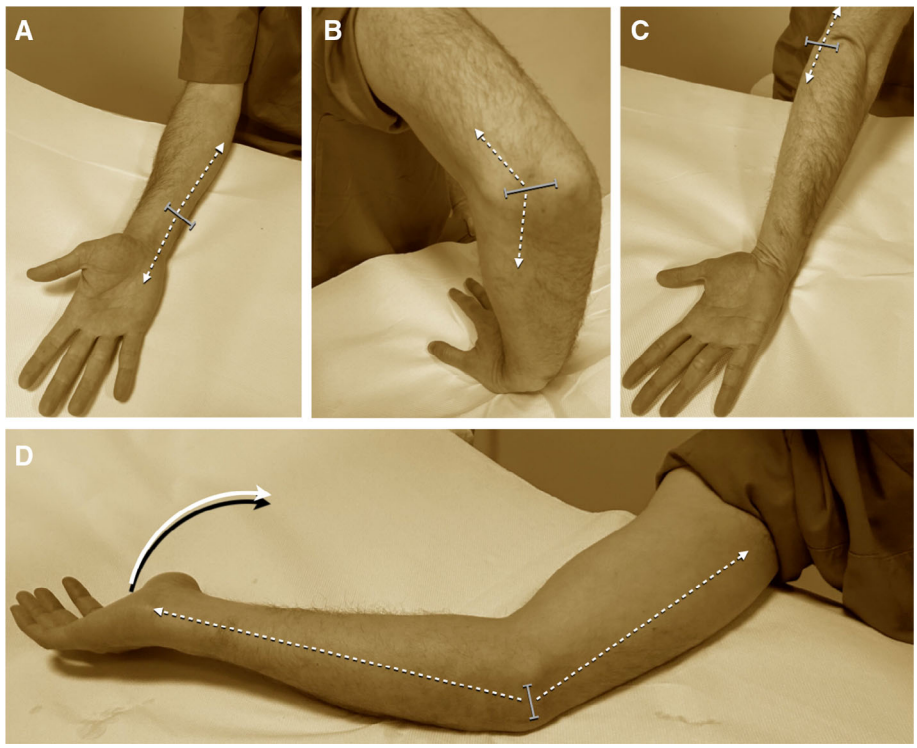
Normal Anatomy and US Anatomy of the UN

For didactic purposes, we will describe the nerve from proximal to distal. The course of the brachial plexus proximal to the axilla is not described in this pictorial review.

The UN is located at the level of the axilla near the axillary artery and the median nerve, anterior to the teres major and latissimus dorsi muscles (Figure 3A). It descends on the upper arm in a compartment delimited by a division of the medial intermuscular septum (MIMS), posteromedial to the brachial artery and the basilic vein (Figure 3B), to pierce the MIMS passing in the posterior compartment approximately at the middle third of the arm (Figure 3C).[22] There may be variability in the passage through the MIMS: as described by Won, in 43% of the cases, the nerve passes in the posterior compartment without clearly piercing the MIMS; in 27% of the cases, the UN pierces the MIMS; and, in 30% of the cases, the UN passes through fibers of the septum for a variable distance (5 to 55 mm).[23]

Then, the nerve lies close to the medial head of the triceps muscle together with the superior ulnar collateral artery, which originates from the brachial artery.[24,25] At the distal third of the upper arm, around 8 cm cranial to the medial epicondyle, the UN is reported to pass under the arcade of Struthers (Figure 3D).[26] This anatomical structure is controversial and some authors believe that the UN merely passes beneath the brachial fascia (or its thickening), whereas other confirm the existence of an arch, which

Figure 2. Alternative patient positioning to study the UN, with the patient seated in front of the examiner. **A**. The forearm of the patient lies on the examination table, the hand is supinated. The course of the UN distal to the elbow can be easily followed with the elevator technique. An advantage is the possibility to have a quick comparison with the contralateral side. **B**–**D**. These positions are needed to study the nerve at the cubital tunnel and proximally. In **B**, the elbow is 90° flexed with the hand of the patient resting on the table, facing himself. In **C**, from the previous position, the elbow is extended, and the hand lies pronated over the table so that the arm is in internalrotation. In **D**, the shoulder is externally rotated, the forearm supinated lying over the table, and the body of the patient oriented to the side to be examined. The position is quite similar to the one discussed in Figure **1**A, in which the elbow can be flexed (curved arrow) to study the nerve dynamically.

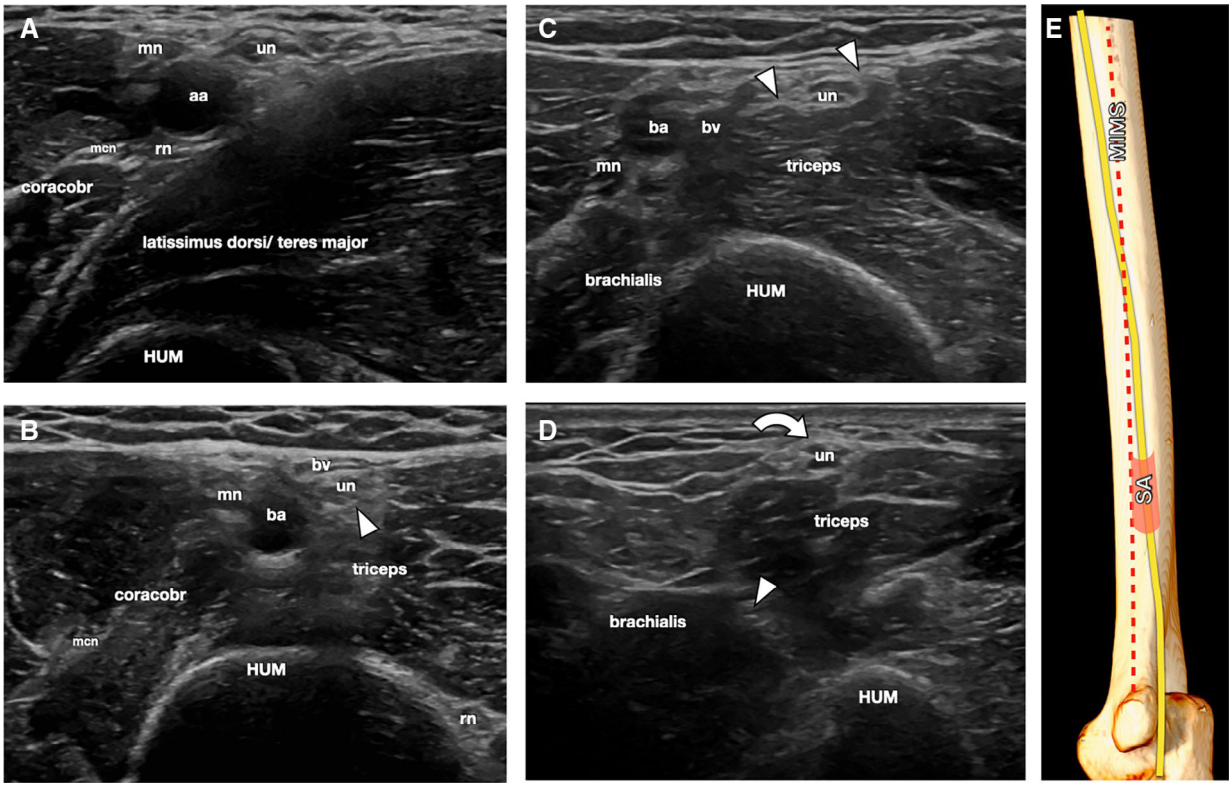


may be muscular.[26] The arcade was first reported by Kane in 1973, referring to an anatomical study by Struthers, who reported a ligamentous cord posterior to the MIMS, which he called the internal brachial ligament (IBL).[27–30] The IBL is not constant, it is reported to originate from the MIMS at the level of the insertion of the coracobrachialis and to continue with the aponeurosis covering the medial head of the triceps.[30]

The described variability may create confusion. From a practical sonographic point of view, the UN distal to the axilla (Figure 3A) is initially in the same compartment with the median nerve and the brachial artery at the proximal upper arm (Figure 3B), then passes posteriorly (Figure 3C). The passage through the MIMS, which appears as a thin hyperechoic line,[25] may be more or less evident at US. Distally, the UN can be seen close to the medial head of the triceps, deep to the fascia, which can be slightly thicker and which we believe represents what is usually referred to as the arcade of Struthers (Figure 3D).

With high-frequency transducers, fine anatomical details can be obtained, which are not clearly reported, to the best of our knowledge, in the radiological literature. In some patients, at the middle third of the arm a tendinous structure crossing the nerve can be seen (Figure 4). This is more evident when pressing with the probe during the elevator technique. We hypothesize that this first "tendinous slip" is the IBL, which crosses the nerve deeply to re-join distally the superficial fascia of the triceps (Figure 4D, online

Figure 3. UN course at the level of the arm. **A**–**D**. Transverse sonograms of the UN from proximal (**A**) to distal (**D**). In **A**, at the axilla, the UN (un) is near the axillary artery (aa), and the median (mn) and radial nerve (rn). The musculocutaneous nerve (mcn) can be seen entering the coracobrachialis muscle (coracobr). The latissimus dorsi and teres major muscles lie posterior. **B** and **C**. The UN is at first (**B**) in the anterior compartment, with the mn, the brachial artery (ba), and basilic vein (bv) anterior to the MIMS (white arrowhead); whereas, at the middle third of the arm (**C**), it has passed the MIMS, to lie superficial to the triceps muscle, in the posterior compartment of the arm. In **D**, the UN around 8 cm proximal to the medial epicondyle passes deep to a slightly thickened fascia (curved arrow), which is usually referred as the Struther's arcade. HUM indicates the humerus.



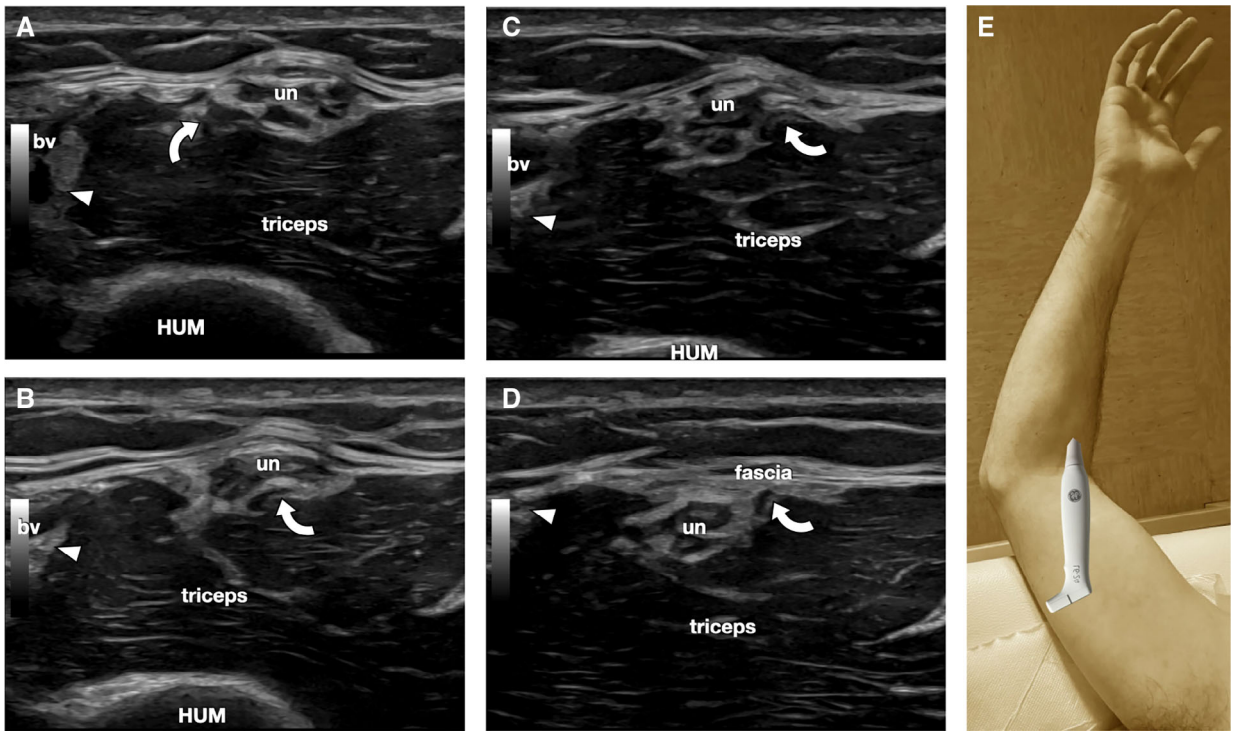
supplemental Movie 1). We think that the IBL may be probably under-recognized due to its small size, so that it is better depicted in slender patients.

Caudally, at the distal third of the arm, near the elbow, the nerve usually lies posterior to a second "tendinous cord," which inserts at the medial epicondyle and which is more constant (Figure 5, A–C). We think this is usually reported as the distal MIMS.[31] At US, it appears as a thin fibrillar structure in the anterior and superficial region of the medial head of the triceps that continues deeply with the MIMS and posteriorly with the fascia of the medial head of the triceps (Figure 5A) and it is re-joined by the IBL, if present (online supplemental Movie 1). It is interesting to note that the nerve, usually with the arm internally rotated (eg, as in Figure 2C), may, instead, be initially located anterior to this tendinous slip to cross it distally (Figures 5D and 6, online supplemental Movie 2) and may snap, particularly if the transducer is pressed (online supplemental Movie 3). This is mostly an asymptomatic finding in our experience. Morag also recently described a possible snap at the distal MIMS.[31]

The UN usually does not provide branches in the upper arm.[32]

At the level of the elbow, the UN passes an osteofibrous tunnel in the retro-epicondylar area, between the medial epicondyle of the humerus and the olecranon process of the ulna, which is commonly referred as the cubital tunnel. In the tunnel, the nerve is surrounded by fat and it gives off one or more articular branches.[33] The floor of the tunnel is composed of the posterior bundle of the medial collateral ligament (pbUCL), which represents a thickening of the posteromedial joint capsule.[34] The roof of the tunnel is variably reported in literature.[35] It is created by a

Figure 4. UN crossed by a tendinous slip at the middle arm, which we hypothesize is the IBL. **A**–**D**. Axial sonograms from proximal (**A**) to distal (**D**) at middle to distal third of the arm. In **A**, the UN (un) has already passed the MIMS (arrowhead). Note the anteriorly placed basilic vein (bv). A tendinous structure (curved arrow) can be seen near the nerve course, originating from the MIMS (not shown). In **B**, the tendinous slip crosses the UN deeply. By compressing the probe, the nerve assumes a flattened appearance between the slip and the fascia. **C** and **D**. The tendinous slip progressively moves away from the nerve and merges with the superficial fascia covering the UN. **E**, Transducer position corresponding to the crossing point. This is a normal finding present in some patients, more obvious in slender people and, without symptoms and US signs of compression neuropathy, should be addressed as related to this variant. HUM indicates the humerus.

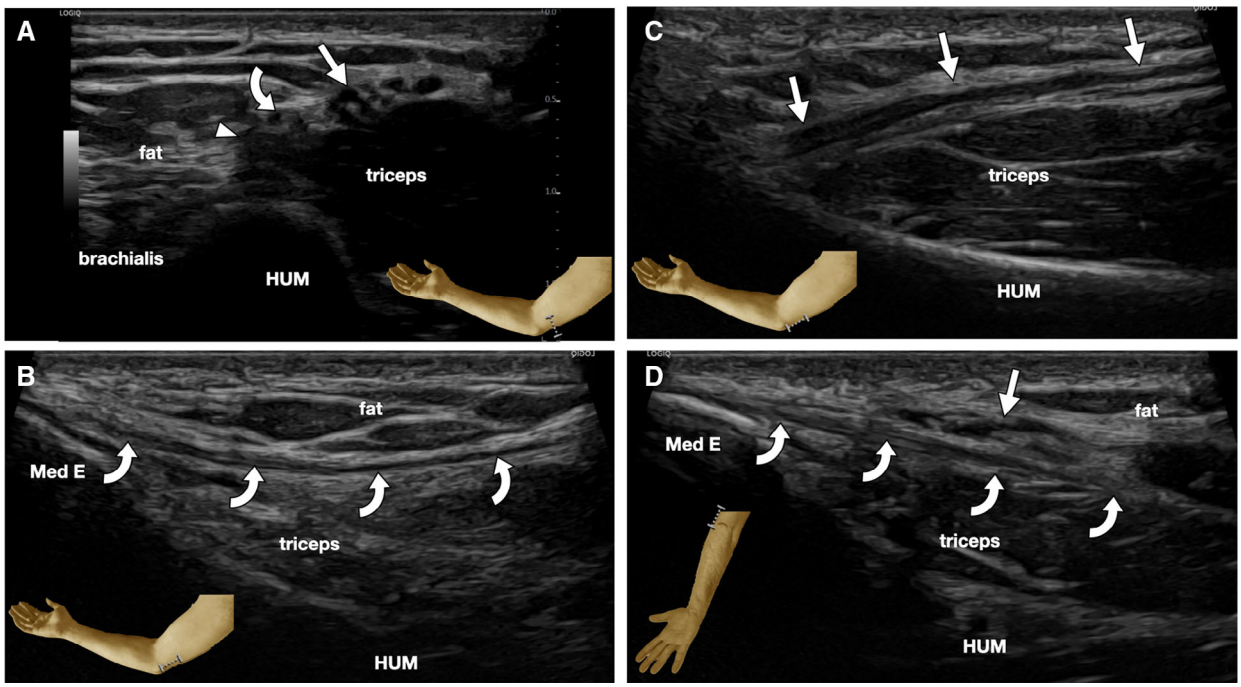


retinacular thickening of the fascia also called the Osborne retinaculum. It is in direct distal continuation with the Osborne ligament (also called the humeroulnar arcade or arcuate ligament), which is a fibrous band connecting the humeral and ulnar heads of the flexor carpi ulnaris muscle (FCU); this region is called the proper cubital tunnel by some authors.[36] Despite the described variability, it should be noted that, with US, in our experience, it is not possible to clearly differentiate the Osborne retinaculum from the ligament, since these structures are in continuity. At the elbow, the UN is accompanied by the posterior ulnar recurrent artery,[37] that anastomose with the superior ulnar collateral artery.[26,35] Variants exist in which the retinaculum may be replaced by an accessory muscle, the anconeus epitrochlearis, which may be of a different size. Then, the UN runs deep to the FCU on the deep flexor aponeurosis, called the intermuscular aponeurosis by Won,[38] which divides the FCU from the flexor digitorum superficialis and profondus. Fibrous bands are reported to possibly cover the UN in this area.[39] At this level, the nerve is close to the coronoid tubercle of the ulna; it supplies the FCU and the medial half of the flexor digitorum profundus muscle.[38]

Since the elbow is the principal location of pathology, we prefer, as previously stated, to start the US examination at this region. The UN is easily demonstrated, on the short axis, between the two bony landmarks of the medial epicondyle and the olecranon process, over the pbUCL, deep to the retinaculum (Figure 7), or the anconeus epitrochlearis in case of a variant (Figure 8).

The nerve at this level often has a peculiar morphology; in fact, it usually appears as a single ovoid fascicle (around 80% of the cases according to Jacob) or consists of two or three major fascicles in 20% of the cases.[40] This appearance is normal and more evident when using a transducer with a frequency of 18 MHz or more.

Figure 5. Tendinous slip (which we believe is usually reported as the distal MIMS) at the distal arm and effect of different positioning. **A**, At the distal arm, in an axial sonogram, a tendinous slip (curved arrow) lies anterior to the UN (arrow), continuing deeply with the MIMS and posteriorly with the fascia covering the nerve. **B**, Long axis of the tendinous structure, inserting at the medial epicondyle (Med E). The nerve cannot be seen in this sonogram because it lies posteriorly. **C**, By placing the transducer slightly posterior, the long axis of the nerve is demonstrated. **D**, The position is changed (same as 2C). The tendinous structure is depicted in the long axis, but now the UN is partially observed, because it crosses it.



As demonstrated by Michelin, both the pbUCL and the retinaculum become more tense during elbow flexion (Figure 7B) and the UN becomes more flattened as flexion progresses, in particular during full flexion (Figure 7C). Therefore, the region is studied dynamically by asking the patient to progressively flex the elbow.[34] This is a normal finding that may explain why the UN is predisposed to pathology at the elbow. Dynamic study is also required to depict UN subluxation or luxation over the medial epicondyle during flexion; a good amount of gel is needed to avoid compression of the nerve by operator pressure.

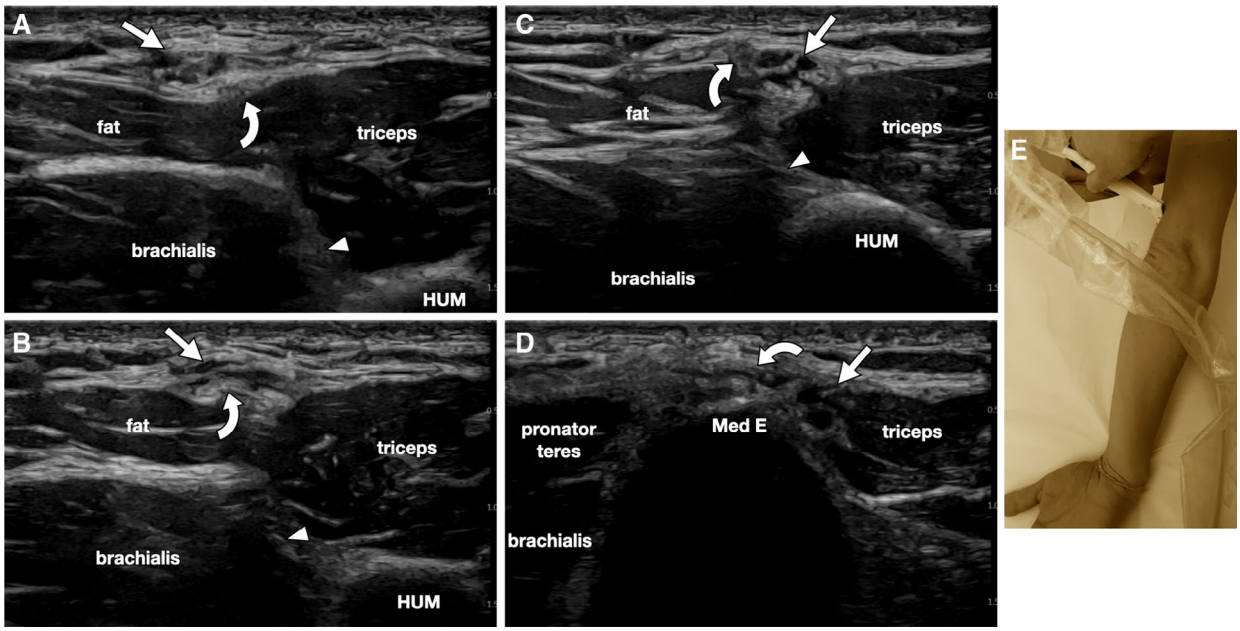
A bit more distally, the UN can be depicted between the two heads of the FCU, underneath the arcade (Figure 9A); a little farther on the nerve passes close to the tubercle of the coronoid process of the ulna, with an elliptical shape (Figure 9B); usually, the normal fascicular pattern can be seen at this level or just below. The deep flexor pronator aponeurosis is difficult to be clearly delineated at US in normal patients, but is possibly indicated by a hyperechoic area (Figure 9B).[25]

Along the forearm, the UN is located deep to the FCU, ulnar to the ulnar artery (UA) (Figure 10). This may be another possible point at which to start the examination, particularly if only the distal part of the nerve has to be studied, because the UN is next to the artery, which is easily identified in the ulnar region of the distal forearm (Figure 11).

At the forearm, the UN provides two sensitive branches, the palmar and dorsal cutaneous branches.

Around 6 cm proximal to the ulnar styloid, the dorsal cutaneous branch of the UN arises from its ulnar side to pass and provide sensory innervation to the dorsal-ulnar side of the hand. The palmar cutaneous branch of the UN (also called Henlè's nerve) usually originates from the radial side of the UN proximally, at the proximal or middle third of the forearm; it then travels with the UA and contributes to its sympathetic innervation, to pierce the antebrachial fascia at the distal third of the forearm, innervating the skin

Figure 6. Tendinous slip (distal MIMS) at the distal arm. Same structure described in Figure 5. UN crossing/snapping related to position. **A**–**D**. Axial sonograms from proximal (**A**) to distal (**D**) at distal third of the arm, with the arm intrarotated (E). The patient is the same in Figure 5**A**. In this position, the UN (arrow) lies anteriorly to the tendinous structure (curved arrow). In **B**, the UN crosses superficial to the tendinous slip. The nerve assumes a flattened appearance, more evident when compressing the probe. In **C**, the UN is now posterior to the tendinous slip. In **D**, the nerve approaches the retro-epicondylar area, whereas the tendinous slip inserts at the medial epicondyle (Med E). This finding, without symptoms and US signs of compression neuropathy, should be addressed as paraphysiological. HUM indicates the humerus.

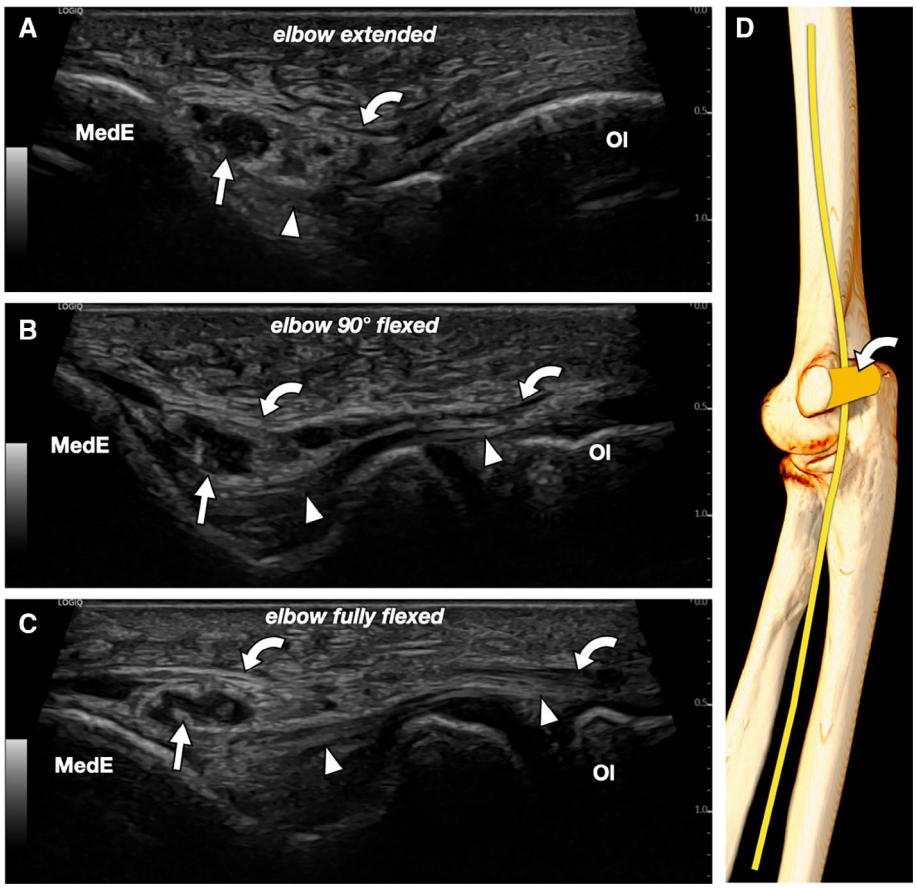


of the ulnar side of the distal forearm and wrist.[41] The UN is easily depicted at the distal third of the forearm, next to the UA, deep to the FCU muscle. The dorsal cutaneous branch can be usually easily demonstrated as well, arising at the ulnar side of the UN to diverge ulnarly, passing between the FCU muscle and the pronator quadratus (Figure 11); distally, it is frequently followed by a branch of the ulnar artery.[42,43] The palmar cutaneous branch can be more difficult to locate at US, due to the small size and variants[44]; we suggest searching for small hypoechoic fascicles superficial to the UA, at the level where the dorsal cutaneous branch emerges (Figure 11); when depicted, the nerve can be followed proximally to demonstrate its origin from the UN.

At the wrist, the UN passes the so-called Guyon's canal (Figure 10): a roughly conic tunnel with an approximate length of 4 cm and extending from the pisiform bone to the hook of the hamatum. The canal is filled with loose fibroadipose tissue.[45] Inside the canal, the UN, accompanied by the UA, usually splits into two branches when it passes the distal edge of the pisiform: one superficial branch (SBUN), mainly sensitive; and one deep motor branch (DBUN).[46–50] The superficial branch divides further—within or distal to the canal—into the proper digital nerve to innervate the ulnar side of the fifth finger and the common digital nerve to innervate the fourth metacarpal space.[43,47,49]

The UN is demonstrated at US radial to the pisiform bone, which can be palpated, near the UA,

Figure 7. UN at the elbow. Effect of different positioning. **A**–**C**. Short-axis of the UN (arrow) at the elbow during different positioning. In **A**, the patient is observed with the elbow extended. The Osborne retinaculum (curved arrow) and the pbUCL (arrowheads) are not tense, and become more and more taught during flexion (**B** and **C**) The UN has a quite similar appearance in A and B, whereas in C appears a bit more flattened. Note the nerve in this case seems to consist of three fascicles (one bigger, two smaller). In **D**, schematic CT drawing illustrates the Osborne ligament (indicated by the curved arrow). MedE indicates the medial epicondyle; Ol, olecranon.



covered by the palmar carpal ligament, and superficial to the transverse carpal ligament (Figure 12A). The nerve is tracked distal to the pisiform where the Guyon's canal is bordered ulnarly by the abductor digiti minimi; radially by the transverse carpal ligament; superficially by the palmaris brevis and the hypothenar fascia; and deeply by the pisohamate ligament and the transverse carpal ligament (Figure 12B). The superficial branch(es) has/have a straight course and can be located just distally, over the tip of the hamatum (Figure 12C), at which point, the proper digital nerve travels to the ulnar side of the fifth finger, whereas the common digital nerve can be located in the fourth webspace (Figure 10).[43] The palmaris brevis is a small, variable muscle, and the only one supplied by the SBUN.[51]

The DBUN diverges within the canal (Figure 12B), deep and ulnarly, to pass near the medial border of the hamatum and underneath to the fibrous arcade of the hypothenar muscles, together with the deep branches of the UA, which usually split from the UA distal with respect to the DBUN origin (Figure 12C).[43] The DBUN along its course provides branches to the

Figure 8. Accessory muscle, anconeus epitrochlearis at the elbow; effect of different positioning. **A**–**C**. Short-axis of the UN (arrow) at the elbow during different positioning, in a patient with an accessory anconeus epitrochlearis (anc epit). In **A**, the patient is observed with the elbow extended. The anconeus epitrochlearis is relaxed and the pbUCL (arrowheads) are not tense, and become more and more taught during flexion (**B** and **C**). In this case, the UN is difficult to be clearly demonstrated in A, easier in **B** and **C**. In full flexion (C), the UN is quite flattened. In **D**, schematic CT drawing illustrates the accessory muscle (in red). MedE indicates the medial epicondyle; Ol, olecranon.

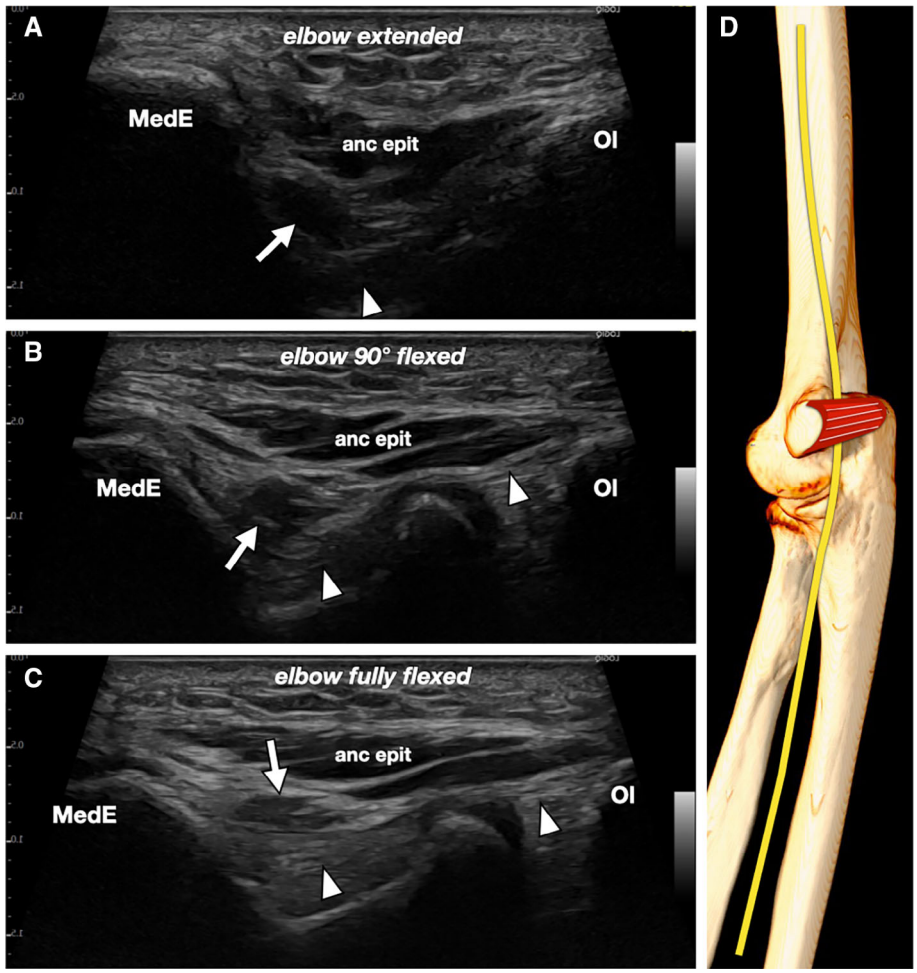


Figure 9. The course of the UN at the proper cubital tunnel and distally. **A**, Axial sonogram at the proper cubital tunnel demonstrates the UN (arrow) passing deep to the Osborne arcade (curved arrow), which bridges the humeral (fcuH) and ulnar (fcuU) head of the FCU. In **B**, just distal, at the level of the tubercle (tub) of the coronoid process of the ulna, the nerve has an elliptical appearance. In this case, the normal fascicular pattern can be depicted at this level. The hyperechoic area indicated by the arrowhead possibly indicates the deep flexor pronator, which may be difficult to be clearly demonstrated. In **C**, schematic CT drawing illustrates the Osborne arcade (indicated by the curved arrow). Fdp indicates the flexor digitorum profundus; fds, flexor digitorum superficialis.

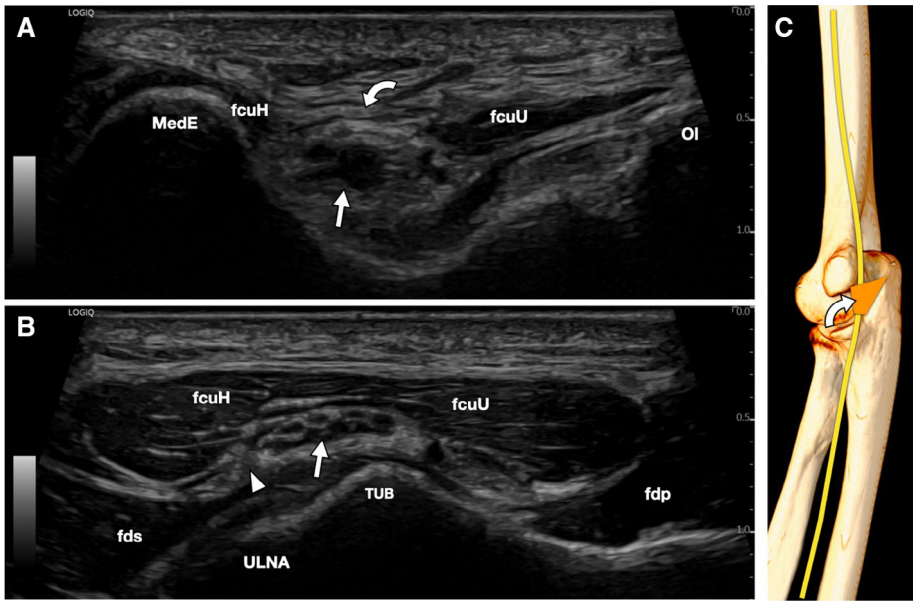
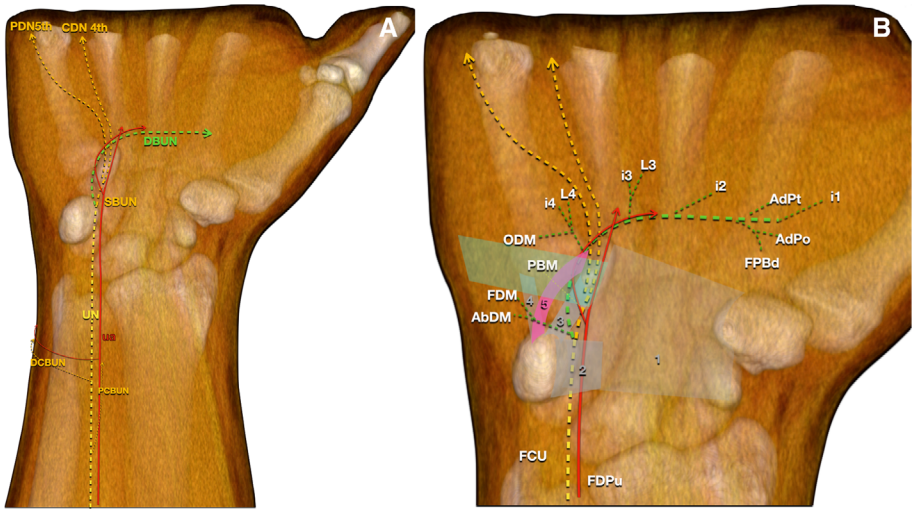


Figure 10. The course of the distal UN and terminal branches. **A**, Computed tomography 3D schematic drawings of the UN and ulnar artery (ua) at the distal forearm, wris t, and hand. **B**, Detailed course of the UN at the hand. The transverse carpal ligament (1), the palmar carpal ligament (2), the pisohamate (3), and pisometacarpal (4) ligament are shaded in gray. The palmaris brevis muscle (PBM) is in light green and the hypothenar arch is in rose (5). All the muscles supplied by the UN are reported: AbDM indicates the abductor digiti minimi; AdPo and AdPt, the adductor pollicis, oblique and transverse; FDM, flexor digiti minimi; FDPu, ulnar part of the flexor digitorum profundus; FPBd, deep part of the flexor pollicis brevis; i1, dorsal interossesus of the first webspace; i2, i3, i4, palmar, and dorsal interosseous of the second, third, and fourth webspace; L3, L4, lumbrical of the third and fourth webspace; ODM, opponens digiti minimi.



intrinsic muscle of the hand (see Figure 10); usually, the first is to the abductor digiti minimi and this small branch can be demonstrated in some patients with high-frequency transducers (Figure 13).[43] To better follow the DBUN at the distal part of the Guyon's canal, it is useful to tilt the transducer over the ulnar part of the wrist, so that its relation with the HH can be demonstrated.[52] Distal to the Guyon's canal, the DBUN passes between the opponens digiti minimi muscle and the fourth palmar interosseous muscle, to redirect radially with the deep palmar arch, beneath the flexor tendons. An axial-oblique sonogram is needed to follow the motor branch along its course (Figure 12D). The DBUN then passes a tendinous arch that connects the transverse and oblique heads of the adductor pollicis at the level of the third metacarpal shaft, which may compress the nerve, to innervate the adductor pollicis and the deep belly of the flexor pollicis brevis.[17] A relatively common variant at the Guyon's canal is the presence of an accessory abductor digiti minimi, present in around 25 to 35% of the population (Figure 14).[43] It mainly does not cause compression to the UN. The muscle appears as a hypoechoic mass covering the proximal tunnel, and dynamic maneuvers during resisted abduction of the fifth finger can clearly demonstrate its contraction, confirming its muscular nature.

Muscles Innervated by the UN

The UN supplies the FCU and the medial half of the flexor digitorum profundus at the forearm.

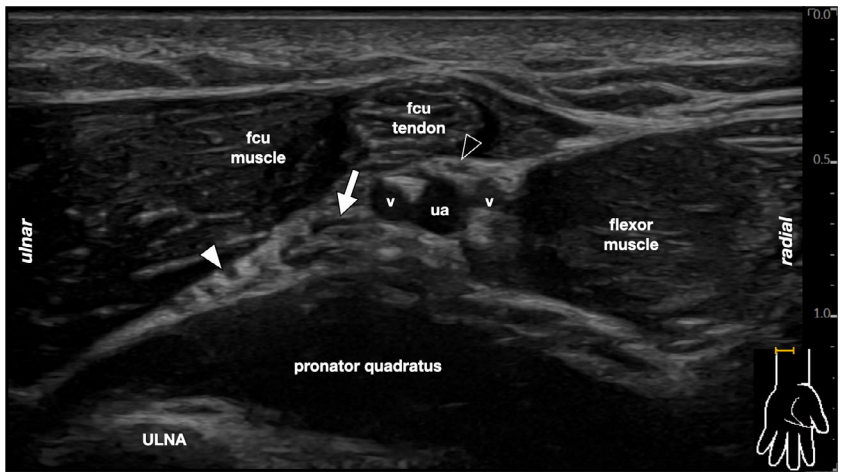
At the hand, it innervates the intrinsic muscle of the hypothenar eminence, the interossei, and part of the lumbricals, as well as some of the muscles of the thenar eminence. Muscles supplied by the UN are described in Figure 10B.

These muscles should always be checked when UN pathology is suspected. We suggest a comparison with the healthy side to demonstrate more or less obvious alterations: in subacute and chronic nerve compression, US can demonstrate a loss in bulk compared to the contralateral side; atrophy is also easily depicted, with a small and hyperechoic appearance of the muscle. The edematous changes of the initial stage of muscle denervation, however, are difficult to be detected at US.

The FCU and the ulnar part of the flexor digitorum profundus muscle are promptly demonstrated by following the UN at the proximal forearm (see also Figure 9B).

The hypothenar muscles (abductor digiti minimi, flexor digiti minimi, oppenens digiti minimi) are also easily demonstrated when checking the UN division at the Guyon's canal (Figure 12) and distally at the middle third of the hand. A comparison with the opposite side can be quickly achieved (Figure 15).

Figure 11. Normal anatomy of the UN at the distal forearm. Transverse sonograms of the UN (white arrow) at the distal forearm. The nerve is located ulnarly to the ulnar artery and vein (ua, v), between the flexor carpi ulnaris muscle (fcu muscle), the pronator quadratus, and the flexor digitorum muscle. The dorsal cutaneous branch (white arrowhead) arises from the medial part of the UN. Superficial to the artery, small fascicles may be located (open arrowhead), related to the palmar cutaneous branch (Henlè's nerve).



Lumbricals are assessed with axial sonograms distal to the carpal tunnel, next to the flexor tendons. Usually, the lumbricals of the third and fourth intermetacarpal space are innervated by the UN. We suggest measuring the anteroposterior diameter (or eventually the CSA) of the lumbricals to increase operator confidence in diagnosing a reduction of muscle bulk (Figure 16). The interosseous muscle (in particular the palmar interossei) can be assessed deep to the lumbricals or, better, by placing the transducer dorsally with axial sonograms. Last but not least, a sonogram at the level of the thenar eminence is suggested. The flexor pollicis longus tendon is taken as the main landmark, which should be identified in its short axis. Superficial and radial to it, muscles are innervated by the median nerve, whereas deep and ulnar to it, by the UN (Figure 17). Therefore, this suggested evaluation may also be performed at the beginning of an examination for suspected UN and/or median nerve pathology to promptly demonstrate whether advanced neuropathy is present.

Normal and Abnormal Reported Values of the UN and Main Branches

A cross-sectional area (CSA) is the usually proposed US method to objectively define nerve alterations.[53] The measure can be obtained by tracking manually the area of the nerve inside the epineurium, tracing the inner border of the hyperechoic rim of the nerve.

Figure 12. Guyon's canal. **A**–**C**. Axial Color Doppler sonograms from proximal to distal over the Guyon's canal. At the proximal canal (**A**), the UN (white arrow) is located near the UA. The roof of the canal is created by the palmar carpal ligament (pcl), and the floor by the transverse carpal ligament (tcl). The fcu inserts on the pisiform bone and the first fibers of the abductor digiti minimi (adm) can be demonstrated. The flexor tendons coursing the carpal tunnel appear hypoechoic due to anisotropy. In **B**, between the pisiform and the hook of the hamatum (HH), the UN starts to split into two or three components. The DBUN is indicated by the open arrowhead; in this case, there are already two superficial branches of the UN (white arrowhead). The palmaris brevis muscle appears as a thin hypoechoic structure forming the roof of the canal. The UA provides a deep branch (dua) that follows the DBUN. The floor of the canal here is also formed by the pisohamate ligament (phl); note also, deeply and ulnarly, the pisometacarpal ligament (pmcl). In **C**, at the HH, the DBUN accompanied by the dua diverges deep to the fibrous arcade of the hypothenar muscles (curved arrow), whereas the SBUN lies superficial. **D**, Axial-oblique Color Doppler sonogram following the course of the DBUN, which travels between the opponens digiti minimi (opponens dm) and the palmar intereossei (palm interossei) to pass deep to the flexor tendons and reach the thenar region. **E** shows transducer positioning, III, IV, and V MC indicate the third, fourth, and fifth metacarpal bones.

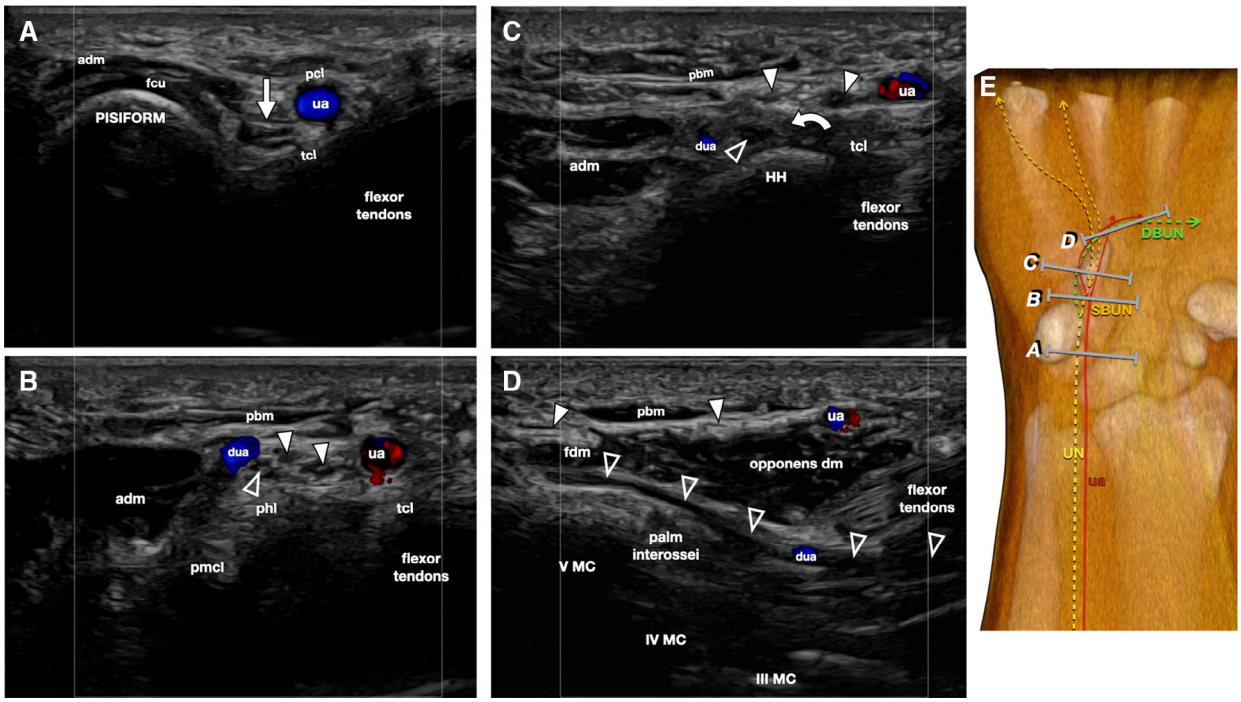


Figure 13. Muscular branch of the DBUN to the abductor digiti minimi muscle. Axial oblique sonogram at the Guyon's canal. The UN divides in the DBUN (white arrow) and SBUN (white arrowhead). A small branch (open arrowhead) detaches from the DBUN to innervate the abductor digiti minimi muscle (adm). The probe is obliquely oriented to follow the course of the branch (dashed line). Note the thin palmaris brevis muscle (pbm) covering the canal. HH indicates the hook of the hamate; phl, piso-hamate ligament; ua, ulnar artery.

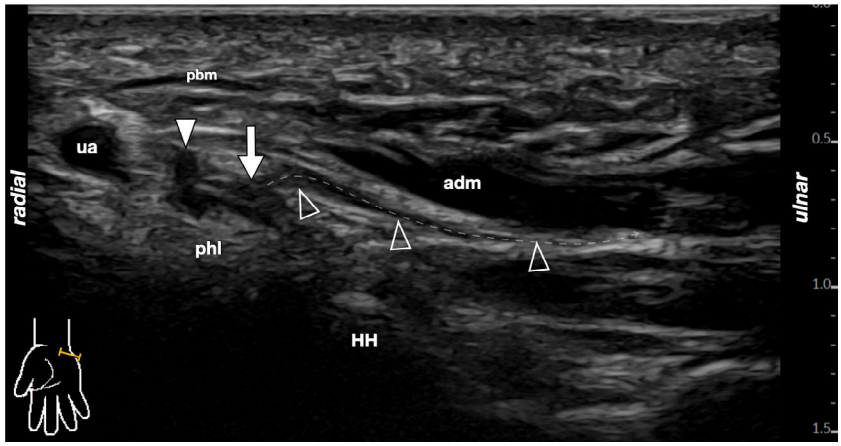
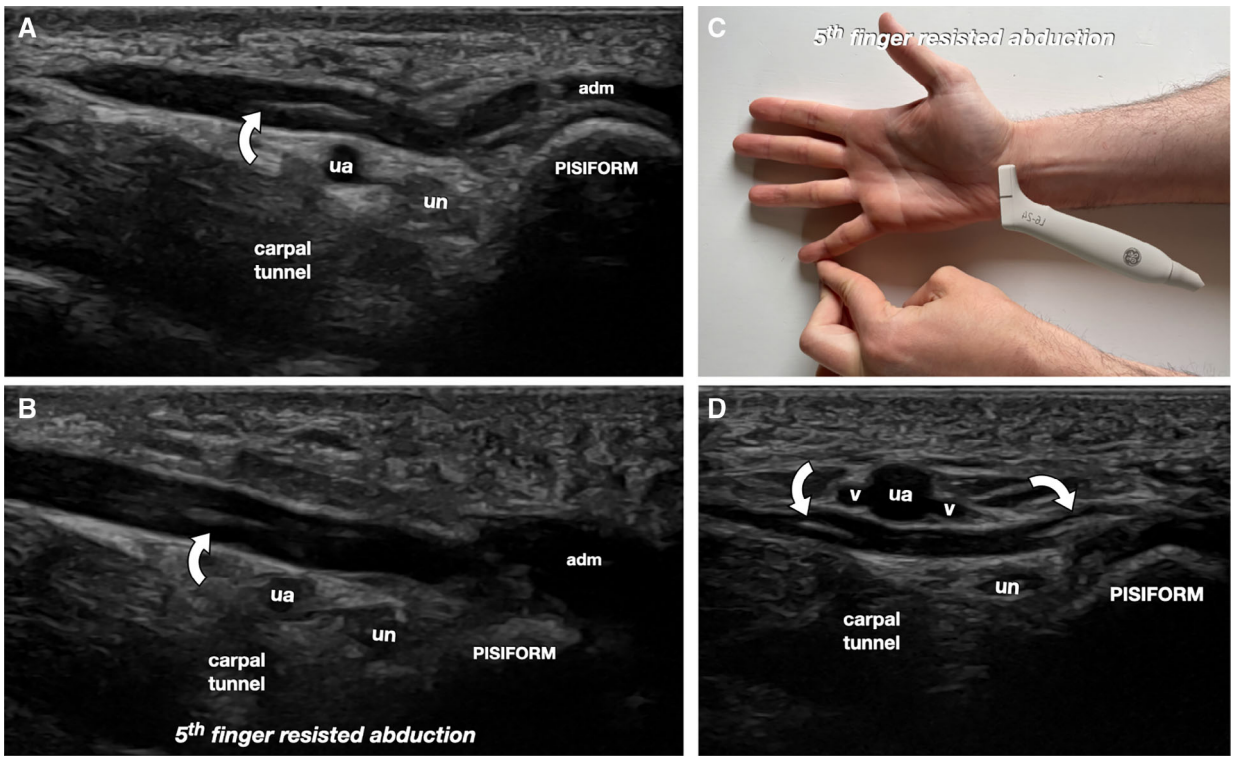


Figure 14. Accessory abductor digiti minimi covering the Guyon's canal. **A**, Axial sonogram at the proximal Guyon's canal demonstrates the presence of a hypoechoic structure (curved arrow) covering the tunnel, continuing with the abductor digiti minimi (adm). **B**, With the probe at the same level as in **A**, the operator asks the patient to abduct the fifth finger against resistance, as demonstrated in **C**. Note the change in volume and orientation, confirming that the hypoechoic structure reflects an accessory muscle. **D**, Axial sonogram in another patient. In this case, a less frequent presentation, the accessory adm (curved arrows) lies between the UN, deeply located, and the UA, with its satellite veins (v), lies superficial.



In particular for the UN, the most accepted CSA cut-off for the diagnosis of cubital tunnel syndrome is 10 mm^2 at the elbow.[53] In fact, according to a review that included 14 studies in patients with and without cubital tunnel syndrome, the mean CSA in healthy controls ranged from 5.5 to 7.4 mm^2, with an upper limit up to 9 mm^2.[53] Pathological values at other sites have been less frequently described.

According to the above-mentioned review, normal mean values at the arm range from 4.4 to 6.6 mm^2; at the cubital tunnel inlet from 6.7 to 8.1 mm^2; at the medial epicondyle from 5.9 to 7.2 mm^2; at the cubital outlet from 5.6 to 9 mm^2; and at the forearm from 5.5 to 6.5 mm^2.[53]

Swelling ratio has been also proposed as an ulterior index in cubital tunnel syndrome, with the potential benefit of avoiding bias related to sex and patient phenotype; it can be also useful to differentiate nerve entrapment in patients with pre-existing neuropathy, in particular. The suggested location for the ratio is

Figure 15. Hypothenar muscles. Suggested measurement to help in determining muscle bulk loss. **A and B**, Transverse comparative sonograms at the base of the fifth metacarpal (Vth MC) demonstrates the normal muscles of the hypothenar eminence (**A**) in a patient with left UN neuropathy (**B**). The abductor digiti minimi (a) can be easily measured in comparison. The flexor digiti minimi (f) and opponens digiti minimi (o) may also be measured. Note a loss in muscle bulk in **B** compared to **A**.

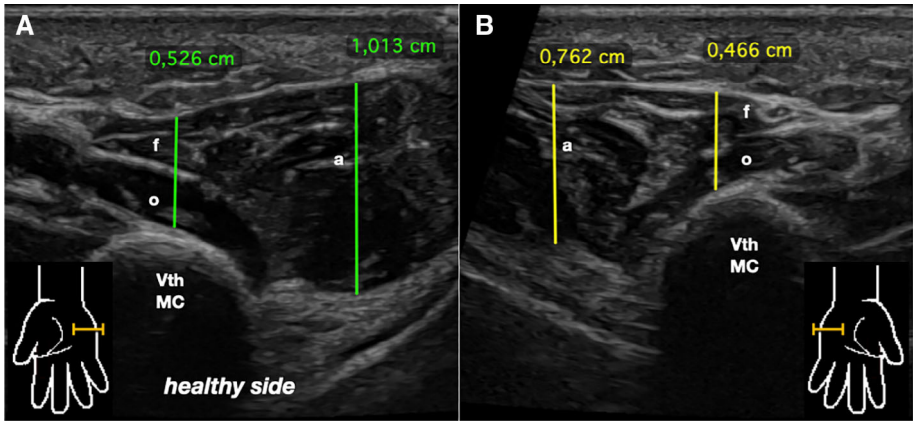
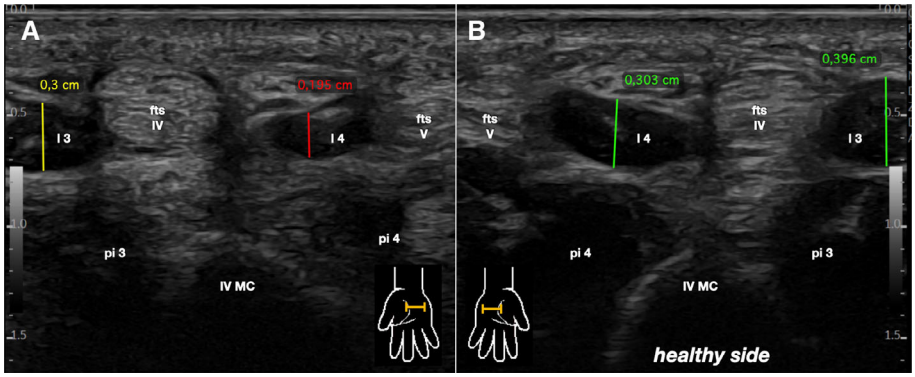


Figure 16. Intrinsic hand muscles: lumbricals and palmar interosseous. **A** and **B**, Transverse comparative sonograms distal in the ulnar region of the hand, distal to the carpal tunnel, centered on the fourth metacarpal (IV MC), in a patient with right UN neuropathy (**A**). Note a reduction in the anteroposterior diameter of the lumbricals innervated by the UN, more evident for the fourth lumbrical space (l4), less evident for the third (l3). Note also that the palmar interossei of the third and fourth space (pi 3, pi 4) appear hyperechoic in A due to hypotrophy. Fts IV and V indicate the flexor tendons of the fourth and fifth finger.



the maximal CSA at the elbow / CSA at the forearm. However, a clear cut-off value was not determined in a retrospective review.[54]

DBUN normal measurements have not been greatly reported in the literature and are based on small series of healthy individuals. Since the shape is similar along its course, diameter may also be used rather than CSA.[17,55,56]

Reported values for the DBUN are summarized in Table 1.

In our report, in pathological cases and when clinically requested (eg, patients sent for suspected UN entrapment), we describe the maximal CSA of the nerve and its location. We also report the CSA at the same area in the contralateral limb. As previously stated, muscles supplied by the UN are studied in comparison to the healthy side. A loss in bulk and/or an altered echostructure are reported.

It must be stressed that a CSA higher than 10 mm^2 does not directly indicate UN pathology. US findings always need to be related to a patient's clinical symptoms. In our experience, in healthy patients with hypertrophic upper limb muscles, it is possible to have a CSA > 10 mm^2 and no symptoms. Moreover, Silvera reported a mean UN CSA of 15 mm^2 in the dominant arm (13 mm^2 in the contralateral) of

Figure 17. Thenar eminence. Median and UN muscle supplied. **A** and **B**, Axial-oblique sonogram at the level of the thenar eminence, obtained by evaluating the flexor pollicis longus (fpl) in its short axis, in a patient with right cubital tunnel syndrome. **A** indicates the right (affected) side, **B** the normal contralateral side. This comparative sonogram allows a quick evaluation of the motor function of the ulnar and median nerves. An imaginary line (dashed lines) divides those muscles. The muscles superficial and radial to the FPL are innervated by the median nerve (ab p^m indicates the abductor pollicis; fpb^m the superficial part of the flexor pollicis brevis), where the anteroposterior diameter is similar between the two sides; whereas those deep muscles are innervated by the UN (ad p^u, adductor pollicis: fpb^u, the deep part of the flexor pollicis brevis, d int^u, dorsal interosseous). Note on the affected side a reduction of the thickness of the muscles supplied by the UN so that the distal radial artery (ra) lies more superficially in **A** than in **B**.

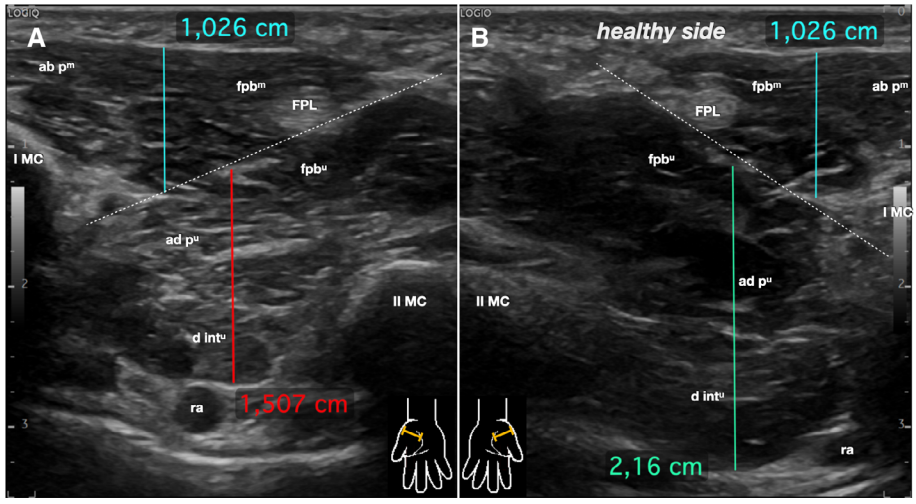


Table 1. Proposed Reference Values of the DBUN at the Hand, in Asymptomatic Volunteers and/or Cadavers.

Reference	Riegler[17]	Meng[56]	Choi[55]
Study subjects	10 healthy volunteer (20 hands)		60 wrists, 30 adults
Measurement obtained			
At its emergence	1.86 ± 0.5 mm^2; 1.6 ± 0.3 mm	1.8 to 2.2 mm^2	
Atop the fourth metacarpal	1.66 ± 0.4 mm^2; 1.5 ± 0.2 mm		
At the HH			1.5 ± 0.2 mm^2; 1.5 ± 0.2 mm
At metacarpal base			1.3 ± 0.2 mm^2; 1.3 ± 0.2 mm

CSA values are reported as mm^2, whereas the diameter in mm.

10 sportsmen of the France weightlifting team, and no one was symptomatic.[57]

Conclusion

US is an excellent modality with which to follow the UN because of its superficial course distal to the axilla. Exquisite anatomical detail can be depicted, particularly when using a high-frequency transducer. The possibility of a dynamic examination allows a demonstration of the nerve as it changes during different positions. Muscles supplied by the UN can also be promptly evaluated at US.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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