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Ultrasound of the Radial Nerve: A Pictorial Review

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This pictorial review focuses on the ultrasound (US) appearance of the normal and pathological radial nerve (RN) and its branches and provides tips with which to locate them and avoid misinterpretation of normal findings. A wide range of our pathological cases are reviewed and presented to help in familiarizing the reader with common and uncommon clinical scenarios that affect the RN and its main branches.

Key Words—Frohse arcade; radial nerve; spiral groove; nerve torsion; Wartenberg syndrome; wrist drop

The radial nerve (RN) is the largest branch of the posterior cord of the brachial plexus (C5 to T1). The RN has a tortuous course in the upper limb and supplies the muscle of the extensor compartment, the skin of the dorsal forearm, and the dorsal-radial region of the hand.[1,2] At the elbow, the RN splits into two main branches: the superficial branch (SBRN) and deep branch (DBRN). Pathologies of the RN and its branches are not frequently encountered in clinical practice; however, there are some conditions related to their courses that predispose them to neuropathies.

Ultrasound (US) is increasingly used as an imaging modality to identify nerves and their injuries, thanks to its high resolution—when nerves are not deeply located—and the possibility to promptly study them along an extended length.[3–8] The RN and its branches are usually superficial enough so that they can be demonstrated accurately by US, especially when pathology is present.[4,9]

In this pictorial review, we describe the normal anatomy and course of the RN and its two main terminal branches. We also describe the US technique, as well as anatomical landmarks by which to locate the nerves, including tips and tricks to avoid misinterpretation of normal imaging findings. We briefly discuss the clinical presentation of RN, DBRN, and SBRN disorders. Last, we discuss and present various pathological cases depicted at US to help sonologists become familiar with common and uncommon clinical scenarios that affect the RN and its main branches.

This study was waived by the Institutional Review Board. Obtaining informed consent was exempted for this study.

General Considerations and US Requisites for RN Evaluation

The US appearance of nerves is well described in the pertinent literature and is, therefore, only mentioned briefly in the present

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pictorial: nerves appear as hypoechoic fascicles with surrounding hyperechoic tissue, resulting in a typical honeycomb structure.[3,5,10]

The transducer frequency required is generally 12–15 MHz, except for those of larger body habitus in whom the frequency may need to be lowered, with a loss in resolution. We suggest completing the examination with higher-frequency probes (≥17 MHz) if the nerves to be examined are superficial (eg, to follow the distal course of the SBRN, and to better depict the RN at the radial groove, particularly in slender patients). Once found, the nerve is followed by axial sonograms proximally or distally, using the elevator technique, to track it along an extended length, to depict normal configuration and/or abnormalities, as well as the relationship with surrounding tissues.[3,11] We usually do not acquire longitudinal sonograms of normal-appearing nerves because it may be difficult due to their tortuous course. Contralateral comparison may be useful in mild and challenging cases. Color Doppler is used to help locate vessels near the nerve, which can serve as anatomical landmarks, and to demonstrate pathological hyperemia. Sonograms of the muscles innervated by the RN and/or its branches should be acquired to depict and/or exclude possible disorders: a muscle that is smaller in size and hyperechoic compared to the contralateral side indicates atrophy (Figure 1).

In general, if RN neuropathy is clinically suspected and the whole nerve and its divisions have to be studied, we prefer to have the patient lying supine, beginning with the forearm extended and supinated to localize the nerve at the distal arm (see next paragraph). Once the nerve is localized, it is followed proximally. The forearm of the patient is flexed to rest, with the hand on the body, so that almost the whole course at the spiral groove can be detected. If the proximal course of the RN has to be evaluated, the arm is elevated, so that the axilla can be checked. (Figure 2).

Alternatively, in particular, if the proximal part of the RN does not have to be evaluated, the patient may be seated in front of the examiner, with the forearm resting on a table.

The technique to follow the distal RN, the DBRN, and the SBRN is described in the next paragraph.



Figure 1. Muscular atrophy in RN injury. **A**, Denervation edema and moderate fatty atrophy of the extensor muscles of the forearm (ext), which are innervated by the RN, in a patient with a fixed humerus fracture. Muscles appear hyperechoic, with a loss in size, compared to (**B**) the contralateral healthy side. **C**, The nerve (black arrow) is entrapped within the beginning callus formation/the bony gap (curved arrow) of the humerus (HUM). **D**, The correlating X-ray shows the bony gap. RAD indicates the radius; U, ulna.

Normal Anatomy and US Anatomy of the RN

The RN in the axilla passes posterior to the axillary and brachial arteries, anterior to the latissimus dorsi and teres major muscles to reach the triangular interval, bounded by the teres major and the long and lateral head of the triceps muscles, to arrive in close contact with the posterior aspect of the humerus. The accompanying deep brachial artery serves as the main US anatomical landmark, together with the cortex of the humerus, to locate the nerve at this location and distally at the level of the spiral groove (Figure 3A and B).[2,12] The deep brachial artery may be located anterior or posterior to the nerve.[13]

The RN courses distally, from medial to lateral, passing at the level of the spiral groove of the humerus, covered by the lateral head of the triceps. The motor branches innervating the triceps usually

Figure 2. Patient positioning for the assessment of the radial nerve (RN). **A**, Suggested starting position to demonstrate the RN. The patient lies supine with the forearm extended and supinated. The transducer (white line) is placed in the axial plane and moved proximal and distal (dashed arrow) using the elevator technique. **B**, To check the RN at the level of the spiral groove, the forearm of the patient is flexed to rest, with the hand on the body. **C**, If the proximal course of the RN has to be evaluated, the arm is elevated, so that the axilla can be checked.

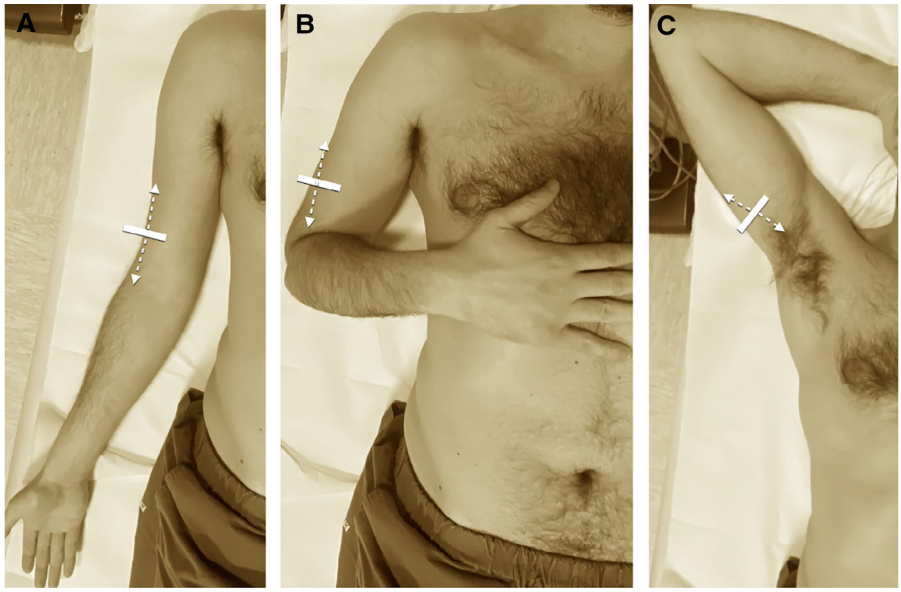
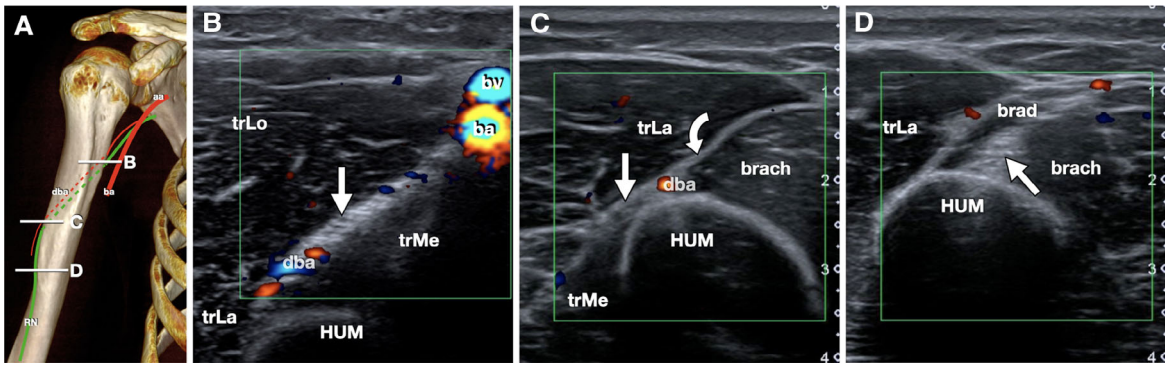


Figure 3. Radial nerve (RN) course at the level of the arm. **A**, Computed tomography 3D schematic drawings of the shoulder and proximal humerus, showing the course of the RN (in green), passing posterior to the axillary artery (aa), which then becomes the brachial artery (ba). The nerve at the spiral groove is accompanied by the deep brachial artery (dba). The positions of the probe in **B–D** are indicated in white. **B–D**, Transverse color Doppler sonograms of the RN (white arrow) from proximal (**B**) to distal (**D**). In **B**, the patient is supine with the arm abducted (axillary view). The RN can be easily found, going deeply and posteriorly, together with the deep brachial artery. **C** and **D**. The patient's elbow is now flexed 90° with the arm internally rotated and the hand resting on his body. In **C**, the RN can be located at the level of the intermuscular septum (curved white arrow), together with the deep brachial artery near the cortical bone of the humerus (HUM). In **D**, the nerve has already passed into the anterior compartment of the arm, between the brachioradialis (brad), which appears small at this level, and the brachialis (brach) muscles. Ba indicates the brachial artery; bv, brachial vein; trLa, lateral head of the triceps; trLo, long head of the triceps; trMe, medial head of the triceps.



arise proximal to the spiral groove and may be difficult to clearly demonstrate at US, like other muscular branches that originate from the RN, due to their small size.[14] Along the course at the groove, the RN appears oval and flattened, whereas proximally and distally it has a more rounded shape: this is a normal appearance, related to the close proximity of the RN to the bone (Figure 3C).[2,12,15]

The RN crosses the posterior humerus for around 6 cm, appearing more and more fixed as it approaches the lateral intermuscular septum; at the distal third of the humerus, around 10 cm cranial to the lateral epicondyle,[16] the nerve pierces the lateral intermuscular septum to pass from the posterior to the anterior compartment of the arm, being located first between the lateral head of the triceps and the brachialis muscle, and then, between the brachioradialis and the brachialis muscle (Figure 3D). In our opinion, this is the easiest region in which to locate the RN at US, as it may be used as the initial reference point to follow the RN proximally and distally. The posterior antebrachial cutaneous nerve, a sensory branch of the RN, originates near the outlet of the spiral groove, and is not discussed in the present pictorial.[6,17,18]

Distal to the lateral intermuscular septum, the RN innervates the brachioradialis and the extensor carpi radialis longus muscles. It may innervate also the radial side of the brachialis muscle. The extensor carpi radialis brevis muscle may be innervated either by the RN, or the DBRN, or the SBRN.[19]

The RN divides into the DBRN and SBRN around 5 cm above to 1 cm below the radiohumeral joint line, usually in front of the lateral epicondyle of the humerus (Fig. 4A–C).[20]

The DBRN is also referred to by some authors as the posterior interosseous nerve (PIN), whereas others refer to it as the PIN only after the nerve has exited the distal edge of the supinator.[21] The DBRN is primarily a motor nerve, with a distal sensory branch that innervates the capsuloligamentous structure of the wrist.

The DBRN enters the so-called "radial tunnel."[22] It is a musculoaponeurotic space extending from the lateral epicondyle of the humerus to the distal edge of the supinator muscle. The radial tunnel is bounded anterolaterally by the brachioradialis and the extensor carpi radialis longus muscles, and medially by the brachialis muscle and the biceps tendon; the floor is formed by the radiohumeral joint capsule and the deep head of the supinator; and the roof, by the medial edge of the extensor carpi radialis brevis and the superficial head of the supinator muscle.[23,24] Along the course at the radial tunnel, the DBRN is crossed by vessels from the recurrent radial artery (leash of Henry), which can be demonstrated by color Doppler, avoiding misinterpretation with branches of the RN; in our experience, vessels may also be found deep to the nerve. Then, the DBRN passes under the arcade of Frohse (AF)—a fibrous or tendinous arch at the level of the proximal edge of the superficial head of the supinator, which may be difficult to be clearly depicted when not pathological (Figure 4C).[25] The DBRN passes through a fatty plane between the deep and superficial heads of the supinator.[26] At US, there may be a normal flattening of the DBRN as it travels the supinator muscle (Figure 4D), which is also evident when imaging the nerve in its long axis, which should not be misdiagnosed as pathological .[27,28] Dong suggested that this pitfall may be avoided by measuring the nerve cross-sectional area (CSA) in the axial plane to differentiate simple changes in shape from nerve compression in which the CSA changes significantly.[27] Moreover, the nerve may show a different appearance during pronation and supination, which should not be assumed to be pathological (Figure 5).[9,29]

To follow the nerve along its course in the supinator muscle with axial sonograms, the patient's forearm must be progressively and gently pronated by the examiner, while the transducer is slowly moved distally (Figure 4D). Alternatively, the elbow is in semiflexion over the examination table, with the forearm pronated and oriented transversely over the examination table.[15,29]

Inside the two heads of the supinator, the DBRN may be seen dividing into a few smaller branches (Figure 4E).[29] Distal to the supinator muscle, it may be difficult to follow the normal branches of the DBRN, especially when they are not involved by pathology. Anatomically, the innervation pattern of the DBRN appears complicated and inconsistent: only a broad generalization is possible.[30] Three major branches are usually described at the distal edge of the supinator: two main short branches to the extensor digitorum (also called the recurrent superficial branch) and the extensor carpi ulnaris muscles, with the branch for the extensor digiti minimi usually arising from one of these two short branches; and a descending, long, deep branch to the abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus, and extensor indicis proprius muscles.[30,31] The main descending branch travels between the extensor pollicis longus and abductor pollicis longus

Figure 4. The course of the raidal nerve (RN) at the elbow and its division. **A**, Schematic drawings of the course of the RN (green line), the superficial branch RN (SBRN) (light green line), and the deep branch RN (DBRN) (dark green line) at the elbow. The positions of the probe in **B–E** are indicated in white. **B–D**, Axial sonograms from proximal (**B**) to distal (**E**). The forearm is supinated in **B** and **C**, in a neutral position in **D,** and pronated in **E**. The operator gently changes the patient's positioning while following the DBRN using the elevator technique. In **B**, note the main structures of the anterior elbow, which help to locate the RN (white arrow), which in this case has not yet divided. In **C**, at the entrance of the radial tunnel, the DBRN (open arrowhead) lies lateral to the SBRN (white arrowhead). The normal AF (curved white arrow) is difficult to be clearly demonstrated. Note the radial recurrent artery (rra), which is not to be mistaken for a nerve fascicle. In **D**, the DRBN has entered the supinator tunnel, between the deep (ds) and superficial (ss) head of the supinator, passing through a hyperechoic fatty plane. **E**, In this volunteer, two branches of the DBRN may be seen at the distal aspect of the tunnel. Apl indicates the abductor pollicis longus; ba, brachial artery; brad, brachioradialis; bt, biceps tendon; ecrb, extensor carpi radialis brevis; ecrl, extensor carpi radialis longus; ecu, extensor carpi ulnaris; edc, extensor digitorum communis; edm, extensor digiti minimi; HUM, humerus; RAD, radius.

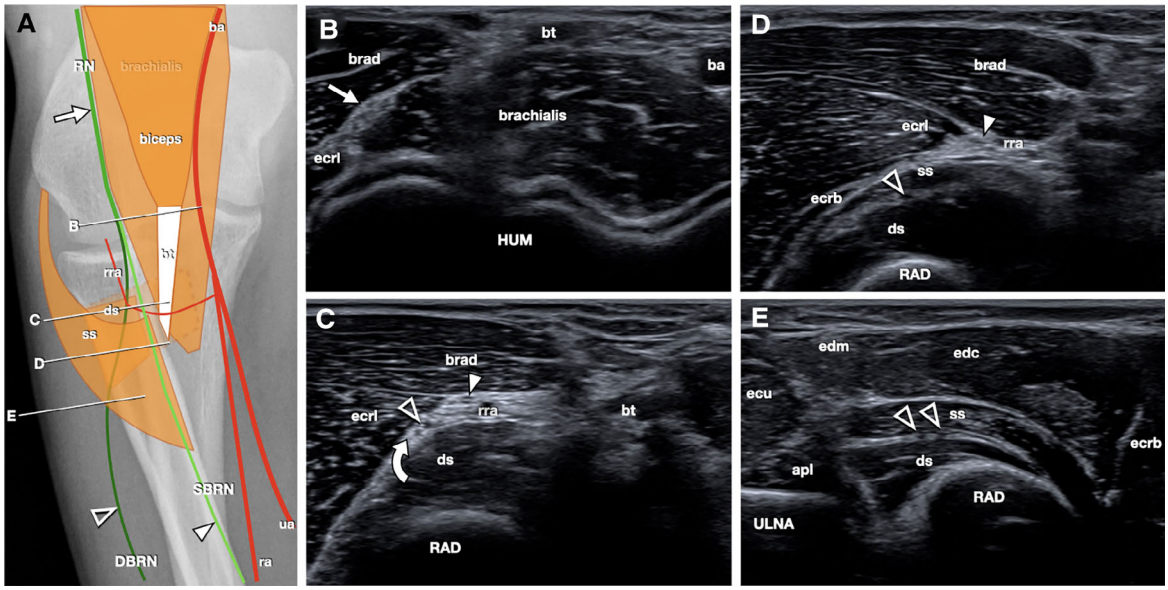


Figure 5. Deep branch radial nerve (DBRN) at the elbow. Effect of different positioning. **A** and **B**, Long-axis of the DBRN (open arrowhead) at the elbow during different positioning. In **A**, the nerve is observed with the forearm in the neutral position. Its straight course can be demonstrated. Neutral forearm position (or a slight pronation without contraction) is the position in which we suggest exploring the DBRN in the long-axis. In **B**, the volunteer actively supinates the forearm: the cartilage (asterisk) of the radial head (RH) can also be demonstrated. Note that the nerve has an angulated course at the level of the arcade of Frohse (curved white arrow) due to supinator muscle contraction. This appearance, which is also variable depending on muscle mass, should not be mistaken for entrapment. Brad indicates the brachioradialis; ds, deep head of the supinator; ecrb, extensor carpi radialis brevis; ecrl, extensor carpi radialis longus; RAD, radius; ss, superficial head of the supinator.

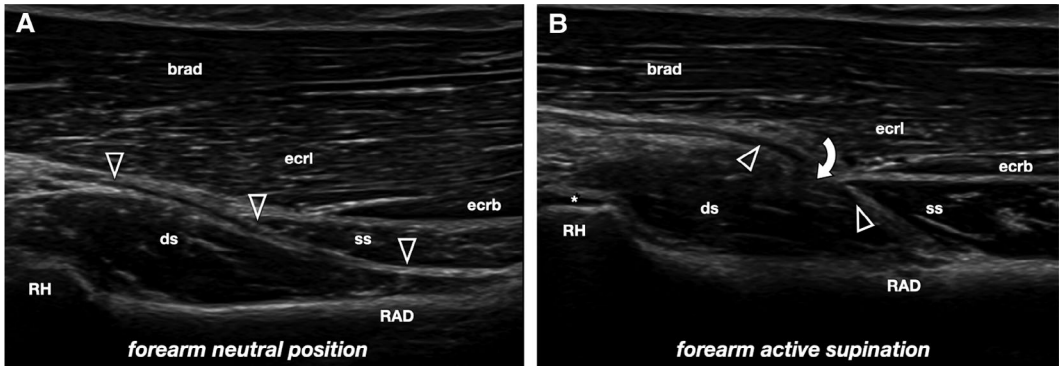
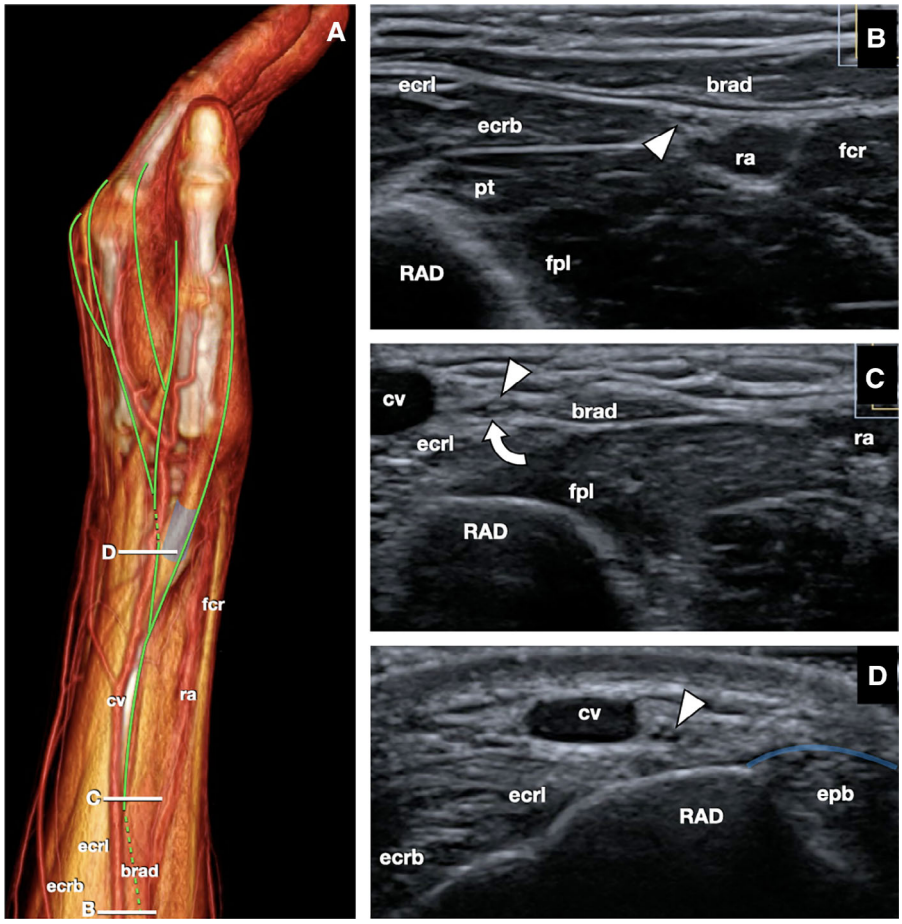


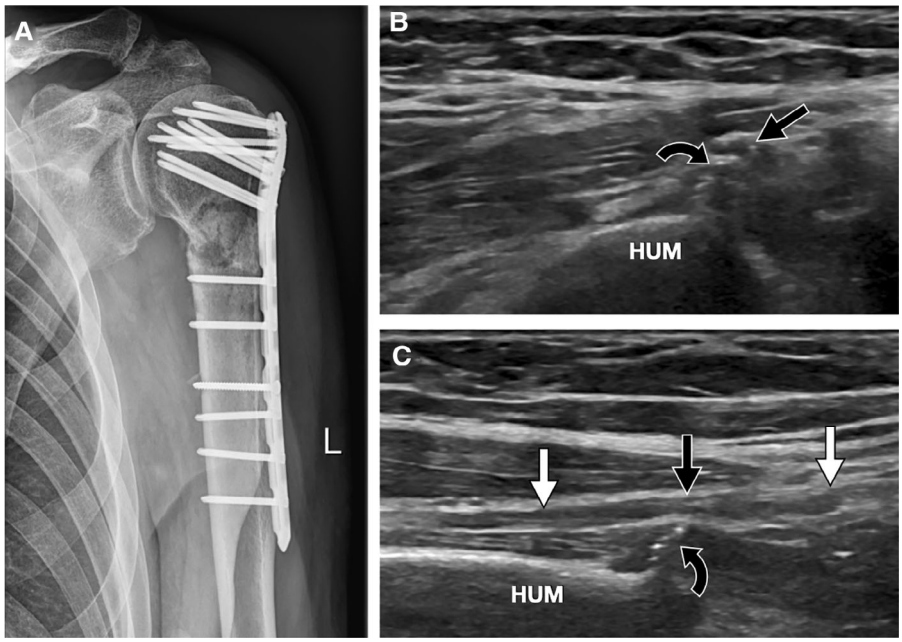
Figure 6. The course of the superficial branch radial nerve (SBRN) at the forearm and its main branches in the hand. **A**. Computed tomography 3D schematic drawings of the SBRN (green line) and divisional branches at the forearm and hand. The positions of the probe in **B–D** are indicated in white. **B–D**. Axial sonograms from proximal (**B**) to distal (**E**). The forearm is supinated in **B** and **C**, and in a neutral position in **D**. In **B**, at the middle third of the forearm, the SBRN (white arrowhead) is deep to the brachioradialis muscle (brad), lateral and near to the radial artery (ra), and medial to the extensor carpi radialis brevis muscle (ecrb). Note that, at this level, the distal pronator teres (pt) inserts onto the radius (RAD). In **C**, the nerve has become subcutaneous, passing first between the extensor carpi radialis longus (ecrl) and the brachioradialis tendon, then piercing the fascia (curved white arrowhead). In **D**, note the close proximity of a branch of the SBRN to the cephalic vein (cv) and the extensor retinaculum of the first compartment (shaded in blue). Epb indicates the extensor pollicis brevis; fpl, flexor pollicis longus.



muscles to go deep and locate near the interosseous membrane. At the level of the wrist, high-resolution US has been demonstrated to be reliable in detecting the sensory distal branch of the DBRN within the fourth dorsal extensor compartment, which appears as a small (1–3 mm) hypoechoic, noncompressible, and nonvascular ovoid structure, deep to the course of the tendon of the fourth extensor compartment, around 2 to 10 mm ulnar to Lister's tubercle.[32] This sensory branch innervates the capsuloligamentous structures of the wrist; the possible enlargement of this branch at the wrist is also known as "Acrel's ganglion."[32]

The SBRN travels distally in the volar forearm, deep to the brachioradialis muscle, in a straight path. It is, therefore, easy to locate and follow this superficial nerve with US. Around 10 cm proximal to the radial styloid, the SBRN passes between the brachioradialis and the extensor carpi radialis longus tendons, moving away from the radial artery

Figure 7. Humerus. (Intermittent) radial nerve (RN) irritation by a screw. **A**, Radiograph of a fixed subcapital humerus fracture with a plate and multiple screws. The patient presented with mild weakness of the extensors of the forearm, as well as numbness on the dorsal aspect of the thumb. **B** shows a transverse sonogram with a screw (curved arrow) directly next to the RN (black arrow). The screw slightly compresses the nerve and the nerve snaps around the screw (see also online supplemental Movie S1). **C**, Longitudinal sonogram demonstrates the screw immediately next to the RN. The course of the RN is indicated by white arrows. HUM indicates the humerus.



(Figure 6). Dynamic US during pronation-supination can demonstrate the nerve gliding between these tendons.[33]

Approximately 2 cm distally, the nerve pierces the forearm fascia (Figure 6C).[34,35] In the subcutaneous tissue, the SBRN is usually located near the cephalic vein, which crosses the nerve and/or its branches once or more than once (Figure 6C and D).[36,37] Variations exist in the distal course and divisions of the SBRN: usually the first branch appears around 5 cm proximal to the radial styloid and innervates the dorsal radial aspect of the thumb.[38] The main trunk of the SBRN continues to split into sensory terminal branches for the dorsal aspect of the first, second, third, and occasionally, fourth finger.[37,38] Due to the superficial position, the distal SBRN and/or its branches may be followed with high-frequency probes ($\geq$ 17 MHz), passing the dorsal-radial aspect of the wrist and hand.[11,39]

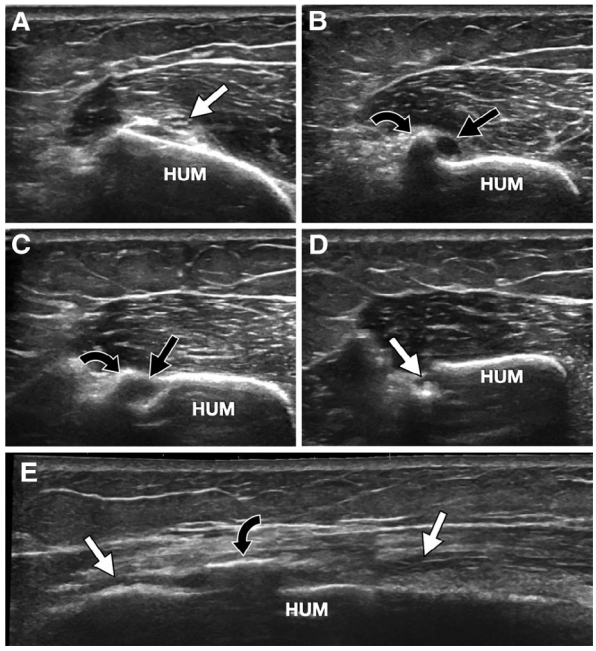
The SBRN or its main branches pass near and may cross the first extensor compartment (Figure 6D) and the radial artery at the level of the radial styloid, whereas distal to the extensor retinaculum, it crosses the extensor pollicis longus tendon.[35,40] Branches of the SBRN may overlap with terminal branches of the lateral antebrachial cutaneous nerve.[38]

Clinical Presentations in RN Neuropathies

An accurate description of clinical findings in RN neuropathies goes beyond the intent of this pictorial; thus, there will be only a brief summarization.

The RN is usually injured at the level of the spiral groove, resulting in wrist-drop with preservation of triceps function. Proximal RN pathology will result also in a loss of forearm extension due to triceps impairment. Further, the sensation of the dorsal-radial hand is affected; sometimes also the dorsal side of the forearm if the lesion is proximal to the origin of the posterior antebrachial cutaneous nerve, whereas

Figure 8. Spiral groove of the humerus (HUM). Radial nerve (RN) entrapment in a bony callus formation. **A–D**, Transverse sonograms of the RN (white arrow) at the level of the radial groove from distal to proximal in a patient with incomplete radial nerve palsy after a HUM fracture approximately 20 years ago. In **A** and **D**, the nerve presents a normal fascicular pattern. In **B** and **C**, the nerve is thickened and loses the normal pattern (black arrow), coursing through the bony callus formation (curved arrow). **E**, Longitudinal sonogram of the RN clearly depicting the callus formation and the nerve underneath it.

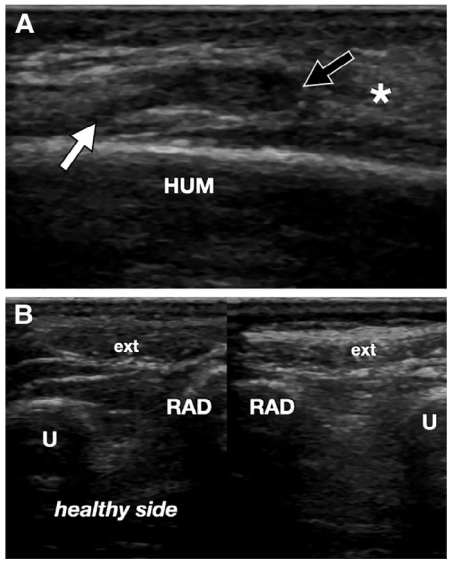


the sensation of the dorsal side of the arm is usually preserved.[19]

DBRN neuropathies at the level of the elbow are mainly reported as two distinct syndromes. The first is a well-defined, purely motor affection in which patients present with a deficit in finger extension without wrist-drop because the extensor carpi radialis longus is usually spared.[21,27] The second and more controversial is also known as "radial tunnel syndrome," with proximal forearm pain that can mimic lateral epicondylitis, without motor symptoms (no muscle involvement).[21,41] In this condition, pain seems to be related to the small fibers that are carried by the nerve: unmyelinated afferent fibers from the wrist and small myelinated afferent fibers from the muscles.[42]

The distal branches of the PIN at the level of the wrist seem to have a role as mediators in dorsal wrist pain syndrome.[32]

Figure 9. Arm. Amputation neuroma of the RN. **A**, Longitudinal-oblique sonogram of the arm over the course of the RN (white arrow), in a patient with an amputation neuroma (black arrow). The nerve was cut by a knife. **B**, Comparative axial sonograms at the middle third of the dorsal forearm. Note extensor muscle (ext) atrophy (on the right), compared to the normal healthy side (on the left). Asterisk indicates scar tissue; HUM, humerus; RAD, radius; U, ulna; RN, radial nerve.



Selective SBRN pathology may result in pain/paresthesia/abnormal sensation at the level of the dorsal hand, thumb, and index finger. Wrist movement and particularly forearm pronation may increase the symptoms. Entrapment of the SBRN is also called Wartenberg's syndrome or Cheiralgia paresthetica or "handcuff palsy."[43]

US Pathological Findings

At the level of the axilla, RN injuries are rarely encountered. There are reported cases in the literature of compressive neuropathies due to inappropriate use of crutches.[44]

At the arm, the RN is commonly involved at the level of the spiral groove, due to its proximity to the bone. The condition is also known as "spiral groove syndrome." RN is the nerve most commonly injured in long-bone fractures, with a reported incidence between 2 and 18% of humerus

Figure 10. Spiral groove of the humerus. Pressure palsy ("Saturday night palsy"). **A**, Transverse comparative sonograms at the level of the spiral groove demonstrate a slightly thickened radial nerve (RN) (black arrow, on the right) compared to the healthy contralateral side (white arrow, on the left), in a patient with an incomplete RN pressure palsy after a long sleep during a train ride. Also note the loss of the fascicular pattern on the pathological side. **B**, Longitudinal scan of the subtle thickening of the RN. HUM indicates the humerus.

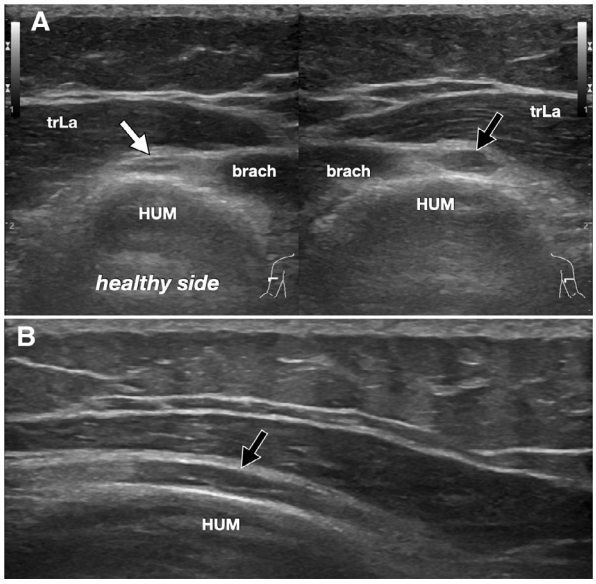
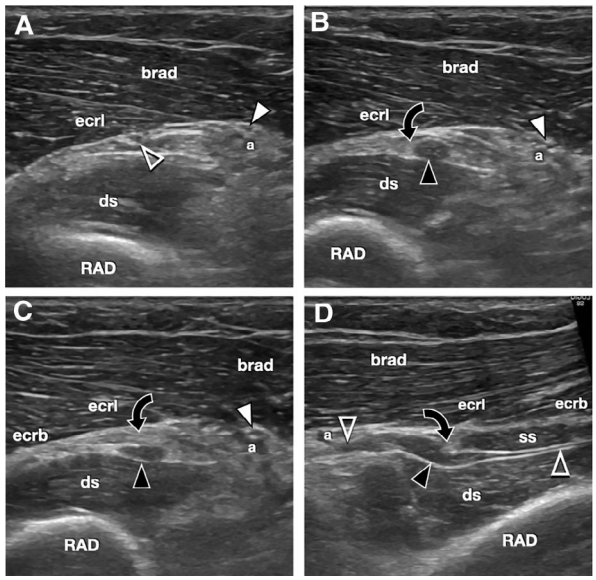


Figure 11. Elbow. Deep branch radial nerve (DBRN) entrapment at the arcade of Frohse (AF). **A–C**, Axial sonograms at the level of the elbow joint, from cranial (**A**) to caudal (**C**), showing entrapment of the DBRN at the AF. In **A**, the normal, contralateral DBRN (open arrowhead) can be demonstrated, as well as the superficial branch radial nerve (SBRN; white arrowhead), at the level of the proximal radius (RAD). In **B**, note the thickened DBRN (black arrowhead), just before passing under a fibrous hyperechoic evident AF (curved black arrow). In **C**, the nerve is flattened under the AF. **D**, Longitudinal sonogram of the course of the DBRN: the nerve is thickened just before the AF and then flattens. **A** indicates the radial recurrent artery; brad, brachioradial; ecrb, extensor carpi radialis brevis; ecrl, extensor carpi radialis longus; ds, deep head of the supinator; ss, superficial head of the supinator.



fractures.[41,45] RN injuries are mainly located at the middle or distal third of the bone, related to the fact that the nerve is more fixed near the lateral intermuscular septum. The RN may be damaged in acute trauma by direct contusion or laceration, by osseous fragments, or by traction in high-impact trauma with bone separation.[2] Esparza suggested that US should be proposed as an effective tool in evaluating patients with RN palsy with humeral shaft fractures in the acute phase (within 24 hours), to aid in clinical decision-making so as to differentiate patients with damaged nerves who would benefit from surgery from those patients who could be managed conservatively.[46]

In patients who have undergone surgery, the RN may be compressed, stretched, or displaced by orthopedic hardware: US can demonstrate the close proximity of an enlarged nerve to plates or screws (Figure 7)[47]; dynamic maneuvers may also demonstrate intermittent impingement of the nerve, which cannot be as well depicted by other imaging modalities (online supplemental Movie S1). US can also show cases of nerve encasement in a hypertrophic callus (Figure 8).[2,12,15,48] More rarely, penetrating trauma may be the cause of amputation neuroma at the spiral groove (Figure 9).

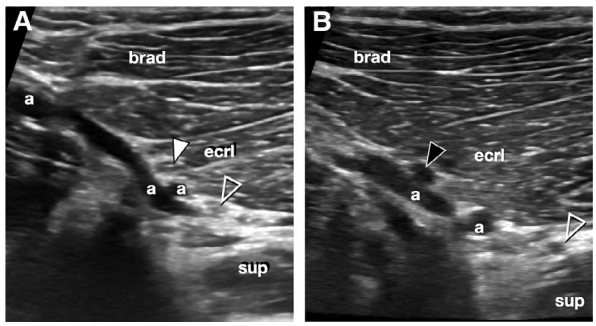
"Saturday night palsy" refers to RN compression at the arm by a firm object. It is usually the consequence of deep sleep on the arm, often in patients with alcohol intoxication.[49] Similar compression has been described in other conditions, eg, in soldiers after prolonged shooting training, related to a kneeling posture.[50] US may show, in some cases, a mild hypoechoic enlargement of the nerve: a comparison with the healthy contralateral side can help with the diagnosis (Figure 10). In other cases, US may not show evident abnormalities. According to Kerasnoudis, patients with RN CSA enlargement have a

Table 1. Proposed Reference Values of the DBRN at the Level of the Elbow, in Asymptomatic Volunteers and/or Cadavers

Reference	Dong[27]	Won[59]	Tagliafico[60]	Raeburn[61]	Meng[58]
Study subjects	50 elbows of 47 asymptomatic patients	97 healthy volunteers	40 healthy volunteers	50 healthy volunteers; 30 cadavers	21 cadavers
Measurement obtained					
Immediately proximal to the AF	1.9 SD 0.73				
1 cm proximal to the AF	1.6 SD 0.38				
1 cm distal to the AF	1.8 SD 0.21				
1 cm distal to branching		1.99 SD 0.43			
Supinator muscle			2.3 SD 1.3		
Immediately proximal to the AF				2.2 SD 0.5	
Immediately distal to the AF				2.3 SD 0.4	
Proximal to the supinator					2.27 SD 0.76
Inside the supinator					1.95 SD 0.72
Distal to the supinator					1.78 SD 0.72

Note: All values are in mm^2.

Figure 12. Elbow. Leash of Henry. **A** and **B**, Transverse sonograms of the superficial branch radial nerve (SBRN) (white arrowhead) and the deep branch radial nerve (DBRN) (open arrowhead) at the level of the anterior lateral elbow in a patient with slight numbness in the area of the thumb. Vessels (a) originating from the recurrent radial artery (leash of Henry) are in close proximity to the SBRN, potentially irritating the nerve, which appears a bit enlarged and hypoechoic in **B**. Brad indicates the brachioradialis; RAD, radius; sup, supinator.



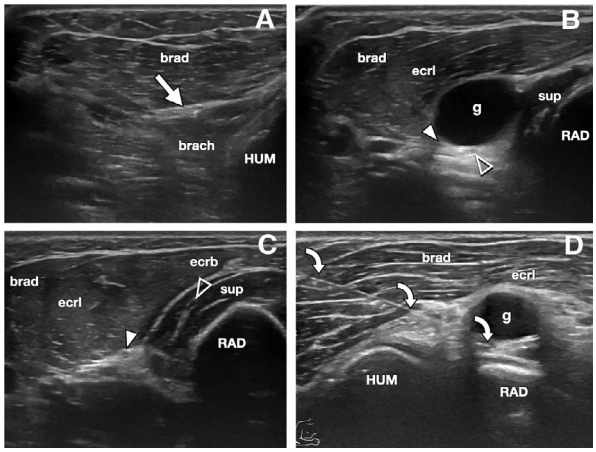
poor prognosis compared with a patient with a preserved CSA.[51]

Other rare reported cases of nerve entrapment at the level of the spiral groove and in proximity to the lateral intermuscular septum are related to muscular hypertrophy of the triceps or teres major muscle, or the presence of fibrous bands under the triceps (eg, fibrous arch of the lateral head described by Lotem).[12,52–55]

Because of its proximity to the elbow joint, the RN and its branches may also be injured in fractures such as supracondylar and Monteggia fractures.[56]

One of the most reported sites of compression of the DBRN is the AF.[41,57] US can demonstrate the swollen and hypoechoic nerve at the level of the AF, with an abrupt reduction in CSA between the superficial and deep head of the supinator (Figure 11).[15,27,58] As described in the anatomical section, the normal flattening of the nerve may raise some doubt in the examiner. In our experience, the US diagnosis of DBRN entrapment at the AF is not always straightforward, especially in mild cases in which the contralateral side should be evaluated for comparison. Moreover, there is not a clear cutoff value for pathologic nerves. Proposed reference values in asymptomatic volunteers and/or cadavers are described in Table 1 and are limited by the low numbers of participants and the lack of reported values in pathological cases.[27,59–62] Magnetic resonance imaging (MRI) may play a complementary role because it

Figure 13. Elbow. Ganglion cyst near the course of the superficial branch radial nerve (SBRN) and deep branch radial nerve (DBRN). **A–C**, Axial sonograms from proximal to distal, at the level of the elbow joint. In **A**, the RN is located just proximal to its bifurcation at the anterolateral elbow. **B**, A ganglion cyst (g) arises from the radiohumeral joint, displacing the already divided SBRN (white arrowhead) and DBRN (open arrowhead). **C** shows the two branches distal to the ganglion. The DBRN already lies within the supinator muscle (sup). **D**, Ultrasound-guided needle into the neck of the ganglion cyst. Note the needle (curved arrows) tip underneath the ganglion. Brad indicates the brachioradialis; ecrb, extensor carpi radialis; ecrl, extensor carpi radialis; HUM humerus; RAD, radius.



may detect subtle muscle edema, when present.[63] Orthopedic implants limit MRI due to artifacts, and US has other advantages over MRI since it has a higher spatial resolution, allows for evaluation of an entire extremity in a short time, it has dynamic capabilities, and it is widely available.[1,41]

The leash of Henry has been reported to be a rare possible cause of DBRN compression. Doppler imaging should, therefore, be used in this region to depict atypical and prominent pulsating vessels near the nerve.[64] The SBRN may also be compressed by these vessels, which has not, to the best of our knowledge, been described in the literature (Figure 12). Diagnosis remains difficult, in the absence of normal values for the vessels, since vessels can be found near the nerve in the absence of pathology. In our experience, the most important finding when a compression is suspected is the depiction of an enlargement and a more hypoechoic appearance of the nerve near the course of the vessel(s) (Figure 12B), compared to a more proximal or distal level (Figure 12A).

Ganglion cysts at the level of the anterior elbow joint may compress the RN and/or its branches. They are easily diagnosed at US, as they usually appear

Figure 14. Elbow. Bicipitoradial bursitis. **A–C**, Transverse sonograms of the elbow joint, from cranial (**A**) to caudal (**C**), in a patient with known rheumatoid arthritis. Note the close proximity of the SBRN (white arrowhead) to a proliferative bicipitoradial bursitis (asterisk). **D**, Long-axis color Doppler sonogram along the distal biceps brachii tendon (bt) confirms the proliferative bursitis. Brad indicates the brachioradialis; HUM, humerus; RAD, radius; sup, supinator; SBRN, superficial branch radial nerve.

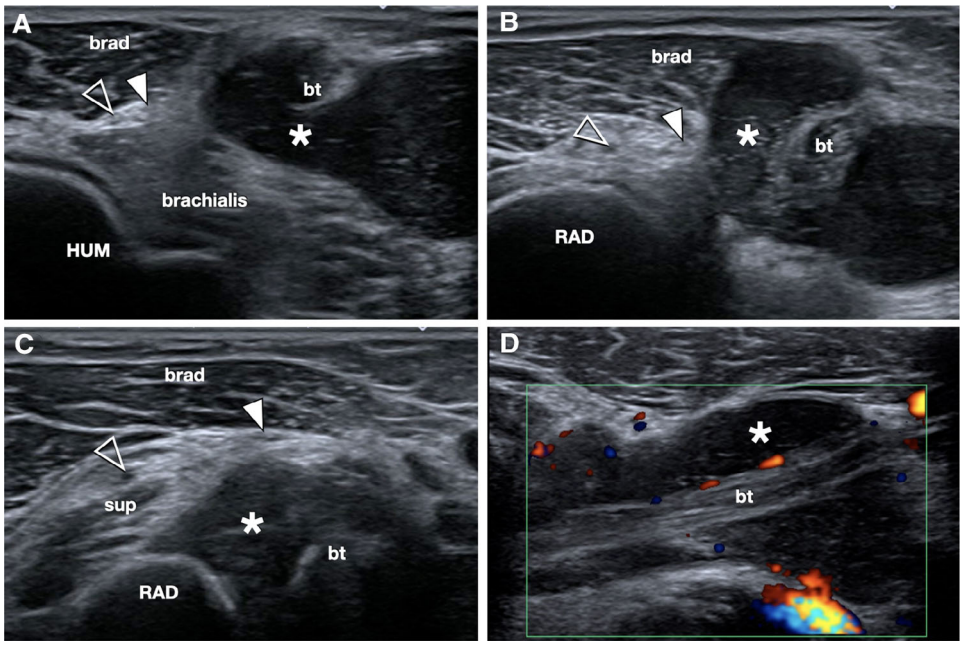


Figure 15. Elbow. Iatrogenic damage of the DBRN in a distal biceps repair. **A–D**. Axial sonograms at the level of the anterior lateral elbow from proximal to distal show the SBRN (white arrowhead) and DBRN (open arrowhead) in a patient with an incomplete radial nerve palsy after a surgically fixed distal biceps tendon (bt) rupture. In **B–D**, scar tissue formation (asterisk) surrounds the nerve branches (in particular, the DBRN). Also note that the fascicular pattern of the DBRN (black arrowhead) is clearly diminished compared to the SBRN. Brad indicates the brachioradialis; HUM, humerus; RAD, radius; DBRN, deep branch radial nerve; SBRN, superficial branch radial nerve.

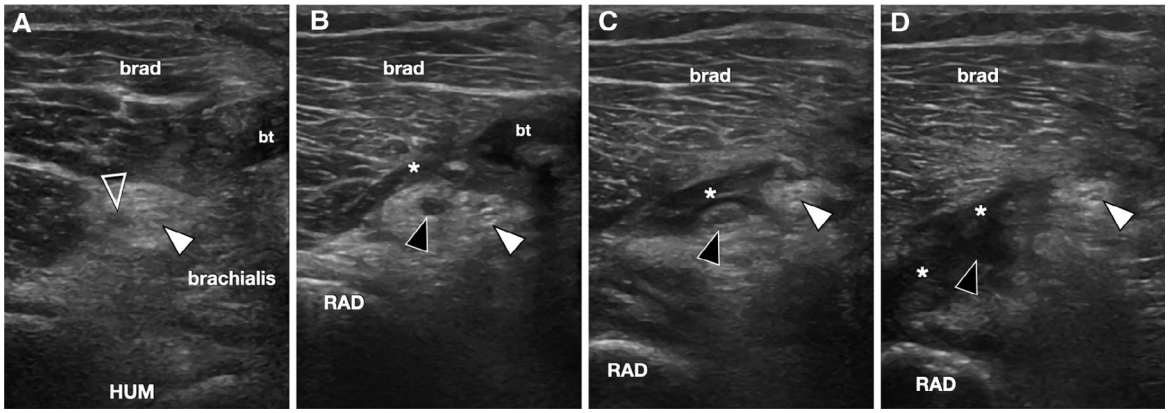


Figure 16. Supinator tunnel. DBRN "pseudoneuromatous" appearance. **A–C**, Sonographic findings in a patient with a humerus (HUM) fracture at the level of the radial tunnel (**A**) and the spiral groove (**B** and **C**). **A**, Transverse comparative sonogram demonstrates a clearly enlarged PIN (black arrowhead) within an atrophied supinator muscle (sup) compared to the contralateral healthy side (white arrowhead). This finding was presumed to be a "pseudoneuromatous" swelling of the PIN due to muscle atrophy. **B**, Transverse comparative sonogram shows a severely thickened RN (black arrow) compared to the healthy side (white arrow) after a humerus fracture. **C**, Longitudinal sonogram of the RN depicts a loose fragment (between calipers) within the nerve. Ext indicates extensor muscles; RAD, radius; DBRN, deep branch radial nerve.

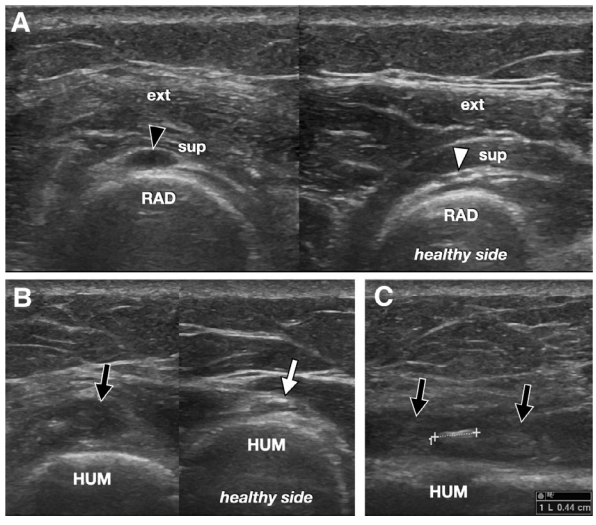
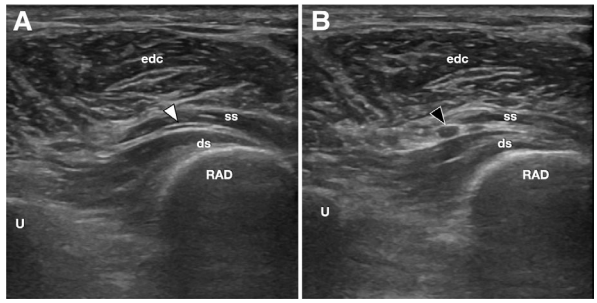


Figure 17. Distal supinator tunnel. **A** and **B**. Transverse sonograms within the supinator muscle (**A**) and, a bit further distally, at the level of the distal supinator tunnel (**B**). The DBRN appears normal in **A** (white arrowhead), whereas it appears thickened (black arrowhead) at the distal aspect of the supinator. Edc indicates the extensor digitorum communis; ds, deep head of the supinator; RAD, radius; ss, superficial head of the supinator; U, ulna; DBRN, deep branch radial nerve.



anechoic, nonvascular, and possibly multiloculated (Figure 13). US may also serve as a guide for therapeutic purposes, such as puncture or/and aspiration (Figure 13D).

Bicipitoradial bursitis is an uncommon cause of nerve compression. Both the SBRN and the DBRN may be compressed in cases with large and chronic bursitis, such as in patients with rheumatoid arthritis (Figure 14)[41]; a similar compression may originate from elbow joint synovitis.[65,66]

Figure 18. Wrist. Entrapment of the distal DBRN (PIN). Axial US comparative sonograms at the dorsal wrist, in a patient with previous trauma, who presented with pain. The extensor tendons of the fourth compartment (ecd-eip) are enlarged and hypoechoic due to tendinosis, and the extensor retinaculum is also thickened (black curved arrow). The healthy side for comparison is on the right (note the normal retinaculum, indicated by a white curved arrow). The distal PIN also appears a bit swollen (black arrowhead, on the left), compared to the normal PIN (open arrowhead, on the right). DBRN indicates deep branch radial nerve; PIN, posterior interosseous nerve

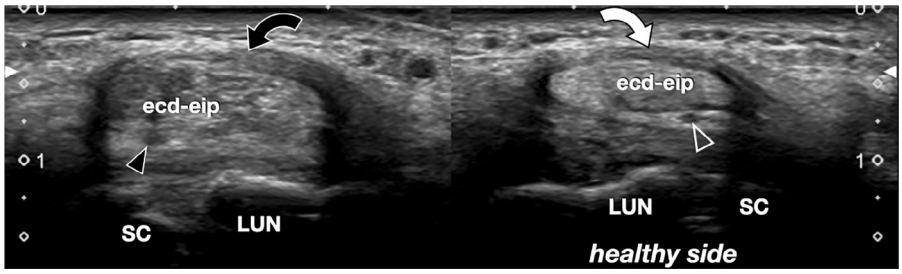


Figure 19. Forearm. Entrapment/friction neuropathy of the SBRN. In **A**, the SBRN with a normal fascicular pattern (white arrowhead) can be seen deep to the brachioradialis tendon (brad). In **B**, the nerve appears swollen (black arrowheads), passing between the brachioradialis and the extensor carpi radialis longus (ecrl) tendons, deep to the fascia (curved white arrow). In **C**, the nerve is normal, superficial to the fascia. **D**, In vivo normal anatomy of the SBRN, observed during reconstruction surgery in another patient. Note that, the SBRN passes between the brachioradialis and the extensor carpi radialis longus, explaining its possible irritation during repetitive pronation-supination movements. Fpl indicates the flexor pollicis longus; ra, radial artery; SBRN, superficial branch radial nerve.

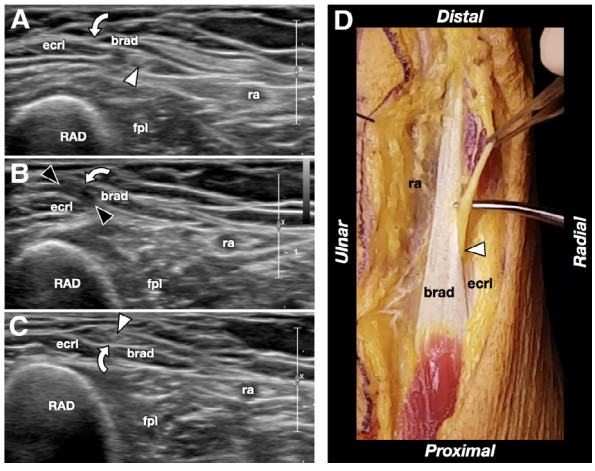
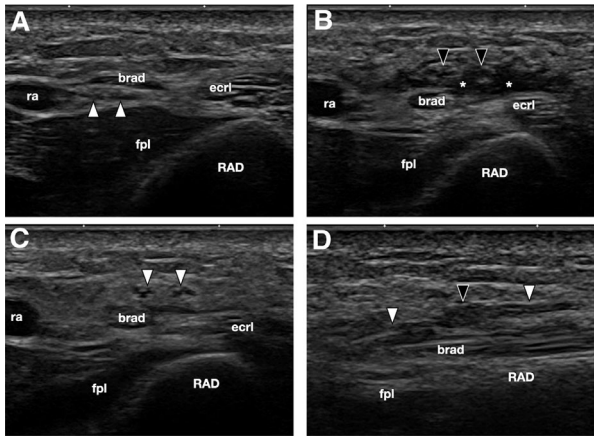


Figure 20. Forearm. In-continuity neuroma of the superficial branch radial nerve (SBRN). **A–C**, Axial ultrasound (US)sonograms from proximal (**A**) to distal (**C**) at the level of the distal third of the volar forearm in a 32-year-old man who presented for dysesthesia over the radial aspect of the distal forearm and hand, 1 month after a chainsaw injury. In **A**, note a high division (variant) of the SBRN, which can be seen already divided into two components (white arrowhead), under the brachioradialis tendon (brad), and over the flexor pollicis longus (fpl). In **B**, the SBRN branches appear thickened (black arrowhead) and surrounded by hypoechoic scar tissue (asterisks). Local pressure with the probe increased the patient's symptoms. Distally (**C**), the branches appear with a normal fascicular pattern. **D**, Sagittal-oblique sonogram, along the course of the SBRN, confirms the in-continuity neuroma. Note that, proximally and distally, the nerve appears normal. Ecrl indicates the extensor carpi radialis longus; ra, radial artery; RAD, radius.



DBRN disorders in distal biceps brachii tendon repair has also been described. According to a recent review of 3091 surgically treated patients, the nerve was involved in around 1.6% of the cases; most often, there is a transient neurapraxia.[67] The SBRN may be also injured. US can demonstrate nerve encasement in scar tissue (Figure 15), as well as iatrogenic injury by inadequate guidance, traction, or during drilling of the bone; in rare cases, the nerve may be incarcerated with the endobutton.[68,69]

Figure 21. Wrist. SBRN irritation-friction in DeQuervain's disease. **A** and **B**, Axial B-mode (**A**) and color Doppler (**B**) sonograms acquired over the first extensor compartment of the wrist in a patient with long-standing DeQuervain's disease, associated with mild paraesthesia that radiated to the dorsal aspect of the radial fingers. The retinaculum is swollen (curved white arrow) and hyperemic. The tendons of the first compartment look quite enlarged. In **C**, note the normal retinaculum (curved white arrow), as well as the tendons and the nerve (white arrowhead). **D**, Coronal-oblique sonogram of the diseased side demonstrates the close relationship of the thickened SBRN (black arrowhead) to the retinaculum. Note that, proximally and distally, the nerve appears normal (white arrowhead). Apl indicates the abductor pollicis longus tendon; cv, cephalic vein; epb, extensor pollicis brevis tendon; RAD, radius

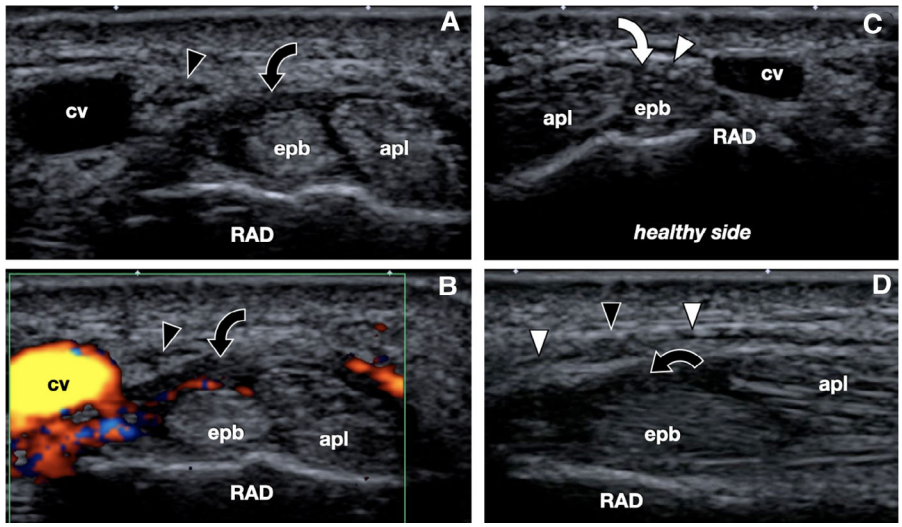


Figure 22. Wrist. SBRN scar encasement and radial artery thrombosis post-trapeziectomy. **A** and **B**. Axial ultrasound (US) color Doppler proximal (**A**) and distal (**B**), at the level of the dorsal base of the first two metacarpals (M1, M2) in a patient with pain after trapeziectomy. In **A**, the radial artery (ra) is thrombosed (curved black arrow) and encased in a hypoechoic scar (asterisks). Note also a distal branch of the superficial branch radial nerve (SBRN) thickened (black arrowhead), near the scar tissue. In **B**, distal reconstitution of arterial flow (curved white arrow) from the deep palmar arch. The distal branch of the SBRN appears normal (white arrowhead). **C**, Sagittal-oblique sonogram over the course of the radial artery confirms the hypoechoic thrombus. Cv indicates the cephalic vein; ecrl, extensor carpi radialis longus.

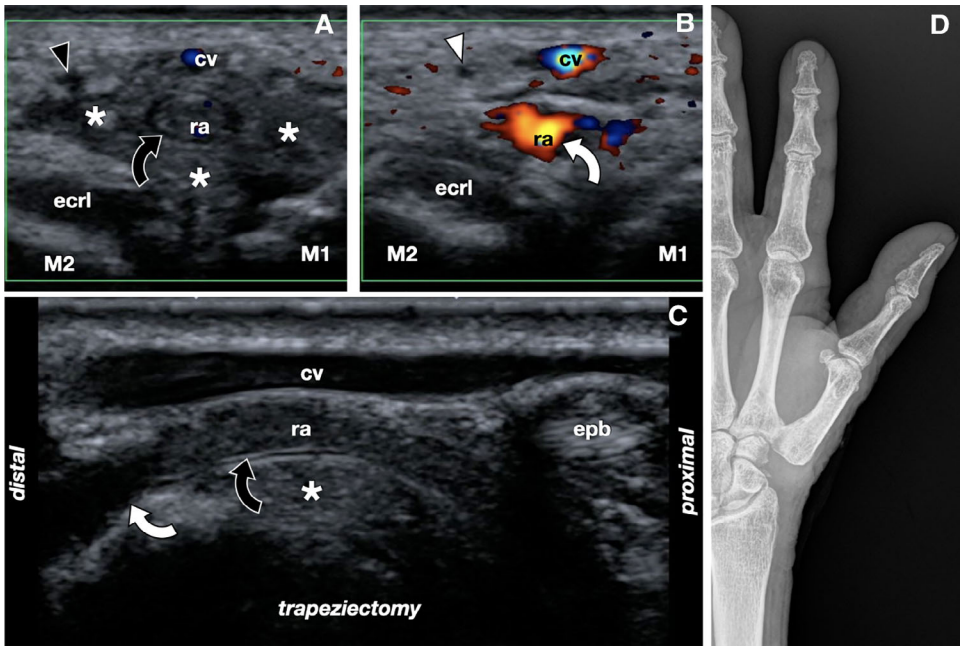


Figure 23. Distal Forearm. Iatrogenic superficial branch radial nerve (SBRN) neuroma. **A** and **B**. Axial ultrasound (US) sonograms at the distal forearm, proximal (**A**) and at the level of venipuncture (**B**). In **A**, the SBRN appears normal (white arrowhead), whereas in **B**, where the nerve is closer, deep to the cephalic vein (cv), it appears swollen with a loss of the fascicular pattern (black arrowhead). **C**, corresponding color Doppler sonogram confirms a normal flow of the vein. RAD indicates the radius.

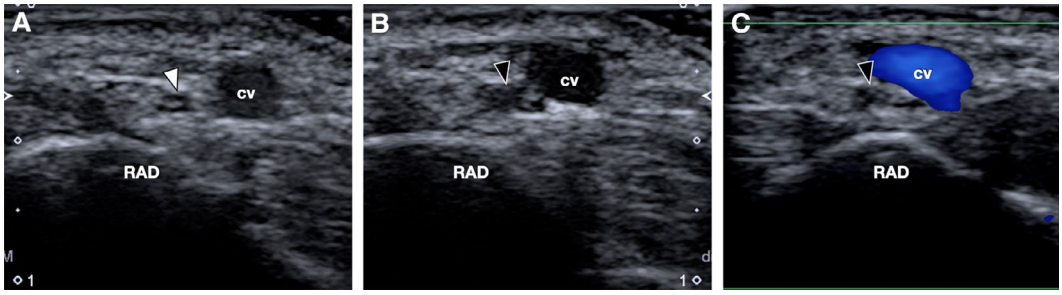
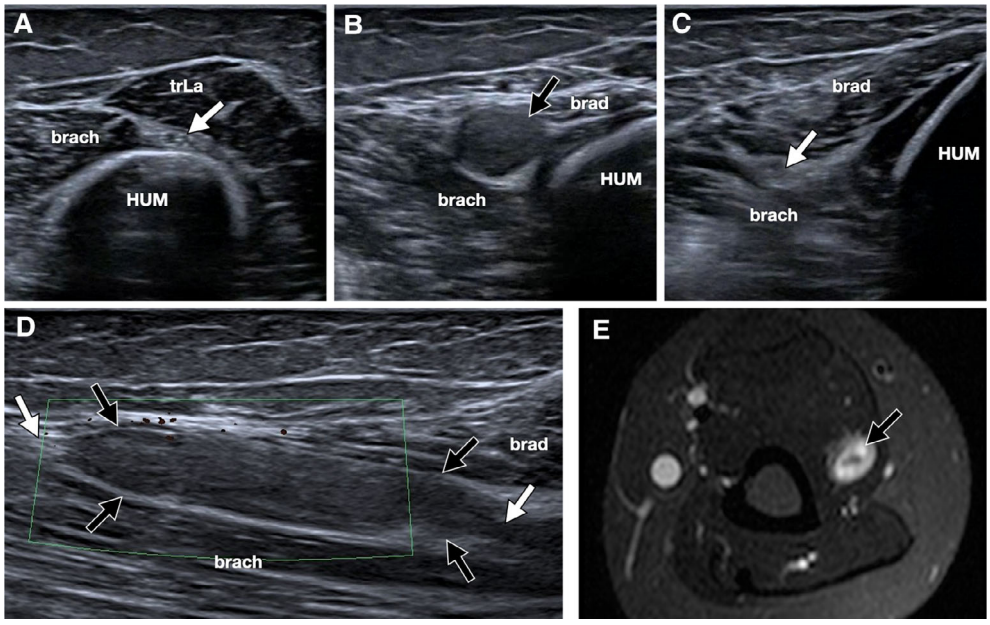


Figure 24. Arm. Radial nerve (RN) tumor. **A**–**C**. Axial sonograms obtained from cranial (**A**) to caudal (**C**), at the level of the arm, in a young patient referred for "shoulder/arm pain." Rotator cuff examination was normal (not shown). The patient complained of pain and discomfort at the middle third of the humerus, distal to the deltoid, radiating distally to the dorsal hand. In **A**, the RN (white arrow) appears normal between the lateral head of the triceps (trLa) and the brachialis (brach) muscles. In **B**, a hypoechoic mass can be depicted (black arrow). Distally (**C**), the nerve is normal. **D**, Longitudinal-oblique color Doppler sonogram demonstrates a 6-cm fusiform mass (black arrows) along the course of the RN (white arrows), with no apparent vascularity. A diagnosis of neurogenic tumor, possibly a neurofibroma, was made and contrast-enhanced magnetic resonance imaging (MRI) requested. **E**, Correspondent axial T2 short tau inversion recovery MRI demonstrates a hyperintense mass with a more hypointense central area (black arrow). Surgery confirmed a neurofibroma of the RN.



Enlargement of the DBRN in the region of the supinator tunnel may reflect a local process, as previously discussed, but may also be associated with a more proximal RN disorder (Figure 16). Therefore, when DBRN enlargement is found at the level of the supinator, we suggest scanning proximally along the nerve, which is a significant advantage of US compared to MRI. According to a study by Zaidmann, the association was found in 6 of 15 patients with proximal radial neuropathy. Further studies are needed to clarify this phenomenon; however, possible theories to explain it include mechanical injury secondary to

Figure 25. Proximal forearm. Tumor near the superficial branch radial nerve (SBRN). **A** and **B**. Axial and sagittal sonograms acquired at the level of the proximal forearm in a patient who presented for the evaluation of a slowly growing mass. Ultrasound demonstrates a deep-seated lipoma (asterisk) near the course of the SBRN (arrowhead). The lipoma displaces the radial artery (a). Note that the nerve maintains a normal fascicular pattern. The patient, a 65-year-old man, was referred only for some discomfort while gardening, without a distinct neuropathic pain. Brad indicates the brachioradialis; ecrb, extensor carpi radialis brevis; ecrl, extensor carpi radialis longus; fcr, flexor carpi radialis; pt, pronator teres.

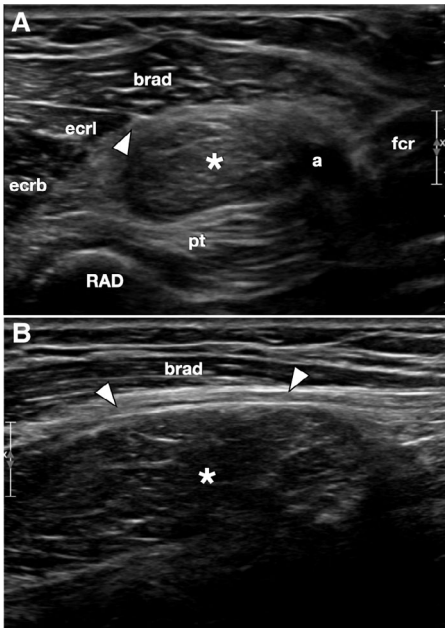
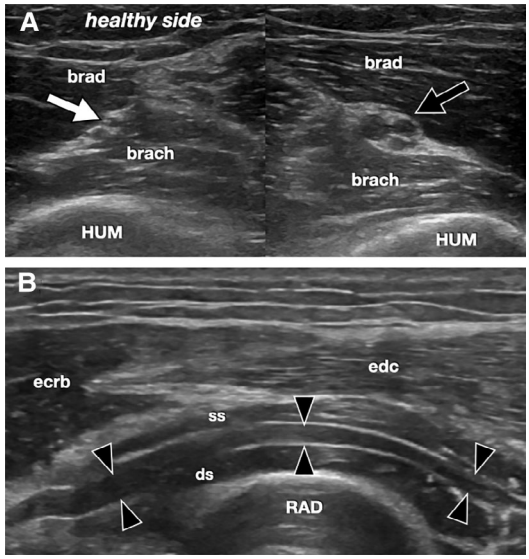


Figure 26. Distal arm. RN and DBRN enlargement in neuralgic amyotrophy. **A**, Comparative axial sonograms at the level of the distal upper arm. On the right, the fascicles of the RN are clearly swollen (black arrow) compared to the normal opposite side (white arrow, on the right). **B**, Long-axis sonogram at the level of the supinator tunnel in the same patient. The nerve swelling is obviously visible throughout the whole course of the DBRN within the supinator muscle (black arrowhead). Brach indicates the brachialis; brad, brachioradialis; ecrb, extensor carpi radialis brevis; edc, extensor digitorum communis; HUM, humerus; RAD, radius; RN, radial nerve; DBRN, deep branch RN.



the trauma; mechanical constriction related to the denervation and atrophy of the supinator muscle; and the so-called "double crush injury" in which the distal nerve may be more susceptible to injury due to proximal involvement.[70]

As reported by Anania, the PIN may be rarely entrapped at the distal edge of the supinator (Figure 17).[71]

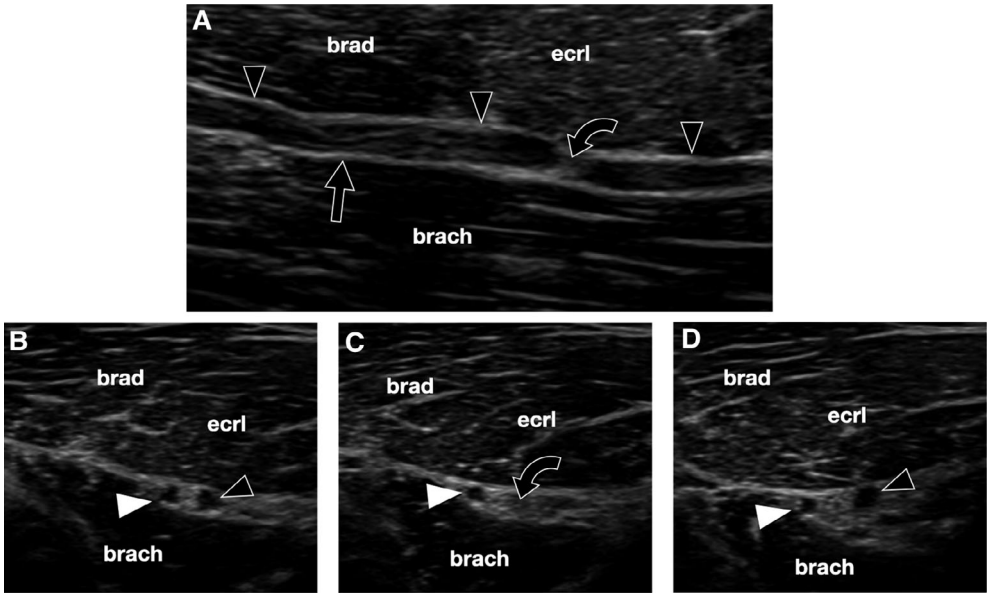
Distally at the forearm, PIN neuropathy is rarely reported and is mostly iatrogenic.[72] At the level of the wrist, the nerve may be compressed, eg, by ganglia, extensor tendon tendinopathy (Figure 18), or joint synovitis, or may be damaged during surgery. Compression of the PIN by ganglia may explain how some ganglia of small size may be associated with significant symptoms.

The SBRN rarely presents pathology at the elbow and proximal forearm. It can be entrapped when becoming superficial, passing between the brachioradialis and the extensor carpi radialis longus tendon, especially in manual workers who frequently exhibit pronation-supination movements of the hand (Figure 19).[33] The SBRN and the lateral antebrachial cutaneous nerve may both be subject to disorders since branches may overlap.[38]

Penetrating trauma may affect the SBRN, particularly from the point where it pierces the fascia, due to its superficial course (Figure 20).

The association of de Quervain's disease with SBRN neuropathy is probably underestimated[9,73]; in long-standing de Quervain's disease, a possible irritation of the SBRN may be demonstrated (Figure 21) or the nerve may also be damaged by blind injection.[9] In a postoperative setting (eg, also post-trapeziectomy or during percutaneous fracture fixation, wrist arthroscopy, Stener lesion surgery),[74] US may show nerve damage or encasement in scar (Figure 22). Moreover, US has been useful in demonstrating the course of the SBRN to possibly prevent injury during surgery.[75]

Figure 27. Elbow. DBRN torsion in neuralgic amyotrophy. **A**, Longitudinal sonogram at the level of the elbow joint, along the course of the DBRN. The DBRN (black arrowhead) appears swollen, then presents a sudden reduction in caliper size at the level of the torsion (curved arrow). Note also how US depicts a distortion in the course of the nerve fascicles (black arrow). **B–D**. Axial corresponding US images from proximal (**A**) to distal (**D**). In **B**, the SBRN (white arrowhead) and the DBRN can be depicted. Note that the DBRN appears a bit swollen. In **C**, just caudally, there is an apparent disappearance of the DBRN, which cannot be clearly demonstrated (curved arrow). In **D**, the swollen DBRN can be demonstrated. The patient was referred because he arose 6 months before with a hand drop, with no associated trauma. There was no sensory deficit. Electromyographic study demonstrated a motor palsy that involved the muscles innervated by the DBRN. Brach indicates the brachialis; brad, brachioradialis; ecrl, extensor carpi radialis longus; DBRN, deep branch radial nerve; SBRN, superficial branch radial nerve; US, ultrasound.



During venipuncture of the cephalic vein at the wrist, the SBRN (or its branches) may be damaged (Figure 23).[76]

Tumor may involve the RN and its branches (Figure 24) or may be located near and compressing the nerve (Figure 25).

At any level, the RN may be involved by neuralgic amyotrophy. This rare condition is also known as Parsonage-Turner syndrome, related to an axonal acute lesion that seems to be related to autoimmune-inflammatory causes.[77–80] The RN seems to be one of the most involved by this pathology.[77,81] Four types of abnormalities, which may be present within the same nerve at different levels, have been described by Aranyi: nerve enlargement with loss of fascicular pattern (Figure 26); focal complete/incomplete constriction, giving an hourglass-like appearance to the nerve when imaging it in the long axis; complete constriction in which, when imaging in axial sonograms, there is an apparent sudden "disappearance" of the nerve at the site of constriction, with enlarged nerves proximally and distally (Figure 27); and the fourth type is described as "fascicular entwinement" in which nerve fascicles rotate with each other within a small tract (few centimeters): this pattern can be demonstrated with slow axial sonograms, using the elevator technique (online supplemental Movie S2).[78] Cases of nerve torsion not necessarily associated with neuralgic amyotrophy have also been reported.[80,81]

Conclusion

The RN and its main terminal branches can be accurately assessed with US, particularly when modern, high-frequency transducers are used. Knowledge of the anatomy and the course of these nerves, as well as the main disorders that can affect them, are mandatory for an appropriate diagnosis, which requires correlation to clinical data.

Acknowledgments

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