REVIEW / Neuroradiology

Ultrasonography of the brachial plexus, normal appearance and practical applications

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KEYWORDS
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Abstract Ultrasound examination of the brachial plexus, although at first sight difficult, is perfectly feasible with fairly rapid practical and theoretical training. The roots are accurately identified due to the shape (a single tubercle) of the transverse process of C7 in the paravertebral space, and the superficial position of C5 in the interscalene groove. The téléphérique technique allows the roots, trunks and cords to be followed easily into the supraclavicular fossa. In just a few years, ultrasound imaging of the plexus has become a routine anesthesia examination for guiding nerve blocks. In trained hands, it also provides information in thoracic outlet syndromes, traumatic conditions (particularly for postganglionic lesions) and tumoral diseases. Even if MRI remains the standard examination in these indications, ultrasound, with its higher definition and dynamic character, is an excellent additional method which is still under-exploited.

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In the last 10 years, ultrasonography has become an extremely effective examination for exploring the nerves of the upper limb.

The brachial plexus is still one of the few areas dreaded by musculoskeletal ultrasonographers because of its complex anatomy and its bony relations (the clavicle) hindering exploration.

Ultrasound examination of this difficult region becomes less daunting with knowledge of some reference slices and a few anatomical landmarks.

It is no longer a research application since it is commonly used in anesthesia to perform ultrasound-guided nerve block. Because of its definition and dynamic character, it is also proving to be very useful for studying thoracic outlet syndrome, tumor disease and traumatic lesions.

Anatomy of the brachial plexus

Anatomical description

The brachial plexus is formed from the ventral nerve roots of C5 to T1 (Fig. 1). A contribution from C4 or more rarely T2 roots may be found in certain cases. The size of the roots increases from C5 to C7 then decreases from C8 to T1.

These ventral roots unite to form the trunks:

- C5 and C6 give rise to the upper trunk;
- C7 to the middle trunk;
- C8 and T1 to the lower trunk.

The suprascapular nerve arises from the upper trunk. Each of these trunks separates into an anterior and posterior division, these divisions in their turn reuniting to form 3 cords. The anterior divisions of the upper and middle trunks give rise to the lateral cord, the anterior division of the lower trunk gives rise to the medial cord, and the three posterior divisions of the trunks anastomose to form the posterior cord.

The following terminal nerve branches arise from these cords:

- the musculocutaneous nerve (lateral cord, roots C5-C6-C7);
- the median nerve (lateral and medial cords, roots C5-C6-C7-C8-T1);
- the ulnar nerve (medial cord, roots C7-C8-T1);
- the radial nerve (posterior cord, roots C5 to T1);
- the axillary nerve (posterior cord, roots C5-C6).

This complex intermixing of the nerve fibers is subject to very many interindividual variations and the classic description given above is only found in 50 to 70% of cases [1,2].

Topographic anatomy

The brachial plexus is roughly shaped like an hourglass with the long axis represented by the 7th pair of cervical nerves.

The proximal base of the hourglass is formed by the cervical vertebral foramina from which the ventral roots emerge.

A little further distally the roots enter the interscalene groove (between the anterior and middle scalene muscles), where they are superjacent to the subclavian artery, before regrouping into trunks.

The narrowest area of the hourglass is the narrow costoclavicular gap where the trunks are redistributed into cords. In the sagittal plane, the cords are superior and posterior to the subclavian artery forming a 'Phrygian cap' over it.

In the axial plane, the cords are lateral to the subclavian artery, which is itself lateral to the subclavian vein.

Distal to the costoclavicular gap the plexus expands again.

Figure 1. Diagrammatic representation of the brachial plexus according to Netter, and anatomical relations with the scalenes, clavicle and pectoralis minor. UT: upper trunk; MT: middle trunk; LT: lower trunk; LC: lateral cord; PC: posterior cord; MC: median cord; ss: suprascapular nerve; mc: musculocutaneous nerve; a: axillary nerve; r: radial nerve; m: median nerve; u: ulnar nerve.
Below the tunnel formed by the pectoralis minor, the cords give rise to the terminal nerve branches which are distributed to the upper limb.

Some collateral branches start directly from the trunks or cords; this is the case for the suprascapular nerve (C5, C6) which arises from the upper surface of the upper trunk, leaves the plexus shortly after its origin and passes behind the omohyoid muscle to innervate the supraspinatus and infraspinatus muscles.

Ultrasound anatomy of the brachial plexus

Exploration of the brachial plexus requires a high frequency probe, generally between 10 and 18 MHz. A short or broad neck can considerably hinder exploration, in particular visualization of roots C8 and T1 [3].

Normally the roots, trunks and cords appear as homogeneous, hypoechoic structures, tubular in longitudinal slices and oval in axial slices [4]. It should be noted that this appearance differs from the appearance of peripheral nerves, the fasciculated nature of which can be clearly identified with ultrasound (hypoechoic bundles embedded in more or less hyperechoic supporting connective tissue and surrounded by the hyperechoic epineurium).

In broad outline, 4 anatomical regions can be identified where the different components of the brachial plexus can be studied [5–7]: the paravertebral region, the interscalene region, the periclavicular region and the retropectoral region.

The paravertebral region

Demondion [3,8] proposed a sagittal approach to this region, in order to reproduce the MRI slices now familiar in this plane. Martinoli and Bianchi proposed horizontal exploration [4]. The probe is positioned in a laterocervical position in a horizontal plane, from which position sweeping the probe from the top downwards should allow the different roots to be seen.

Two anatomical structural landmarks will help find the actual level of the roots: the transverse process of C7 (Boxed text 1) and, secondarily, the deep cervical artery.

The transverse processes are found at the junction of the laminae and vertebral pedicles. From C2 to C6 they look similar and shaped like a 'U', with the 2 branches forming the anterior and posterior processes (Fig. 2).

On leaving its foramen, a given root positions itself between the two processes of the vertebra with the same number, for example root C6 will be positioned between the two projections of the transverse process of vertebra C6.

The shape of the transverse process of C7 is different. Here there is a prominent posterior tubercle, much greater in size than the anterior process which is often absent. After leaving its foramen, the C7 root positions itself in contact with the anterior part of the prominent tubercle.

In 98% of cases, this tubercle has no foramen for the vertebral artery which remains just anterior to this bone structure, whereas it passes through the higher processes.

Despite the limitations of ultrasound for studying bone, it is perfectly good for visualizing cortical bone, which appears as a hyperechoic line associated with a posterior shadow.

Figure 2. Shape of the transverse processes: an essential ultrasound landmark: a: lateral view VRT reconstruction of a cervical spine CT scan; b: the transverse processes from C2 to C6 have a similar appearance, being 'U' shaped with an anterior and posterior process (arrows). A given root will position itself between the 2 processes of the vertebra with the same number (dotted line), e.g. the C6 root intercalates between the anterior and posterior processes of the transverse process of vertebra C6; c: the shape of the transverse process of C7 is different. It has a projecting posterior tubercle (dotted arrow), and the C7 root is in contact with the anterior part of this tubercle.
Boxed text 1  Simplified method for ultrasound exploration of the brachial plexus.
1. Find the roots at the transverse processes in horizontal axial slices.
2. Number these roots according to the shape of the transverse processes: single process for C7, bifid transverse process for C5 and C6.
3. Use the téléphérique technique to follow the roots, trunks and cords in a transverse axial plane.
4. In a horizontal slice through the interscalene groove the roots are superposed and sandwiched between the anterior and middle scalene muscles; C5 is the most superficial root, T1 the deepest.
5. Above the costoclavicular gap, in an axial slice the cords are grouped posterior and lateral to the subclavian artery (lateral cord superficially, medial cord deeply and the posterior cord posteriorly and laterally).
6. Repeated supraclavicular and infracavicular slices help you understand how the plexus and vessels pass through the costoclavicular gap.
7. Doppler flow analysis of the subclavian artery distal to costoclavicular gap in a resting position and with the arm raised will give an indirect idea of the narrowing of this gap.
8. If exploration of the cords proves difficult under the pectoralis minor in the axilla, it may be helpful to start from the arm where the nerves are easy to pick out and follow them back using the elevator technique.

cone. The particular shape of the transverse process of C7 can thus be considered a reliable indicator for determining the level of the C7 root. On moving the probe upwards, the C6, C5, and C4 roots can be individually distinguished; by moving the probe downwards a little, in favorable cases the C8 (80% of cases) or even the T1 (40% of cases) may be visualized [4]. It should be remembered that the T1 vertebra has no tubercle.

The deep cervical artery leaves the neck proper and enters the nape of the neck passing between the transverse process of C7 and the first rib (Fig. 3). Typically (but variations are possible), it passes between roots C7 and C8 [2,3,9].

The interscalene region
The interscalene triangle is bounded anteriorly by the anterior scalene muscle and posteriorly by the middle scalene muscle (Fig. 4).

The subclavian artery passes at the base of this triangle posterior to the anterior scalene.

The subclavian vein is outside of this triangle just in front of the anterior scalene.

Roots C8 and T1 are posterior to the subclavian artery, this deep position making their visualization more difficult.

Roots C5, C6, and C7 are situated above the subclavian artery.

The posterior scapular artery is another anatomical vascular landmark. It arises from the upper side of the interscalene segment of the subclavian artery then weaves through the brachial plexus generally passing between the primary upper trunk (C5-C6) and the middle trunk (C7).

Figure 3  Deep cervical artery: a: anatomical diagram of the passage of the deep cervical artery (arrowhead) between the C7 and C8 roots. This artery arises from the costocervical trunk (arrow). SA: subclavian artery; SV: subclavian vein; AS: anterior scalene muscle; R1: first rib; b: extraforaminal ultrasound slice in the oblique sagittal plane: detection with Doppler of the deep cervical artery which typically passes between C7 and C8.
Ultrasonography is the technique (more precisely the téléphérique technique here) used classically for peripheral nerve ultrasonography.

During this dynamic examination, the roots insinuate themselves between the bellies of the anterior scalene muscle anteriorly and the middle scalene muscle posteriorly (Fig. 4), C5 then being the most superficial root and T1 the deepest (Boxed text 1).

The sternocleidomastoid and omohyoid muscles can also be used as reference points. The sternocleidomastoid muscle is the most superficial muscle of the region; it appears relatively thick and ovoid in an axial slice. Just a little deeper a thin digastric (two muscle bellies joined by an intermediate tendon) muscle can be found, the omohyoid muscle (Fig. 5).

This superficial muscle is inserted on the anterior surface of the hyoid bone and arises on the upper border of the scapula.

The probe is placed level with the thyroid and neck vessels (carotid and jugular), then moved laterally and downwards along the omohyoid muscle. The roots of the plexus are situated under an arch composed in the transverse plane of the following [10]:

- superficially, the junctional fibrous layer of the omohyoid muscle;
- anteriorly and medially, the anterior scalene muscle;
- posteriorly and laterally, the middle scalene muscle.

Using these anatomical landmarks, the roots then the trunks in the interscalene groove can be identified, in the sagittal plane.

The plexus can also probably more easily be approached at this level using horizontal axial slices (and in any case it is this examination plane which will be used by anesthetists to produce interscalene block).

The easiest technique is to start with axial slices of the roots, described in the previous section, and to follow them by moving the probe laterally using the elevator technique.

Figure 4. Horizontal slice centered on the interscalene groove. Before regrouping into trunks the roots appear superposed (dotted rings) between the anterior scalene (AS) anteriorly and the middle scalene (MS) posteriorly. The C5 root is the most superficial, T1 the deepest.

Figure 5. Anatomical 'panoramic' cervical (a) and ultrasound (b) horizontal slice showing the interscalene groove and its relations. The omohyoid muscle (*) is inserted on the anterior surface of the hyoid bone and arises on the upper border of the scapula. It can be used as a guide to find the roots and trunks of the brachial plexus: the probe is placed level with the thyroid and neck vessels (carotid and jugular), then moved laterally and downwards along the omohyoid muscle. The roots (dotted line) of the plexus occur under an arch formed in the transverse plane superficially by the junctional fibrous strap of the omohyoid muscle, anteriorly and medially by the anterior scalene muscle (AS), posteriorly and laterally by the middle scalene muscle (MS). Thy: thyroid; CA: carotid artery; JV: jugular vein; SCM: sternocleidomastoid muscle.
The periclavicular region
The clavicle prevents direct visualization of the brachial plexus and the vascular components in the costoclavicular gap, a key area of the thoracic outlet where narrowing is greatest (Fig. 6).

We have to be satisfied with studying the supra- and infracavicular areas.

To do this, in the first instance, as in MRI or CT [11–16], the sagittal (oblique) plane will be preferred, with the small axis (circular and pulsatile) of the subclavian artery as a landmark. The trunks or the cords (interindividual variation in the precise level of division and anastomosis) will form a ‘Phrygian cap’ over this artery, being above and slightly behind it:

- the posterior cord occurs in the upper part of the cap;
- the lateral cord at the front;
- the medial cord behind.

Oblique axial slices can be attempted to try to visualize the vascular/neural components under the clavicle.

A horizontal axial slice is used in anesthesia for supraclavicular blocks. Laterally to medially and from the posterior forward, the following can be recognized (Boxed text 1): the cords of the brachial plexus, the subclavian artery just in contact, and the subclavian vein a little farther away. Deeper down the first rib can be made out (hyperechoic cortex with a shadow cone) and the apex of the lung (hyperechoic pleura moving with breathing).

Retropectoral and axillary regions
The retropectoral region (Fig. 7) can be studied in sagittal or axial transverse slices by translating the probe from a subclavicular slice or from a slice passing through the coracoid (proximal insertion of the pectoralis minor).

The pectoralis major muscle can easily be seen superficially with the pectoralis minor just below.

Deeper than the latter, and although it is not always easy, the cords of the brachial plexus can be seen surrounding the axillary artery (which is the continuation of the subclavian artery distal to the costoclavicular gap). These cords divide into terminal branches at the lateral edge of the pectoralis minor.

It is sometimes less difficult to identify for certain the nature of a terminal branch by starting from the inner surface of the arm, where finding the main nerves (radial, median and ulnar) is easy, and following them back into the axilla using the elevator technique.

Practical applications
In this section we shall describe the different practical applications of brachial plexus ultrasonography.

Ultrasound-guided brachial plexus nerve blocks [17]
This is without doubt the most common application of ultrasound examination of the brachial plexus, practiced daily by our anesthetist colleagues.

Plexus or trunk blocks were initially performed based on anatomical landmarks and neurostimulation (triggering a nerve impulse and paresthesia or muscular movements in the corresponding territory by electrical stimulation).

Ultrasoundography allows direct visualization of the nerve structures and shows the distribution of the anesthetic product around them in real time: we talk of the ‘doughnut sign’ to describe the distribution of the anesthetic as a hypoechoic ring surrounding a nerve structure. In order to optimize diffusion of the product, it is sometimes useful to move the needle, halfway through the injection.

Figure 6. Slices in the supraclavicular region: a: anatomical sagittal slice (with the kind permission of Prof. Xavier Demondion); b: horizontal ultrasound slice (cords surrounded by a dotted line). Cla: clavicle; R1: first rib; SV: subclavian vein; SA subclavian artery; LC: lateral cord; PC: posterior cord; MC: medial cord; Pl: pleura of the dome of the lung.
Ultrasonography has another major advantage in that it reduces certain complications (vascular, pleural and intra-neural puncture) by viewing the path of the needle directly.

Despite the accurate targeting provided by ultrasound, anesthetists continue to confirm correct positioning of the needle by electrical stimulation.

Interscalene block (Fig. 8) [18] is used for shoulder surgery and allows all the nerves innervating the shoulder to be reached, in particular the suprascapular nerve arising from the upper trunk, which would not be anesthetized by another approach.

The patient is in the dorsal decubitus position with the head turned at 45° to the contralateral side. The probe is placed in an axial plane at the level of the cricoid cartilage. The small axes of the roots or the trunks can be seen between the anterior and middle scalene muscles. A posterolateral puncture is often the most ergonomic, since the anesthetic product gradually surrounds the nerve structures and opens the interscalene space.

Electrical stimulation leads to contraction of the deltoid or the biceps.

A supraclavicular block [19] is used particularly for arm and elbow surgery.

Ultrasound has made this block considerably safer by limiting the risks of pneumothorax which frequently used to complicate the original technique described by Kulenkampf [20] in 1928.

The patient is in the dorsal decubitus position with the head turned at 45° to the contralateral side.

The probe is placed horizontally above the clavicle.

The trunks or cords of the brachial plexus are lateral to the pulsatile subclavian artery.

The needle approaches the nerve structures laterally following the long axis of the probe.

Neurostimulation leads to contraction of the biceps or the triceps.

An infraclavicular block is performed with the patient in the decubitus position, with the arm along the body. The coracoid is found in the sagittal plane and the probe is translated medially.

![Figure 7](image1.png)

**Figure 7.** Sagittal slices through the tunnel under the pectoralis minor: a: anatomical sagittal slice (with the kind permission of Prof. Xavier Demondion); b: sagittal ultrasound slice: at this topographic level the cords (surrounded by a dotted line) are deep and difficult to visualize. PMaj: pectoralis major; Pm: pectoralis minor; AV: axillary vein; AA: axillary artery; LC: lateral cord; PC: posterior cord; MC: medial cord.

![Figure 8](image2.png)

**Figure 8.** Ultrasound-guided interscalene block: a: position of the patient and approach for inserting the catheter (simulation); b: the needle visible as a hyperechoic line (arrows) is positioned via the posterolateral route in the interscalene triangle (MS: middle scalene muscle; AS: anterior scalene muscle); the anechoic anesthetic (asterisks) is injected so as to mold the trunks of the brachial plexus (T): the ‘doughnut sign’.
Behind the pectoralis minor, the compressible vein is identified surmounted by the pulsatile artery, around which the nerve cords are found.

This is a deep block and is more difficult to perform than a supraclavicular or axillary block, which therefore seems preferable.

The cords can only be correctly visualized in 27% of cases [21].

An axillary block is performed for distal upper limb surgery.

The patient is in a dorsal decubitus position, the arm abducted almost perpendicular to the torso.

The probe is placed in the distal part of the axilla so as to obtain a slice in the short axis of the axillary artery and vein.

The nerves (radial, median and ulnar) are detected around the pulsatile artery, and are anesthetized one by one, or by an injection on each side of the axillary artery.

**Thoracic outlet syndrome**

Thoracic outlet syndrome is a complex controversial entity which most often affects women (4/1) between 20 and 40 years of age [8].

In physiopathological terms it is compression of the neural and/or vascular structures passing through the superior thoracic outlet, encouraged by the arm positioned in abduction.

There are many functional clinical signs: pain, numbness, tingling, paresthesia, weakness of the upper limb. In practice, it is often difficult to distinguish between the neurological and vascular signs, which are often associated.

MRI and CT angiography are the reference examinations for studying thoracic outlet syndrome. For these two techniques, sagittal slices made with the arm raised allow the different potential sites of conflict to be studied: the interscalene groove, the costoclavicular gap, the tunnel under the pectoralis minor.

The interscalene groove is perfectly accessible to ultrasound exploration. Guided by standard radiography, it is thus possible to search for the presence of a rib or rib-like process (Fig. 9) harming the roots or trunks.

On the other hand, finding a fibrous adhesion directly by this technique seems very unlikely.

The clavicle interferes with a direct ultrasound approach to the costoclavicular gap.

Since compression of nerves of the plexus is often associated with vascular compression, indirect signs of vascular compression will suggest conflict.

The Doppler spectrum of the axillary artery (the continuation of the subclavian artery) distal to the costoclavicular gap can be studied dynamically with the patient seated with the arm in different positions of abduction (MRI or CT demand a choice between one or two positions, and the patient lying).

A significant increase in speeds and the dark window under the systolic peak being filled suggest compression of the artery and therefore probable concomitant compression of the trunk and cords of the brachial plexus (Fig. 10).

The caliber of the subclavian artery can also be studied by subclavicular oblique horizontal slices with various degrees of abduction of the shoulder [22].

**Brachial plexus trauma**

Traumatic lesions make up more than half of pathological brachial plexus conditions. They include avulsions (stretching of the plexus), penetrating wounds and iatrogenic causes (in most cases, surgical biopsies) [23].

MRI is currently the standard examination in this indication. It is particularly effective for diagnosing preganglionic conditions (lesions before the spinal ganglion).

In this context, it looks for the following:

- a pseudomeningocele present in 50% [24] to 87% [25] of root avulsions (Fig. 11);

![Figure 9](image-url)  
**Figure 9.** Conflict in the interscalene groove. Pain and paresthesia of the left upper limb in a 50-year-old sportsman, related to a left rib-like transverse process on C7 in conflict with the roots and trunks of the brachial plexus in the interscalene groove: a: horizontal ultrasound passing through the interscalene groove; AS: anterior scalene muscle; MS middle scalene muscle; the dotted line surrounds the roots of the brachial plexus. The rib-like transverse process of C7 responsible for the symptoms is marked by arrows; b: CT equivalent (lateral VRT).
Figure 10. Narrowing of the costoclavicular gap. Hypertrophic clavicular bone callus narrowing the costoclavicular gap when the arm is raised resulting in a thoracic outlet syndrome in this motocross champion: a: in Doppler performed in a neutral position distal to the costoclavicular gap, the spectrum and speed are normal in the axillary artery; b: Doppler performed this time in the stress position with the arm in abduction shows a clear increase in speeds (2 m/s) and disturbance of the distal flow with filling of the dark window under the systolic peak; c: despite the metallic artefact of the clavicle plate, the CT scan (MIP) shows marked narrowing of the subclavian artery in the stress position related to a hypertrophic clavicular bone callus.

Figure 11. A pseudomeningocele, a sign of preganglionic damage. Deficit of the left upper limb persisting 2 years after a road accident in a 25-year-old man: a: T2-weighted axial MRI slice showing a fluid collection which does not contain a root at the C7 foramen: a pseudomeningocele. Note on this slice the anterior displacement of the left vertebral artery (va) and the lack of visualization of left rootlets; b: equivalent horizontal ultrasound slice; the single transverse process of C7 is picked out by a dotted line, the anechoic pseudomeningocele (arrow heads) displaces the vertebral artery (va) anteriorly.
• a gap in or contrast uptake by a rootlet at the dural sheath;
• contrast uptake by the paraspinal muscles.

In postganglionic damage, MRI usually shows T2-weighted STIR hyperintensity and thickening of the trunks and cords of the brachial plexus. Quite often, however, MRI fails in these distal conditions, giving negative results despite evident clinical and EMG lesions (30% of cases in the Vargas series [26]). Ultrasound is little used for investigation of plexus trauma.

Its advantages are limited where there is preganglionic damage, but it can show pseudomeningoceles that extend sufficiently out of the foramina (Fig. 11).

On the other hand, it seems more useful for studying the roots, trunks and cords in the interscalene groove and beyond the costoclavicular gap. Its definition, clearly better than that of MRI, and its dynamic character are unquestionable advantages that are not used to the full. Comparison with the healthy side is always possible.

It can be used to look for the following signs:
• thickening of the trunks or cords compared with the contralateral side (Fig. 12);
• a gap in the trunks or cords (Fig. 13);
• a hematoma in contact with neural structures (Fig. 13);
• an area of hypoechoic fibrosis sheathing neural structures in the late phase.

Tumor invasion of the brachial plexus

Invasion of the brachial plexus is a classic evolutionary feature of tumors of the apex of the lung, constituting Pancoast’s syndrome. The mass, its origin and the invasion of the trunks and cords of the brachial plexus is ideally shown by MRI [27].

Ultrasound does not permit the tumor to be staged exhaustively but can show this supraclavicular or infraclavicular invasion and any associated lymphadenomegaly.

Other clinical situations are accompanied by invasion of the plexus: breast cancer metastases (the main lymphatic drainage of the breast being through the axilla explains the frequency of metastases to the brachial plexus), metastases of other cancers (lung, bladder, testicular and thyroid cancers, melanoma, etc.), lymphomas or sarcomas.

In these cases, the invasion may take a slightly different form: the tumor process infiltrates the nerve structures and their sheaths using them as a pathway for its progression.

Because of CT’s poor contrast resolution, and the low spatial resolution of MRI, this type of neural infiltration by a tumor may be difficult to identify with these techniques. In certain cases, ultrasound, with its unrivaled spatial definition and the possibility it provides of following a nerve over a long distance (elevator technique), will objectify the lesion more easily (Fig. 14).

Radiation-induced fibrosis

Radiation-induced fibrosis is a common cause of damage to the brachial plexus, forming 25% of non-traumatic plexopathies [28–30]. Histologically, dense fibrous tissue is found sheathing the brachial plexus combined with Wallerian degeneration.

In general, the fibrosis follows 10 to 20 months after the radiotherapy, and is seen in MR imaging as T2-weighted hyperintensity and homogeneous enhancement of the nerve structures and the adjacent soft tissues, and as regular symmetrical thickening of the trunks and cords [27], which may persist for months or years.

Ultrasound shows rather hyperechoic thickening of the nerve structures and surrounding fat (Fig. 15).

Differentiating between radiation-induced nerve damage, a residual tumor, recurrence or secondary lesions is a problem with MRI and will also be the case with ultrasound. Prospective or retrospective monitoring of images [27] using PACS then proves particularly useful.

Figure 12. Focalized postganglionic traumatic lesions of the brachial plexus. Clinical deficit in the left C5-C6 territory, 3 months after a motorcycle accident in a 24-year-old man: a: this MR T2-weighted STIR coronal image shows thickening and hyperintensity of the left roots and trunks (arrows) compared with the healthy side (dotted arrows); b: horizontal ultrasound slice of the healthy side; the small caliber C5 to T1 roots (dotted line) are superposed between the anterior scalene muscle (AS) and the middle scalene muscle (MS) in the interscalene groove; c: horizontal slice on the pathological side: marked thickening of the 2 superior roots (C5 and C6): lesion and hypertrophic scarring of these roots and of the upper trunk into which they are prolonged.
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Figure 13. Extensive acute postganglionic traumatic lesions of the brachial plexus. Complete deficit of the right upper limb 2 weeks after a motorcycle accident in a 27-year-old man: a: the normal architecture of the cords of the right plexus (arrows) cannot be recognized on the T2-weighted STIR coronal slice; with MRI it is difficult to differentiate the thickened cords, the broken cords, the peripheral hematoma; b: on the T1-weighted sagittal ‘anatomical’ MRI slice a hypointense area (arrows) encompasses the subclavian artery (arrowhead) and the cords cannot be individualized; c, d: the supraclavicular coronal (c) and horizontal (d) ultrasound slices show more specifically the complete rupture of a cord (arrows), the hematoma at the gap (asterisks), and the thickening of the other cords (double arrows) posterior to the subclavian artery (A).

A PET scan is also of particular use in this type of clinical situation: unlike fibrosis, a tumor will fix a radioactive tracer.

Neurogenic tumors [27]

Neurofibromas (Fig. 16) make up 50 to 60% of the neurogenic tumors encountered in the brachial plexus.

One third of neurofibromas appear in patients known to have type 1 neurofibromatosis (NF1) while two thirds are sporadic. NF1 patients present multiple lesions of the brachial plexus whereas in the sporadic form the lesion is usually solitary. Histologically, the non-encapsulated neurofibroma develops at the expense of the nerve fascicles.

In ultrasound, the lesion typically presents well-defined margins and is homogeneous and hypoechoic with intratumoral blood vessels visible with Doppler.

In the brachial plexus, the roots are usually clearly hypoechoic and the neurofibroma may appear relatively hyperechoic [10].

Unlike a schwannoma, a neurofibroma is centrally positioned relative to the nerve fibers. There can be satellite lymphadenopathies and a collateral circulation.

Schwannomas (20% of neurogenic tumors) result from the benign transformation of Schwann cells (nerve sheath tumors).

The lesion is eccentric relative to the nerve fibers, usually solitary and well encapsulated. With ultrasound, the mass is hypoechoic, with regular margins [10]; sometimes, an echogenic capsule can just be distinguished, difficult to recognize in the fat which is hyperechoic [31,32]. Doppler may show an internal vascular circulation.

In practice, ultrasound can detect these two benign neurogenic tumors (neurofibroma and schwannoma) in the plexus without too much trouble, but it may be difficult to differentiate between them in this position.

Outside of the clinical context, it seems that MRI tractography [33] is the best technique for showing the eccentric or centered position of the tumor relative to the nerve fibers and thus for giving a pointer to its type.

Finally, Malignant Peripheral Nerve Sheath Tumors (MPNSTs) constitute 14% of neurogenic tumors of the plexus. They are mainly encountered in two clinical situations: neurofibromatosis, or as the sequelae to radiotherapy.

Parsonage-Turner syndrome

The incidence of this condition is 2/100,000, with male predominance (2/1) [34], and it is bilateral in a third of cases.

It is often preceded by a fever, vaccination or by childbirth. Whether the etiology is viral or autoimmune is open
Tumor invasion of the brachial plexus. 64-year-old female patient with a history of left breast neoplasia 15 years previously presenting a recent deficit of the left upper limb: a-b: CT sagittal (a) and horizontal (b) slices show a lymph node/tumor blockage in the tunnel under the pectoralis minor and the axilla (dotted line); c-d: ultrasonography confirmed the presence of a voluminous lymphadenomegaly (c), 25 mm in diameter, in contact with the cords of the brachial plexus (solid line) and the axillary artery (AA). The slice (d) shows tumor infiltration of the lateral cord as fusiform thickening centered on this cord (arrows), not shown by the other techniques.

Figure 15. Radiation plexitis. Radiation-induced changes in a female patient with a history of radiotherapy more than 10 years previously for right breast neoplasia: a: supraclavicular horizontal slice showing thickening of all the cords of the right brachial plexus (dotted line) posterior and lateral to the subclavian artery, and the discreetly thickened and dedifferentiated appearance of the surrounding fat; b: comparison with the healthy side (cords outlined by a dotted line).

to question. Clinical onset is sudden with pain and more or less marked motor impairment.

The suprascapular nerve is affected in 97% of cases, and in isolation in 50% of them.

MRI is still the standard examination showing denervation edema with no detectable abnormality of the nerves themselves.

A little later ultrasound will find hypotrophy and isolated fatty degeneration of the muscles concerned, with no detectable nerve compression or tendon lesion (Fig. 17). It should endeavor to look for a cyst of the spinoglenoid notch potentially compressing the suprascapular nerve (the main differential diagnosis of idiopathic damage of this nerve in Parsonage-Turner syndrome).
Figure 16. Multiple neurofibromas in type 1 neurofibromatosis: a: T1-weighted axial MR image; b: horizontal ultrasound slice: the major thickening of all the cords (dotted line) is related to the many neurofibromas.

Figure 17. Parsonage-Turner syndrome. Left shoulder motor deficit in a young post-partum woman after an episode of hyperthermia: a, b: horizontal slices of the infraspinatus (IS) through the spinoglenoid notch: on the right, the muscle shows normal trophicity (a); on the pathological side, the infraspinatus muscle is hypotrophic and its ultrasound structure is discreetly more hyperechoic; c, d: the MRI slices of the pathological side show marked T2-weighted hyperintensity (denervation edema) of the supraspinatus and infraspinatus muscles with no obvious compression of the suprascapular nerve.
Clinical case

Mr. V., 36 years old, underwent surgery 6 months ago for high grade osteosarcoma of the arm. The procedure removed his radial nerve. He complains of recent atypical pain in the radial nerve territory. MRI of the brachial plexus was requested (Figs. 18 and 19).

Questions

1. Does MRI make a useful contribution? What information can you obtain from it?
2. What help does the additional ultrasound examination provide?

Figure 18. a, b, c: T1-weighted sagittal slices of the right brachial plexus passing respectively through the interscalene groove, the costoclavicular gap and the tunnel under the pectoralis minor. The arrows indicate the trunks and cords of the brachial plexus; d, e: T1-weighted axial slices of the axilla: the arrows indicate the nerve structures; f: STIR-weighted axial slice of the axilla. MR imaging does not show extrinsic compression or an obvious mass in contact with the right brachial plexus or terminal nerves.

Figure 19. Additional ultrasound examination of the axilla: a: horizontal axial slice through the axilla showing a radial nerve (RN, dotted line) which is particularly voluminous and hypoechoic posterior to the axillary artery (AA); b: equivalent on the healthy side; c: longitudinal slice of the stump of the radial nerve. The swelling of the nerve which extends for 5 cm was shown to be due to an infiltration of the neural tissue by the initial sarcoma.
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Figure 19.  Additional ultrasound examination of the axilla: a: horizontal axial slice through the axilla showing a radial nerve (RN, dotted line) which is particularly voluminous and hypoechoic posterior to the axillary artery (AA); b: equivalent on the healthy side; c: longitudinal slice of the stump of the radial nerve. The swelling of the nerve which extends for 5 cm was shown to be due to an infiltration of the neural tissue by the initial sarcoma.

Answers

1. MRI did not find any evident mass invading or compressing the terminal nerves, cords or trunks of the brachial plexus. It is not very effective for studying the nerve structures in great detail (large field, insufficient definition).

2. Ultrasound, on the other hand, gives a poorer overview but can study a nerve in considerable detail because of its clearly better definition and dynamic character.
Here the radial nerve is thickened (16 mm²) and hypoechoic over a distance of 5 cm. Surgical revision and histological examination showed infiltration of the stump of the radial nerve by the initial sarcoma. In this case, ultrasoundography proved to be the more effective technique.

**Conclusion**

Ultrasound examination of the brachial plexus, although at first sight difficult, is perfectly feasible with fairly rapid practical and theoretical training.

Examination consists of sagittal slices usually preferred by radiologists, and horizontal slices normally preferred by anesthesiologists, and which seem easier to perform.

The roots are accurately identified due to the shape (a single process) of the transverse process of C7, and the superficial position of C5 in the interscalene groove. The télephérique technique allows the roots, trunks and cords to be followed easily into the supravacular fossa.

Over the last few years ultrasound examination of the plexus has become routine in anesthesia for guiding nerve blocks.

In trained hands, it can also provide information in thoracic outlet syndrome, traumatic injuries (particularly for postganglionic lesions) and in tumoral diseases.

Even if MRI remains the standard examination in these indications, and the one that offers the most promising outcomes (tractography, etc.), ultrasoundography with its greater definition and its dynamic character is an excellent additional resource which is still under-exploited.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

**References**


