PERIPHERAL NERVE ULTRASOUND – AN IMAGE GUIDED TUTORIAL FOR BEGINNERS*

ECOGRAFIA DE NERVOS PERIFÉRICOS – UM TUTORIAL GUIADO POR IMAGEM PARA INICIANTE*

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Abstract

Technical advances in US made examinations of small superficial structures possible and reliable. Currently, evaluation of peripheral nerve disorders still depends on clinical data supplemented by electrophysiological studies. Ultrasound can be applied in the evaluation of peripheral nerve disorders, contributing for the differential diagnosis with other MSK pathologies. The exponential rise in publications regarding this topic in the past 10 years has been greatly driven by the development of image guided intervention now commonly used for selected anaesthetic procedures such as nerve blocks. Pain-related disorders is an another field for peripheral nerve ultrasound, where image guided intervention is being used for diagnosis and treatment. Ultrasound is safe but very operator dependent thus making solid anatomical knowledge of peripheral nerve anatomy a mandatory condition.

A pictorial essay of the normal sonographic appearance of peripheral nerves will be provided, along with the technical parameters used to optimize image quality. The authors will mainly focus the presentation on easily recognisable anatomical landmarks of the neck, upper limb, groin, thigh and leg matching with B mode scans and probe positioning. A brief review of commonly described pathologic finding will also be performed.

Conclusion: Sound knowledge of peripheral nerve anatomy is a pre-requisite for those interested in peripheral nerves ultrasound assessment. The role of ultrasound guided interventions has been expanded to the field of anaesthetic and pain-relief procedures. Radiologists are in the best position to match imaging anatomy with sound technical knowledge, thus expanding the role of imaging procedures and guided-interventions.

Key-words

Ultrasonography; Peripheral nerve; Anatomy.

Resumo

Avanços técnicos na ecografia facilitou o uso fáceis a avaliação de pequenas estruturas. Atualmente, a avaliação de nervos periféricos depende ainda de dados clínicos suplementados por estudos eletrofisiológicos. A ultrassonografia pode ser aplicada na avaliação de patologia de nervos periféricos, contribuindo para o diagnóstico diferencial de patologias músculo-esqueléticas. O crescimento exponencial de publicações sobre esta temática nos últimos 10 anos foi fortemente fomentado pelo desenvolvimento de intervenção guiada por imagem, frequentemente utilizada em procedimentos analgésicos e anestésicos, tais como bloqueios nervosos. A Medicina da Dor é outro campo para a ecografia de nervos periféricos onde a intervenção pode ser usada como forma de tratamento ou diagnóstico.

A ecografia é uma técnica segura, embora fortemente dependente do utilizador, implicando firmes conhecimentos de anatomia. Elaborou-se uma revisão pictórica, assim como dos parâmetros e peculiaridades técnicas utilizadas para otimizar a imagem obtida. Serão demonstrados os marcos anatômicos mais frequentes e reconhecíveis no pescoço, membro superior, virilha, membro inferior, assim como a forma de colocação da sonda. Será efetuada uma breve revisão dos achados descritos em casos patológicos.

Um firme conhecimento da ecografia dos nervos periféricos é um pré-requisito para os interessados na avaliação destes. O papel da intervenção guiada por ecografia tem evoluído no campo da anestesia e no campo da medicina da dor. Os radiologistas estão em excelente posição para relacionar a adequada técnica e o conhecimento anatômico, permitindo expandir o papel dos procedimentos guiados por imagem.

Palavras-chave

Ultrasonografia; Nervos periféricos; Anatomia.
To its known advantages such as accessibility, non-invasiveness, absence of radiation, we may add versatility (comparing to contralateral side, proximal and distal segments), possibility of assessing systems (musculoskeletal or nervous structures), enabling assessment of large extension of a long structure with oblique course, and even the possibility of a brief anamnesis. Compared with MRI, it has a higher spatial resolution (at high frequencies). The number of articles indexed in PubMed® related to the research “nerve ultrasound” increased from 168 articles published in 2000 to 758 in 2013, many of these related to the intervention aimed at nervous structures used for anesthetic procedures, analgesics, or diagnoses in pain medicine. The sonographic study of the nervous structures (and possibly intervention) is technically within reach of radiologists. Our goal with this paper is to make identification and assessment of these simple structures more straightforward by describing the ultrasound anatomy of the nervous structures and the most important anatomical references based on tomographic plans variations used routinely by most radiologists.

**General considerations on exam technique**

Basic principles of ultrasound technique optimization apply. The depth should be the minimum necessary and the frequency the highest possible. The focus should be placed in the depth of the region of interest and gains should be adjusted in order to observe the nerve fascicles. To facilitate their identification, the exam starts in an area where they are more easily identifiable so that they may be properly followed. Initially, the nerve should be sought in a transverse plane along its length with the identification confirmed by its path and by the anatomical relationships (exercise of little difficulty for most radiologists, used to follow vascular structures). Pathological changes can be better studied using multiplanar capabilities of ultrasound, compared with the contralateral side and correlated with the clinic information provided (by the patient). The dynamic component of the nerve evaluation is to be noted, which is useful not only for the identification, but also for detection of the pathology.

**Normal appearance of the nerve**

The morphological appearance of the nervous fasciculus on ultrasound has, at best, correlation with the histologic structure and consists of hypoechoic nervous fascicles individualized by the endoneurium, echogenic connective tissue between the fascicles and the echogenic epineurium. In transverse image it resembles a “blackberry”. The distinction of vessel nerves can be made using the Doppler, compression (it conditions the separation of fascicles), marked difference of anisotropy (“erasing” the tendons tilting the sensor) and its characteristic fibrillating pattern [1].

**Nerve pathology in ultrasound**

Ultrasound has been used to study nerve disorders, namely those of traumatic nature (stretch or compression), whether chronic or acute nature [2-4]. Nerve ultrasound aspect usually reveals a flattened morphology, loss of mobility, loss of their fascicular pattern, increase size or internal Doppler signal. In addition to these signals, indirect signs of denervation can be observed, namely atrophy and hyper-reflectivity of the muscles. The ultrasound often allows identifying causes of compression, namely tenosynovitis, ganglionic cysts, lumps, varicosities or anomalous structures (e.g., bifid median nerve with persistent median artery). In cervical trauma high sensitivity (80%) and specificity (100%) were reported in detecting major injury (complete or partial interruption of the epineurium, retraction of the top, wavy look of the top) and are useful in preoperative planning, as well as during subsequent follow-up for post-traumatic neuroma identification [5]. After trauma, focal neuroma may form, identified by a spindle thickening of the nerve [6]. Iatrogenic complications were also described after nerve accidental puncture [7]. Postoperative assessment can also help to identify: terminal neuroma (as hypoechoic mass in the nerve end after complete section); fusiform neuroma (nerve hypoechoic thickening); and stretch with thickened fascicles and peri-nerve fibrosis. Also, characteristic changes on the structures were described and associated with genetic diseases, namely Charcot-Marie-Tooth disease type 1A (area of the upper median nerve to 10mm²; fascicles greater than 0.6 mm²) [8], and 1B type (area of nerve median 20 mm² in the middle forearm, 13.6 mm² on the wrist) [9]; and chronic neuropathies (in chronic demyelinating neuropathies there is usually an increase in the size of the nerve, unlike axonal neuropathies, although a specific cutoff may be difficult to establish) [10]. In diagnosing demyelinating neuropathies there seem to be places where diagnostic accuracy is different (the distal tibial nerve, a sectional area value of 10.5 mm² had a sensitivity of 0.92 and specificity of 0.71, while the cubital nerve at the level of the arm had a sensitivity of 0.60 and specificity of 0.92 for an area of 8.5 mm²), suggesting the use of measures at various levels if there is suspicion of polyneuropathy; axonal neuropathies do not seem to imply an increase in nerve area. [11] Most of the tumors in the cervical plexus are benign. The most common histologic types are Schwannomas and neurofibromas. In the evaluation of masses, the most important data are the relationships with the muscular structures and continuity with the nervous structures (very painful masses at the time of the puncture). [12]

**Brachial plexus and upper limb nerves**

The brachial plexus (Figure 1A, 1B, 1C, 1D, 1E) is composed of the ventral branches of C5 to T1 and is responsible for the upper limb innervation. The roots can be identified between the middle and anterior scalene (Figure 1B). The root level can be accurately determined by identifying C7 (absence of anterior tubercle in the transverse apophysis) (Figure 1A, 1B) [13]. By turning 90° one can obtain a coronal plane of the exit of the cervical roots. At this level, the phrenic nerve can be identified diverting from C5 and descending along the anterior scalene [14]. The ventral branches can be followed distally in the transverse plane to the supraclavicular region, where they form the trunks. At the base of the neck, the nerve structures relate to some vessels: vertebral artery (Figure 1D), dorsal scapular artery; cross cervical artery. In the lateral edge of the posterior cervical triangle, nerves cross the first rib posterior to the subclavian artery (Figure 1E). The infraclavicular approach (Figure 2C) (inferiorly to the middle third of the clavicle, medial to the coracoid apophysis and posteriorly to the pectoral muscles)
shows the strings: lateral, posterior and medial. There are 13 terminal branches that originate from this region and its final assessment is difficult. The four major nerves (musculocutaneous, median, radial and ulnar) can be identified in the armpit, and followed distally (or vice-versa). Given the wide variability of the anatomy in this topography the use of dynamic capabilities of ultrasound is essential [15]. The musculocutaneous nerve is a branch of the lateral cord, easily identified due to its early origin and path in the common tendon of the biceps short head and coracobrachialis muscle (Figure 2A). It progresses between the brachial muscle and brachial biceps, which innervates and provides its terminal branch (lateral cutaneous nerve of the forearm). The median nerve is formed by merging two branches (the lateral and medial cord). It travels in close relationship with the brachial artery. In the forearm, it passes between the heads of the round pronator (Figure 2J), subsequently progressing between the finger flexors, where the anterior interosseous nerve originates, pursuing the deep flexor. In the wrist, it emerges from the lateral face of the surface flexor of the fingers, passing in the carpal tunnel (Figure 2G) and lies along the axis of the ring finger. Along its route, the most typical places of compression are the ligament of Struthers, the bicipital aponeurosis, between the heads of the pronator and carpal tunnel (a difference of 2 mm² in the sectional area in the carpal tunnel compared to its area at the level of the quadratus pronator obtained sensitivity and specificity of 99% and 100%, respectively) [3]. The radial nerve (Figure 2D, 2F, 2I) is the main nerve of the posterior cord, running through the radial groove of the humerus, between the median and lateral triceps heads, in relation to the deep brachial artery. It is divided into deep branch (motor) and superficial (sensory) in the lateral epicondyle, deeply to the coracobrachialis muscle, giving a characteristic appearance of “snake eyes” (Figure 2F). The radial nerve when subjected to compression is hypoechoic, swollen and fascicle not well defined [16]. The most common sites of compression are: laterally to the long head of the triceps and the spiral groove between the brachialis and brachioradialis muscle. The deep branch enters the supinator muscle and then runs as posterior interosseous nerve (Figure 2I), innervating the majority of the forearm and hand extensors, hence the classical clinical picture of pending hand on the radial nerve injury. It may be compressed by Frohse arcade, by a recurrent branch of the radial artery (“Henry leash”), between the heads of the supinator. The superficial branch may be compressed between the brachioradialis and the long radial extensor carpus, conditioning the Wartenberg syndrome. The ulnar nerve (Figure 2E and 2H) arises from the medial cord. It goes along posterio-medially and deeply to the triceps in the distal arm. In the medial epicondyle of the humerus, goes though the cubital tunnel (Figure 2E), running afterwards through the forearm between the humeral head and the ulnar head of the flexor carpus. The ultrasound allows the evaluation of the elbow’s flexion / extension and search the nerve subluxation. Distally it becomes more superficial and passes in Guyon’s canal, in close relationship with the pisiform, unciform and ulnar artery (Figure 2H).

Nerves of the anterior thigh

The femoral nerve is formed by the posterior division of L2 to L4. It can be identified when passing in the inguinal ligament, where it splits, relating to the femoral artery (Figure 3D). It is unusual to be subject to compressive lesions, but it is subject to iatrogenic damage [17] because it is a central vascular access place. When assessing the inguinal fossa it is important to identify the iliopsoas muscles, pectineus, adductor longus, femoral rectus and tensor fascia lata. The saphenous nerve is the terminal branch of the femoral nerve, and it can be identified in the proximal thigh (anterolateral to the femoral artery; posterior to aponeurosis of the adductor canal) or in the distal thigh (piercing

![Fig. 1 - Sonographic images obtained with linear probe of high frequency in the brachial plexus of a healthy volunteer (see text for description). The arrow indicates the direction traveled by the probe for evaluation in transverse plane.](image-url)
the fascia deeply to the sartorius muscle). Distal to the knee is located on the medial side of the leg, following the magna saphenous vein (Figure 3E). The lateral cutaneous nerve of the thigh starts at L2-L3, laterally to the psoas muscle, it is directed toward the anterior-superior iliac spine and passes inferiorly to the inguinal ligament, which then innervates the tensor fascia lata and the lateral skin of the thigh, after crossing the sartorius muscle [18] (Figure 3A). It is responsible for the “paresthetica meralgia” syndrome, with few to any morphologic changes on ultrasound, but whose response after anesthetic infiltration is diagnostic [19]. The obturator nerve originates from the ventral divisions of the lumbar plexus, L2-L4. It appears in the medial portion of the psoas, posteriorly to the iliac vessels, follows posterolaterally to the bladder and through obturator hole. In the obturator channel it is divided into anterior branch (between long and short adductor) and the posterior (between short and adductor magnus) (Figure 3C). They are easily identifiable in the longitudinal plane, medially to the thigh. Its direct evaluation is difficult, especially in cases of suspected piriformis syndrome. Along its passage through the thigh and at a variable height, the tibial nerve and the common peroneal nerve emerge (Figure 4C) [21]. The tibial nerve runs through the soleus arcade, originating the sural nerve in the popliteal fossa, small branch that accompanies the small saphenous vein. It accompanies the posterior tibial artery, direct continuation of the popliteal artery to the tarsal tunnel (Figure 4F), where it can be compressed [22]. The common peroneal nerve passes between the lateral head of the gastrocnemius and the distal portion of the femoral biceps. It passes deep to the insertion of the peroneus longus muscle in intimate relationship with the fibula, which contours around. It originates the superficial and deep branch. The superficial peroneal nerve is located in the anterolateral surface of the leg between the peroneal muscles and the extensor digitorum, piercing the fascia 10-12 cm proximal to the medial malleolus, being subject to stretch [23].

**Sciatic nerve**

The sacred plexus is formed by roots from L4 to S3, from which seven nerves originate, one of which is the sciatic nerve. This is formed anteriorly to the sacrum, medially to the iliosposas and it emerges through the sciatic hole anterior to the piriformis and posterior to the ischial tuberosity. In the gluteal region it is anterior to the gluteus maximus and posterior to the quadratus femoris. (Figure 4A). Its direct evaluation is difficult, especially in cases of suspected piriformis syndrome. Along its passage through the thigh and at a variable height, the tibial nerve and the common peroneal nerve emerge (Figure 4C). [21] The tibial nerve runs through the soleus arcade, originating the sural nerve in the popliteal fossa, small branch that accompanies the small saphenous vein. It accompanies the posterior tibial artery, direct continuation of the popliteal artery to the tarsal tunnel (Figure 4F), where it can be compressed [22]. The common peroneal nerve passes between the lateral head of the gastrocnemius and the distal portion of the femoral biceps. It passes deep to the insertion of the peroneus longus muscle in intimate relationship with the fibula, which contours around. It originates the superficial and deep branch. The superficial peroneal nerve is located in the anterolateral surface of the leg between the peroneal muscles and the extensor digitorum, piercing the fascia 10-12 cm proximal to the medial malleolus, being subject to stretch [23].

**Other nerve structures and other applications**

Several publications have shown that other nerve structures are approachable by ultrasound, particularly the cervical nerve plexus (Figure 5), the vagus nerve (Figure 6) [24], and the accessory nerve [25]. Some of these may have interest for the diagnosis. Another interest in ultrasound applied to nerve structures is performing targeted procedures (nerve block or infiltrations), some of which may not require direct visualization of nerves for clinical and practical success (Figure 7 and Figure 8). These blockages have had a rapid evolution in recent years. In addition
Fig. 3 – Typical images of the lateral cutaneous nerve of the thigh (A), location of obturated nerve branches, location of femoral nerve (D) and its continuation as saphenous nerve (E). (See text for details)

Fig. 4 – Typical images of the main nerves in the posterior thigh, particularly the sciatic nerve (A, B), bifurcation in tibial and common peroneal branch (C), a characteristic location of the peroneal nerve in relation to fibula (E) and tibial nerve (F) in the tarsus tunnel (not shown) (see text for details).
to the diagnostic tests they make highly aggressive and painful procedures (even surgery) tolerable. The risks are the puncture risks (infection, iatrogenic injury), the toxicity of local anesthetics that occurs when maximum dosages are exceeded or in case of accidental intravascular injection. Clinically it manifests by neurological symptoms (tinnitus, lightheadedness, visual disturbances, paresthesia of the tongue and lips, metallic taste) which can evolve to seizures or coma and later on to cardiovascular collapse.

Conclusion

The use of ultrasound has its merits in the evaluation of nerve structures: it allows to identify the level of injury; it has an excellent temporal and spatial resolution (for some structures, higher than the resonance’s); it is a dynamic examination; and it allows a collection of an oriented anamnesis. In traumatic pathology, its use has been explored for early lesion characterization (in surgical correlation series in the pathology of the brachial plexus, with positive and negative predictive values of 1.0 and 0.92 respectively, in the distinction between major and minor pathology) [5], with very interesting results since in the nervous trauma the clinical and electromyographic evaluation is limited in the early stages (first 6 weeks), not managing to distinguish axonotemese of neurotemese (complete section) [26].

Ultrasound has the advantage guiding procedures, which led to a huge interest in its application to anesthetics and analgesics procedures. The main challenges of this technique are the demanding required knowledge of it (of ultrasound anatomy, of indications for procedures), the need for high quality equipment (for assessment of fascicular structure) and the fact that there are relatively few studies investigating its diagnostic accuracy. However, the initial results have been encouraging in various pathologies, the intervention is already a reality and continues to be an area with room for progression. For example, given the encouraging results in traumatic pathology of the brachial plexus, why not apply it to the plexopathy of the newborn? Thus, the ultrasound of nervous structures, more than an isolated modality, either diagnostic or therapeutic, makes sense in a context of musculoskeletal assessment by adequately addressing the complaints of patients in terms of diagnosis and opens the possibility of having a useful role in treating the painful disease through intervention.

Fig. 5 - The superficial cervical plexus can be identified with the patient with the head turning to the opposite side, placing the probe in the cricoid and sliding sideways to the edge of the sternocleidomastoid. This is located in the posterior cervical triangle, defined by the sternocleidomastoid, trapezius muscle and clavicle. The pavement is composed of the splenius muscles, lift of the scapula, anterior and middle scalene.

Fig. 6 – Vagus nerve demonstration in cervical vascular space
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References