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Introduction

Technical Considerations of High Resolution Ultrasonography

This is primarily a book for the clinician and will therefore not address the technical basis of sonography in any detail. However, it is necessary for the clinician to know about the limitations resulting from the underlying mechanisms of sonography. We will briefly consider these in the following.

High resolution ultrasound is based on an electromechanical transducer probe issuing ultrasonic waves which are transmitted into the tissue to be examined. As the ultrasonic waves travel into the tissue, the varying reflective properties of the tissue cause differential reflection, resulting in the waves being reflected back to the transducer at different times. This allows a picture of the tissue to be created; the details of the process can be found in the literature.[1] The most commonly used insonation frequencies for HRU range between 7 and 15 MHz, but sometimes, depending on the circumstances, a range of 3–20 MHz is used. Modern transducers have greater resolution, mainly because there are more arrays of transmitting and receiving crystals within them. More technical details can be obtained from expertly summarized publications in the literature.[2]

The clinician needs to remember certain simple technical considerations when using HRU:

(1) The higher the frequency of the ultrasound probe used, the greater the axial resolution. However, this comes at the cost of less depth of tissue penetration. For example, a 15 MHz probe would be able to reveal superficial structures of up to 1–2 cm with good resolution but would not be able to show the deeper-lying nerves such as the sciatic nerve, which would be best imaged with a lower frequency of 3–7 MHz.
(2) Nerves may be difficult to separate out from surrounding fat tissue because of their similar echogenic properties.
(3) Bones overlying nerves result in acoustic shadowing and thereby render them invisible.
(4) Because of the phenomenon of anisotropy, the ultrasound probe needs constant steering to adjust for the best angle of insonation. Anisotropy describes the property of being directionally dependent. In other words, the ultrasound waves are transmitted in an inhomogenous way and do not reflect evenly in all directions.
(5) The pressure applied to the probe will determine the degree of deformation of the underlying structures and for this reason should be kept to a minimum. The examiner needs to remember that instead of applying more pressure on the area of examination, when trying to obtain better ultrasound pictures, a clearer picture is produced with plenty of contact gel in place and if possible using insonation angles which avoid obstructing tissue (fat or bone). In the heat of the battle, it is easy to forget that ultrasonic waves need gel, gel, and gel!

In remembering these technical limitations, HRU can be very useful for aiding the diagnosis of many peripheral nerve entrapments in the human body, as well as guiding anesthetic nerve blocks and localizing other musculoskeletal elements such as muscles and tendons.

Advantages of HRU

(1) A significant advantage of HRU in contrast to most neurophysiological techniques is that it causes little or no discomfort to the patient.
(2) HRU provides real time images of the nerve anatomy and its surrounding structures, and gives clues to the etiology of nerve dysfunction (for example, ganglion cysts as etiology of peroneal nerve palsy, or showing whether trauma has resulted in nerve discontinuity).
(3) Compared to MRI, HRU can be performed very fast, is considerably cheaper, and can be combined with anesthetic procedures.
(4) Integrated color Doppler allows concomitant measurement of the blood flow of surrounding structures.

Characteristics of Healthy Peripheral Nerves

Appearance and identification

Characteristics of peripheral nerves

(1) More echogenicity than muscles but less echogenicity than tendons
(2) Honeycomb appearance
(3) Less mobility than tendons

In HRU, normal peripheral nerves have the appearance of being more echogenic than muscles but less echogenic than tendons (Fig. 1).

A nerve visualized longitudinally is characterized by tubular, more echogenic (darker) structures separated by less echogenic lighter ones. Thus the hypoechoic fascicles surrounded by hyperechoic perineurium reveal the fascicular structure of peripheral nerves.[3] Viewed in transverse cuts this gives rise to the characteristic "honeycomb structure" which nerves are often typified by. Because tendons can sometimes produce a quite similar structural pattern, it is worthwhile to remember that tendons are generally more echogenic (i.e. darker in the ultrasound picture) and characteristically more mobile during extension–flexion maneuvers. In some instances, when differentiation between a tendon and a nerve is difficult, following the structure to an anatomical site where the nerve anatomy is well known can be helpful (such as the ulnar nerve in the ulnar canal at the elbow).

Measurements

Commonly used nerve measures

Transverse nerve cuts document the cross-sectional surface area, often expressed in cm^2.

Longitudinal nerve cuts measure the nerve diameter.

Make sure that measures are taken inside the hyperechogenic rim of the nerve.

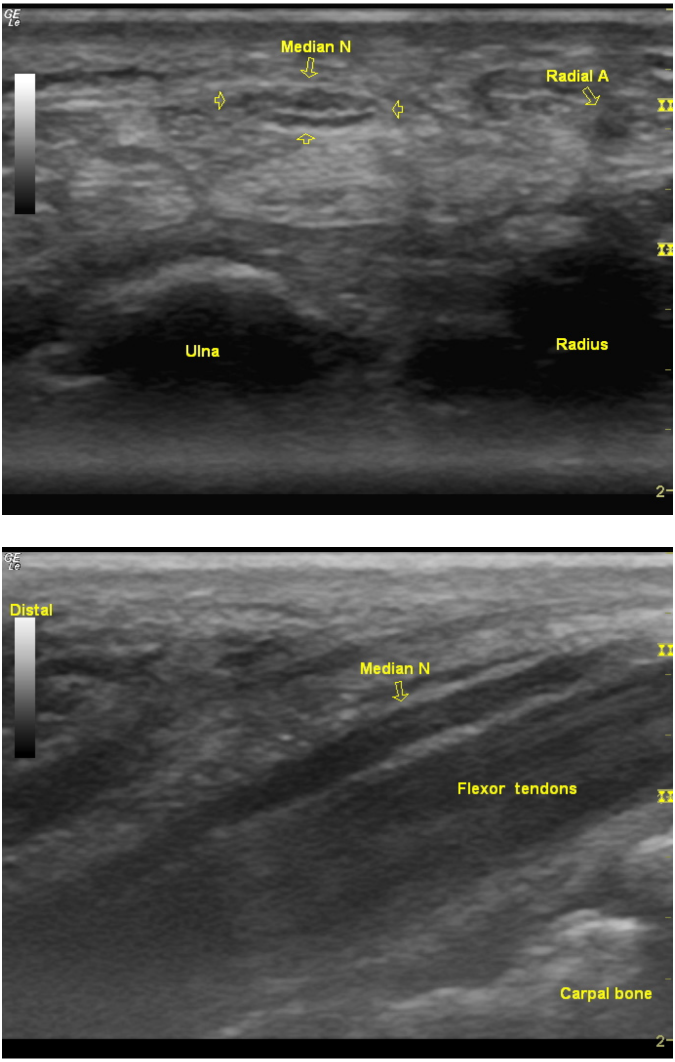

Fig. 1 Normal appearance of the median nerve at the carpal tunnel. On the top is a transverse sonogram of the median nerve at the level of the distal wrist crease, showing the nerve surrounded by flexor tendons. The cross-sectional area of the nerve is 0.08 cm^2 (normal < 0.10 cm^2). On the bottom is a longitudinal sonogram of the median nerve across the proximal carpal tunnel. The maximum anteroposterior diameter of the nerve is 0.16 cm.

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Cadaver studies have shown HRU to be very precise at measuring the dimensions of the nerve diameter, perimeter and surface area.[4] Current technology has an image resolution of around 1 mm.

To make the measurements uniform, the diameter/surface area is taken from inside the hyperechogenic rim of the nerve. Using the hyperechogenic rim as measurement is not advisable, since it is known to be variable and provides less consistent measurement.

The size of normal nerves follows a Gaussian distribution with little or no effect of age, height or weight. For selected nerves (median, radial, ulnar) men show greater size than women.[5] As a rule, it is easier to image upper extremity than lower extremity nerves. This is because lower limb nerve trunks are generally at a greater depth and can have more perineurial fat. In particular, the proximal lower limb nerves exiting the inguinal region can be difficult to image as fat degrades the ultrasonic image quality. The femoral nerve and lateral femoral cutaneous nerve can be especially difficult to image. However, some lower limb nerves are easily imaged, such as the superficial cutaneous nerves like the sural nerve.

Characteristics of Diseased Peripheral Nerves

Characteristics of diseased nerves in sonography

(1) Nerve enlargement
(2) Hypoechoic signal resulting from nerve edema
(3) Discontinuity of nerve fascicles — complete or incomplete

(1) *Nerve enlargement*

Nerve enlargement is the most common characteristic of nerves observed with HRU and can be seen in nerve entrapment, inflammatory disease, hereditary neuropathies, and nerve tumors. The main ultrasound feature of chronically entrapped nerves is nerve enlargement, which occurs mostly proximal to the site of compression and is a result of nerve edema and increased collagen deposition. Nerve enlargement is best measured in transverse sections using the cross-sectional surface area at predefined anatomical locations. Predefined locations should be adhered to, in order to keep to a minimum the variance from the natural proximal-to-distal thinning of nerves. The measure of the nerve surface area is accepted as most representative in capturing nerve enlargement, since it is least affected by nerves' variables in symmetry, which can cause diameter measures taken with longitudinal sections to be more variable and so less reliable.

Although the overall increase in nerve size is one of the best measures of nerve reaction common to many types of pathology, intraneural increases in fascicular size can also be directly visualized and can be helpful in localizing the exact site of pathology.

(2) *Hypoechoic signal resulting from nerve edema and other disease patterns*

A further measure of nerve pathology is increased or decreased echogenicity of the nerve. This is more difficult to quantify or qualify and interpretation depends on the experience of the examiner.

Certain etiologies of nerve pathology have been identified to show typical HRU appearances. Neuromas have a characteristic spindle shape inside nerves at the sites of nerve reconstruction. The texture shows up as being of low or mixed echo texture located close to the inner surface of the epineurium.[6] HRU is particularly good in the identification of intraneural pathology such as neurilemmoma or for cystic structures.[7]

The nerve enlargement seen in inflammatory diseases does not show any characteristics of echogeneity. Leprosy, chronic inflammatory demyelinating neuropathy, and multiple and motor neuropathy with multiple motor conduction blocks (MMN) all show (often greatly) enlarged nerves in multiple areas.[8]

(3) *Fascicular discontinuity*

With the assessment of nerve trauma, apart from showing the exact site of nerve damage, a very useful HRU feature is that it can help in identifying nerve integrity, i.e. demonstrating nerve continuity. The most useful parameter to use is the hyperechoic outer nerve surface, which corresponds to the continuous epineural perineurium. Another helpful measure is disruption of the fascicular structure within the nerve, best seen with longitudinal views.[9]