High-Resolution Sonography of Lower Extremity Peripheral Nerves
Anatomic Correlation and Spectrum of Disease

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Objective. The value of sonography for the diagnosis of diseases of the peripheral nervous system is only little known. This image presentation is intended to raise the awareness of sonographers and clinicians of the potential of sonography by giving an anatomic-sonographic correlation of lower extremity peripheral nerves and an overview of commonly encountered diseases. Methods. On 2 lower extremity cadaver specimens, peripheral nerves were imaged in typical locations such as the tarsal tunnel. During sonography the nerve was injected with blue dye, and thin-slice anatomic sections were obtained at the scan level with a chain saw. In addition, sonographic images of patients with typical diseases are shown. Results. An excellent anatomic-sonographic correlation was obtained, which underlines the feasibility of sonography for imaging of lower extremity peripheral nerves. Reliable results may be obtained with sonography of typical disease processes of lower extremity peripheral nerves. Conclusions. Recent developments in sonographic technology such as the introduction of high-frequency linear array transducers, compound imaging, and extended field-of-view imaging strongly improve the applicability of transcutaneous sonography for the examination of peripheral nerve disease. Key words: sonography; anatomy; peripheral nerve.

Despite early promising reports on the value of sonography for imaging of nerve conditions such as nerve entrapment syndromes, to our knowledge there is no widespread use of nerve sonography in routine clinical practice. This is mainly because of limitations of equipment and lack of expertise. With the introduction of high-frequency linear array transducers with a range of 5–12 to 5–15 MHz and high near-field resolution as well as extended field imaging, direct evaluation of peripheral nerves with sonography has now become more feasible. One notable drawback still is operator ability: the quality of sonographic examinations relies heavily on the familiarity of the examiner with the local anatomy and the typical appearance of normal structures and pathologic conditions. Recent articles have addressed the value of sonography for imaging of peripheral nerves and nerve tumors, but many radiologists and clinicians are still unaware of the poten-
tial application of sonography for assessment of different nerve diseases, especially in the lower extremity. This image presentation is therefore intended to provide information about the anatomic-sonographic correlation of lower extremity peripheral nerves and to give an overview of commonly encountered diseases.

**Anatomic-Sonographic Correlation**

The general echo structure of a peripheral nerve on longitudinal sonograms consists of multiple parallel hypoechoic linear areas separated by hyperechoic bands (Fig. 1). With histologic correlation, the latter was shown to represent the interfascicular epineurium, whereas the hypoechoic elements correspond to the nerve fascicles. The number and size of individual fascicles visualized with high-resolution sonography depend on the frequency of the applied transducer as well as the type of nerve studied.

In the following paragraph, the anatomic correlation of high-resolution sonography of lower extremity nerves is given in 4 locations (Fig. 2), which correspond to the regions where lower extremity nerve diseases typically occur. A preserved right leg cadaver specimen was used for acquisition of sonograms on an HDI 5000 system (Philips Ultrasound, Bothell, WA) with a 5- to 12-MHz linear array transducer. After sonographic identification of a nerve, blue dye was injected into the adjacent soft tissue under sonographic guidance to guarantee the representative locations for anatomic dissections. The latter were acquired with a fine-needle-tooth band saw.

Figure 3A shows a transverse cut through the distal thigh 10 cm above knee level. The sciatic nerve, which traverses at the rear of the upper leg, gives a typical example for the appearance of a peripheral nerve on transverse sonograms, with small hypoechoic dots (nerve fascicles) within a dense network of hyperechoic elements (epineurium).

Figure 3B was acquired at the level of the popliteal fossa and shows the common peroneal and tibial nerves, which may easily be assessed on sonographic examinations of the knee. The common peroneal and tibial nerves give an example of the variability in the sonographic appearance of peripheral nerves, with the tibial nerve showing the typical echo structure (hypoechoic fascicles and hyperechoic epineurium) and the common peroneal nerve consisting of fewer and thicker fascicles with less echogenic stroma. This appearance was previously reported by Silvestri et al. who stated that this distinct appearance may most probably be caused by a different number of fascicles within a nerve.

Figure 3C was acquired at a level just distal to that shown in Figure 3B, where the common peroneal nerve splits into 2 branches. Although the superficial peroneal nerve is easily assessed with sonography, the deep-lying and smaller deep peroneal nerve is hardly visualized.

Figure 3D was acquired just above the ankle, representing the medial structures at the level of the tarsal tunnel. When comparing the sonographic appearance of the superficial peroneal nerve in Figure 3C and the distal portion of the tibial nerve in Figure 3D, we must note that both nerves share the same morphologic characteristics as their parent nerves at knee level on sonography.

**Spectrum of Diseases**

In this section, typical cases of nerve diseases in the lower extremity are discussed. All cases in this series had electrodiagnostic findings suggesting nerve diseases, and the sonographic diagnoses were confirmed by surgery.

**Edematous (“Swollen”) Nerve**

The occurrence of nerve edema is not a disease entity on its own but a quite common nonspecific reaction of a nerve to various exogenous stimuli. The underlying pathophysiologic process for nerve swelling consists of disturbed vascularization with vasocongestion, which may be of a traumatic or nontraumatic nature. Possible causes include long-lasting direct compression of a nerve by a plaster cast, metallic implant, or hematoma; stretching of a nerve due to joint dislocation or during operations; encasement within osteofibrous tunnels; thermal injuries; infection; and blunt trauma. In many cases a nerve with a uniform hypoechoic appearance and thickened fascicles or a sudden change in echo texture at the level of injury is the only apparent sonographic finding (Fig. 4). In these cases, knowledge about the normal echo structure of an examined nerve is crucial, but because interindividual variations may result in misleading findings, a comparison with the contralateral normal side is highly recommended.
Compressive Lesions

In these lesions, direct compression of a nerve by surrounding tissue exists, which may be caused by normal anatomic structures such as in nerve entrapment syndromes (“tarsal tunnel syndrome”), vascular malformations, ganglia, or tumors. Ganglia may occur in any location adjacent to joints or tendon sheaths; common locations with nerve compression are the proximal tibiofibular joint, with compression of the superficial peroneal nerve, and the ankle region, with peroneal or tibialis nerve compression (Fig. 5).

In addition to the more commonly known tarsal tunnel syndrome, a compression syndrome of the common peroneal nerve can often be seen at the level of the fibular head. Although a true osteofibrous tunnel does not exist in this location, the nerve lies in a tight space between the fibular head and the fascia just under the skin. Any reason for a change in the normal alignment of the nerve with the bone, such as malaligned fibular fractures, may therefore result in a kind of entrapment syndrome. Even prolonged sitting with crossed legs has been reported to cause peroneal nerve compression.7

Direct compression of a nerve may also be caused by posttraumatic hematoma or callus formation as well as postoperative scars (Fig. 6).
Figure 3. Sonographic-anatomic correlations. A, Transverse sonogram and anatomic dissection at the level of the distal femur. The sonogram shows the typical fibrillar echo structure of the sciatic nerve, with hypoechic fascicles and dense endoneurial stroma. B, Transverse sonogram and anatomic dissection through a popliteal fossa at the level of the fibular head. Note the different echo texture of the common peroneal nerve (CPN) and tibialis nerve (TN). C, Transverse sonogram and anatomic dissection at the proximal lower leg just below the fibular head. The superficial peroneal nerve (SPN) is seen traversing between the extensor hallucis longus (EHLN) and the peroneal muscle (PM). Note again the rather homogeneous hypoechico fibrillar echo texture of the peroneal nerve, with only sparse stroma. (continued)
Figure 3. (continued) D. Transverse sonogram and anatomic dissection at the medial side of the ankle, the tarsal tunnel. The deep-lying tibialis nerve is shown between the flexor hallucis longus muscle (FHL) and the vascular bundle (PTA/V). Compared with the superficial peroneal nerve in C, more hyperechoic elements with a distinct fascicular echo structure are shown. AT indicates Achilles tendon; BM, biceps muscle; EDLM, extensor digitorum longus muscle; Fi, fibula; FIAL, fibular artery/vein; FH, fibular head; GLM, gastrocnemius lateralis muscle; GM, gracilis muscle; GMM, gastrocnemius medialis muscle; PAV, popliteal artery/vein; PPM, popliteus muscle; PTA/V, posterior tibial artery/vein; SFA, superficial femoral artery; SFV, superficial femoral vein; SMM, semimembranosus muscle; SN, sciatic nerve; SoM, soleus muscle; StM, sartorius muscle; STM, semitendinosus muscle; T, tibia; and VIM, vastus intermedius muscle.

Figure 4. Longitudinal sonogram from a 62-year-old woman with chronic polyarthritis and left total hip and knee replacement. The patient had a worsening sensorimotor deficit in the left leg after knee replacement. Electrophysiologic tests revealed evidence of a sciatic nerve lesion above knee level. Thickened nerve fascicles of the sciatic nerve are shown (thin arrows; compare with the sciatic nerve of the healthy volunteer in Figure 1).

Figure 5. Longitudinal sonogram from a 59-year-old man with a palpable mass above the medial malleolus and dysesthesia in the forefoot. An ovoid, lobulated hypoechoic mass is shown, with a smooth surface and subtle internal echoes (thick arrow) compressing the distal portion of the tibial nerve (short thin arrows). At the upper pole of the mass, the nerve fascicles are slightly thickened because of compression edema (long thin arrow). On surgical exploration, a ganglion cyst with compression of the tibial nerve was confirmed.
Again, the apparent finding on sonography of the nerve itself is mainly edematous swelling of nerve fascicles. In these cases, however, evaluation of the underlying pathologic condition is equally important to evaluation of the nerve itself: a detailed description of the extent of scars encasing a nerve, for example, is important information for the planning of surgical interventions.

**Nerve Tumors**

The most commonly encountered benign tumors of peripheral nerves are neurofibromas and schwannomas, whereas other benign histologic types and malignant peripheral nerve sheath tumors are rare entities. A reliable sonographic diagnosis of a nerve tumor can only be made when continuity between a mass and a nerve can be established. This may often be difficult even with a careful scanning technique, because the nerve itself may be distorted or compressed by the mass. Once this relationship has been established, however, distinct features allow for reliable sonographic differentiation between schwannomas and neurofibromas. Because schwannomas derive from cells representing the supporting tissue of a nerve, they typically appear as ovoid masses arising from the surface of a nerve separated from the unimpaired nerve fascicles (Fig. 7). The nerve itself may be stretched over the capsule of the mass. In neurofibromas, tumor cells spread within the nerve fascicles, giving the nerve a spindle-shaped appearance. The fascicular pattern typically disappears at the site of the lesion.

Neuromas are masslike nerve lesions not representing true tumors but reactive local thickening of a nerve due to various extrinsic causes, such as severe traction injuries (Fig. 8) or complete dissection of a nerve. In these lesions, some or all nerve fascicles are severed, with loss of continuity. If nerve continuation is not reestablished by surgery, or only some of the

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Figure 6. Longitudinal sonogram from a 24-year-old man after ankle fracture and surgical refixation of the fractured medial malleolus. He had hypesthesia of the forefoot and denervation of the abductor hallucis muscle. The distal portion of the tibialis nerve (thin arrows) compressed by hypertrophic scar tissue (thick arrow) is shown. The nerve fascicles are markedly swollen with an enlarged nerve diameter.

Figure 7. Images from a 74-year-old man with a long history of a palpable mass on the left lower leg. **A**, Longitudinal sonogram showing a globoid-shaped hypoechoic but slightly inhomogeneous mass in continuation of a small subcutaneous nerve structure (superficial peroneal nerve). Note the nerve entering the mass from the right side and running along the outer diameter of the mass (arrows). **B**, Longitudinal Doppler sonogram showing hypervascularity of the mass.
fascicles are correctly sutured, regenerating Schwann cells and axons will grow randomly, thus producing a local overgrowth of nerve elements with formation of a hypoechoic ovoid mass. This may lie within a nerve if only some of the fascicles are involved or at the free end if a gap exists between the proximal and distal parts of the nerve. The latter entity is called a stump neuroma and typically occurs in limb amputations (Fig. 9). A special subset of neuromas with distinct pathophysiologic features exists in the interdigital spaces at the level of the metatarsals. These lesions, known as Morton neuromas and typically located at the level of the metatarsal heads in the second or third inter-space, are caused by repeated chronic microtrauma with resulting painful fibrosis of an interdigital nerve (Fig. 10).

Conclusions

We have presented the anatomic-sonographic correlation of lower extremity nerves and typical cases for various nerve pathologic conditions. Such conditions are accessible by sonography, which constitutes an inexpensive and noninvasive diagnostic tool.
References


