Calming your nerves: illustrating the role of magnetic resonance imaging for peripheral nerve disorders of the lower extremity

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Learning objectives

The purpose of this paper is to discuss and illustrate the imaging techniques, normal anatomy and pathologic conditions affecting the major critical nerves traversing the hip, thigh, knee, ankle, and foot, focusing on compressive/entrapment neurophaties on magnetic resonance imaging.
Background

Outline

1) Clinical context
2) General imaging technique
3) Normal structure and MRI appearance of the peripheral nerve
4) MRI aspects of nerve entrapment
5) Findings and procedure details: Anatomy, function and magnetic resonance imaging (MRI) findings of entrapment neuropathies of important nerves of the lower limbs:
   - Femoral nerve
   - Sciatic nerve
   - Obturator nerve
   - Lateral femoral cutaneous nerve
   - Peroneal nerves
   - Tibial nerve

1) Clinical context:

Symptoms of distal numbness, pain and weakness are common complaints in the population. Nerves may be injured anywhere along their course, being more prone to compression or stretching as they traverse anatomically vulnerable regions, such as superficial or geographically constrained spaces. Early diagnosis is essential because the duration of injury affects the extent of neural recovery.

MRI is a noninvasive operator-independent modality that complements the electrodiagnostic evaluations providing further anatomical and functional information, and allowing characterization of the distribution of muscle involvement as well as identification of the underlying cause of injury.

2) General imaging technique

MR high-resolution images of peripheral nerves require the use of phased array surface coils. Sciatic nerve, because its size, can be evaluated without a surface coil, but better
resolution is possible if surface coils are used. Positioning of the patient is determined by which nerve is being evaluated.

Images of nerves should be obtained in two orthogonal planes, if possible. Images that run parallel to the long axis of the nerve are good for an overview of the path of the nerve and to detect displacement or enlargement. Images obtained with the nerve in cross section avoid partial volume averaging artifacts and allow for assessment of the size, configuration, signal intensity, and intraneural fascicular pattern.

T1W and some types of T2W fat-suppressed (Short tau inversion recovery - STIR) images are best to evaluate the peripheral nerves. T1W images show the anatomy adjacent to the nerve, and T2W sequences are required to characterize the lesions in terms of signal intensity.

Peripheral nerves often follow an oblique course and 3D images allows better assessment of nerve orientation and multiplanar reconstruction. 3D anatomic nerve non-selective images include T1W (VIBE or MPRAGE) and T2W multislab acquisition (SPACE). 3D nerve selective imaging includes diffusion-weighting (DW) to enhance the relative nerve sign by suppressing the fat and blood vessels.

MR neurography (MRN) is a specialized technique for depicting the anatomy and course of a nerve visualization by suppressing the signal from adjacent tissue such as fat and blood vessels.

Nerves have no contrast enhancement due to nerve-blood barrier. The administration of an intravenous gadolinium-based contrast agent is rarely made only if need to determine whether a mass is cystic or solid.

Future developments include not only identifying nerve disorders, but also characterizing them using DWI and diffusion tensor imaging (DTI) following interventions, sequences to reduce metallic artifacts, quantitative apparent diffusion coefficients (ADC) and specific contrast agents.

3) Normal structure and MRI appearance of the peripheral nerve

The axon is the fundamental unit of a peripheral nerve. It may be either myelinated or unmyelinated. A myelinated fiber exists when a single axon is enclosed by a single Schwann cell; unmyelinated fibers result if a single Schwann cell encloses multiple axons. Layers of Schwann cells form the myelin sheaths. Large peripheral nerves have three connective tissue sheaths that support and protect the axons and myelin sheaths. The innermost sheath is the endoneurium, which involves each individual axon. Several axons, along with their Schwann cells and endoneurial sheaths, are enveloped together into fascicles that are each wrapped in a dense sheath of perineurium. Fig. 1 on page 7. The third layer is the epineurium, which surrounds the entire peripheral nerve and
protects the axons during stretching forces on the nerve. Fatty tissue is present between fascicles.

The fascicles are uniform in size and similar to muscle on T2W images. On T1W images, the fascicles are similar in signal intensity to muscle with intervening areas of relatively high signal similar to fat. Nerves are easy to identify if they are surrounded by fat; however, if they lie adjacent to muscle, without intervening fat, they can be difficult to detect. T2W images in the axial plane give the best chance of identifying and following the nerve in the latter situation.

4) MRI aspects of nerve entrapment

Peripheral nerves entrapment occurs due to trauma, compression or encasement by an adjacent mass/structure or infiltrative process. The causes of most entrapment neuropathies in the lower extremity may be divided into two major categories: mechanical causes, which occur at fibrous or fibro-osseous tunnels, and dynamic causes related to nerve injury during specific limb positioning.

Nerve problems are evaluated on MRI by directly imaging the nerve and looking for abnormalities in position, size, or signal intensity, and by looking for abnormalities that would indicate denervation in the muscles supplied by the nerve.

Nerve entrapment affects nerve irrigation and leads to the blockade of axoplasmic flow, resulting in pathological conditions and then anatomical changes in the later stages, with epineural edema proximal to the site of entrapment and wallerian degeneration distally. This lead to T2 high nerve signal proximal at the site of entrapment.

LEARNING POINT: Increased signal intensity in the nerve doesn’t always indicate underlying disease. The magic angle effect is a well-recognized artifact that cause this. These signal changes must be kept in mind when interpreting MR images, particularly when increased nerve signal intensity is the sole abnormality. However it was demonstrated that it rarely results in false-positive interpretation of studies, because significant magic angle effect occurs only at angles above 30º, and that true neuropathic lesions generally result in a much greater degree of hyperintensity than can be accounted for by magic angle alone.

Direct MRI signs of nerve injury:
- Increased nerve T2 signal and enlargement when compared with adjacent arteries.
- Loss of the normal fascicular appearance.
- Blurring of the perifascicular fat.
Keep in mind:

1. The increasing abnormal T2 hyperintensity of the nerve fascicles correlates with the severity of the nerve injury.

2. Nerve enhancement due to disruption of nerve-blood barrier may be present.

3. Atrophy of nerve cell body and axon because long-standing compression results in chronic inflammation and perineural fibrosis.

**Indirect MRI signs of nerve injury:**

- Effacement of perineural fat planes due to nerve enlargement.

- Muscle denervation:

  **Muscle edema at the early phase** - reversible acute muscle denervation is seen as homogeneous and diffuse muscle signal hyperintensity on T2 images due to fluid shift into the extracellular compartment and increased blood volume secondary to an enlarged capillary bed.

  **Muscle atrophy at the chronic phase** - muscle signal intensity is increased on both T1-weighted and T2 images due to ongoing denervation. With prolonged denervation, the bulk of the muscle will decrease and be completely replaced by fat.

**LEARNING POINT:** On MRI, nerve disease is inferred from alterations in nerve signal intensity, size, morphology, and location. Nerve disease is presumed when there are indirect signs of neural injury. Fig. 2 on page 7
Fig. 1: Normal anatomy of a peripheral nerve. Fascicles are composed of several axons wrapped in a layer of perineurium. Several fascicles form a nerve, which is surrounded by a layer of epineurium. Individual axons are covered by endoneurium, but are not visible on MRI. Fascicles are the smallest unit of a nerve visible on MRI.

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Fig. 2: 75 year old male with retroperitoneal sarcoma treated with chemotherapy, radiation therapy and surgery. (A) Axial T2 sequence shows retroperitoneal mass in the topography of the right psoas muscle showing contact with the right lateral margin of L4 vertebrae. Such mass involves the path of the right femoral nerve from the L4 plane and including the extraforaminal path of the L3 root (yellow arrow), so it is not possible to individualize the right femoral nerve. (B) Axial T1 SPAIR post contrast and (C) coronal STIR images show muscle denervation edema affecting muscles belly of the anterior compartment of the thigh (quadriceps femoris) and the sartorius (red arrows), indicating chronic compressive neuropathy.

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Findings and procedure details

FEMORAL NERVE Fig. 3 on page 21 Fig. 4 on page 15

The femoral nerve, the largest branch of the lumbar plexus, is derived from the nerve roots L2-L4. That’s why femoral neuropathy may be clinically confused with lumbar plexopathy and L4 radiculopathy.

The nerve descends from the lumbar plexus in the abdomen through the psoas major muscle, passing behind the inguinal ligament into the thigh, it splits into anterior and posterior divisions.

It passes through the femoral triangle lateral to the femoral vessels enclosed within the femoral sheath and gives off articular branches to the hip and knee joints.

Functions

- Motor: Innervates the anterior thigh muscles that flex the hip joint and extend the knee # Remember Fig. 2 on page 20.

The striking feature of femoral neuropathy is wasting and weakness of quadriceps femoris, resulting in difficulty in walking, with a tendency for the leg to colapse.

- Sensory: Supplies cutaneous branches to the anteromedial thigh (anterior cutaneous branches of the femoral nerve) and the medial side of the leg and foot (saphenous nerve).

Sometimes the femoral nerve may be difficult to visualize on MRI despite its relatively large size. While in the iliacus compartment in the pelvis, the nerve lies in a groove between the psoas and iliacus muscles, so it is difficult to distinguish from the iliacus muscle.

It’s most vulnerable to injury while traversing the iliacus compartment and at the level of the inguinal ligament. Most reports of entrapment neuropathies of the femoral nerve are related to traumatic injuries with mass effect due to iliacus or iliopsoas muscle tear and hematoma, iliopsoas compartment masses, a distended iliopsoas bursa, laproscopic hernia repair, arterial punctures, hysterectomy and hip arthroplasty.

LATERAL FEMORAL CUTANEOUS NERVE Fig. 5 on page 23
The lateral femoral cutaneous nerve is formed from the posterior divisions of the anterior rami of L2 and L3 nerve roots. It’s the most commonly injured by mechanical compression at the level of the inguinal ligament.

It courses on the anterior surfaces of the psoas major and iliacus muscles after becoming secured in the iliac fascia. The nerve passes under the lateral aspect of the inguinal ligament about 10 mm medial to anterior superior iliac spine to follow the anterior surface of the sartorius muscle and deep to the fascia lata.

Neuropathy of the LFCN has been termed *meralgia paresthetica* and manifests as sensory deficits and paresthesias in anterolateral thigh.

A protuberant abdomen may compress the nerve against the inguinal ligament, accounting for symptoms in obeses and pregnant. Others conditions like avulsion fractures of the ASIS, sartorius tendon injury, pelvic osteotomy, acetabular fracture or laparoscopic hernia repair. Constricting clothes, tool belts and seat belts can extrinsically compress the nerve.

**LEARNING POINT:** Imaging acquisition must include the skin and subcutaneous tissues to include the lateral femoral cutaneous nerve and its branches. Both the anterior and posterior divisions of the nerve eventually pierce the fascia lata to give terminal cutaneous branches.

**OBTURATOR NERVE** *Fig. 3 on page 21* *Fig. 6 on page 15*

The obturator nerve arises from the ventral branches of the second to fourth lumbar ventral rami.

The nerve descends in psoas major, emerging from its medial border at the pelvic margin to pass behind the common iliac vessels and laterally along the pelvic wall to the obturator foramen. Near the foramen it divides into anterior and posterior branches.

The anterior division descends between the adductor longus and adductor brevis muscles towards the femoral artery. The posterior division descends through the obturator externus muscle before passing anteriorly to adductor magnus and giving off branches to supply it.
It’s slightly smaller and brighter than its accompanying vessels on T1W sequence due to its abundant perineural fat.

Functions:

-Motor: Innervates the medial compartment of the thigh (adductors).

-Sensory: Cutaneous branch innervates the skin of the medial thigh.

The obturator nerve is relatively protected by its deep intrapelvic localization. Obturator compressive neuropathy is most frequently seen in the context of pelvic trauma or pelvic surgery and is related to mass effect and stretching, respectively. Mass effect on the nerve usually occurs around the region of the obturator canal or as the nerve enters the thigh and may be related to pelvic fractures, periarticular cysts, or hernia. In male athletes the nerve may become compressed by normal fascial structures anterior to the adductor brevis.

On MRI, we should appreciate mass effect on the nerve even as infiltration of the fat around the nerve just proximal to and within the obturator canal.

SCIATIC NERVE Fig. 3 on page 21 Fig. 7 on page 16

The sciatic nerve is a major nerve of the lower limb. It is 2 cm wide at its origin and is the thickest nerve in the body. Because of its large size and abundant perineural fat, the sciatic nerve is easy to evaluate in all imaging planes.

The sciatic nerve is derived from the lumbosacral plexus (L4-S3). After its formation, it leaves the pelvis and enters the gluteal region via greater sciatic foramen. It emerges inferiorly to the piriformis muscle and descends in an inferolateral direction.

It crosses the posterior surface of the superior gemellus, obturator internus, inferior gemellus and quadratus femoris muscles and then it enters the posterior thigh by passing deep to the long head of the biceps femoris.

Within the posterior thigh, the nerve gives rise to branches to the hamstring muscles and adductor magnus. In general, when the sciatic nerve reaches the apex of the popliteal fossa, it terminates by bifurcating into the tibial and common peroneal nerves.

Functions:
-Motor: Innervates the muscles of the posterior thigh and the hamstring portion of the adductor magnus. And via its terminal branches innervates the muscles of the leg and foot.

-Sensory: No direct sensory functions. Indirectly innervates (via its terminal branches) the skin of the lateral leg, heel, and both the dorsal and plantar surfaces of the foot.

Injury more commonly affects the peroneal division of the nerve because its fibers are more superficial, have less supporting connective tissue, and are fixed at two points (the sciatic foramen and the fibular head). The most common cause of serious sciatic nerve injury at the hip is iatrogenic and is associated with total hip replacement, related to stretching or direct trauma of the nerve.

**Piriformis Muscle Syndrome** Fig. 8 on page 22

Is a common anatomical variant but an extremely rare entrapment neuropathy. Although the sciatic nerve typically exits the sciatic foramen anterior and inferior to the piriformis muscle, in some cases the nerve or a portion of the nerve may exit above the muscle or traverse the muscle belly itself, predisposing the variant portion of the nerve to entrapment.

This syndrome may result from a variety of conditions affecting the piriformis muscle, including hypertrophy, inflammation, spasticity, trauma, and ischemia.

**LEARNING POINT:** Variant anatomy, such as accessory musculature and variant spatial relationships between nerves and adjacent structures, may result in a predisposition to entrapment.

**COMMON PERONEAL NERVE** Fig. 9 on page 24

The common peroneal nerve (common fibular nerve) begins at the apex of the popliteal fossa, where the sciatic nerve divides into the tibial and common peroneal nerves.

Common peroneal neuropathy is the most common mononeuropathy in the lower limbs. It is relatively unprotected where it traverses the lateral aspect of the neck of the fibula because it is easily compressed at this site. Other reason is that it is fixed in this position and at the greater sciatic foramen.
Its compression is the result of external compression by agents such as crush injury, surgery, tumor, synovial cyst, prolonged immobilization.

**Functions:**

-Motor: Innervates the short head of the biceps femoris directly. Indirectly (via branches) the muscles in the lateral and anterior compartments of the leg.

-Sensory: Innervates the skin over the upper lateral and lower posterolateral leg. Indirectly (via branches) cutaneous innervation to the skin of the anterolateral leg, and the dorsum of the foot.

On MRI, the common peroneal nerve is surrounded by abundant fat, so it can be easily traced on axial T1W at the level of the knee joint, as it migrates from a location medial to the short head of the biceps femoris muscle to a more lateral position, posterolateral to the lateral head of the gastrocnemius muscle.

**TIBIAL NERVE Fig. 10 on page 17**

The tibial nerve is a branch of the sciatic nerve, and arises at the apex of the popliteal fossa. It descends along the back of the thigh and popliteal fossa, giving off branches to muscles in the superficial posterior compartment of the leg.

At the foot, the nerve passes posteriorly and inferiorly to the medial malleolus, through a structure known as the tarsal tunnel. This tunnel is covered superiorly by the flexor retinaculum. Tibial nerve ends under the flexor retinaculum by dividing into the medial and lateral plantar nerves. A clinically important branch of the lateral plantar nerve is the inferior calcaneal nerve (Baxter nerve).

Neuropathies of the tibial nerve can be subdivided into: proximal tibial neuropathy in the leg, tarsal tunnel syndrome, medial plantar neuropathy, lateral plantar neuropathy, interdigital neuropathy (Morton neuroma), and medial plantar proper digital neuropathy (Joplin neuroma). A clinically important branch of the lateral plantar nerve is the inferior calcaneal nerve (Baxter nerve).

**MORTON NEUROMA Fig. 11 on page 18**
Fibrotic nodule ("neuroma") caused by entrapment of the interdigital nerve branch against the transverse metatarsal ligament or nerve ischemia.

Occurs at adjacent metatarsal bones before the division into two digital nerves.

Most common site is 3rd intermetatarsal space (between 3rd and 4th metatarsal heads).

The symptoms are radiating pain and burning in the region of the intermetatarsal space, exacerbated by weight bearing. Sitting and removing shoes improves symptoms.
Fig. 4: Axial T2-weighted MR images show femoral neuropathy characterized by alteration in signal intensity and enlargement of the femoral nerve. It’s closely applied to the surface of the iliopsoas.

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Fig. 6: Axial T1-weighted MR images show obturator neuropathy characterized by alteration in size of bilateral obturator nerves and signal of fat planes. Look at the obturator neurovascular bundles entering the obturator canals.

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**Fig. 7:** 67-year-old woman. Hip arthroplasty 3 years ago. SEMAC T1 (sequence to reduce metallic artifacts) images show sciatic neuropathy characterized by enlargement of the left sciatic nerve.

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**Fig. 10**: 45-year-old man. Burning and paraesthesia in the sole of the foot for 1 month ago, predominantly lateral. T2 FAT SAT images show entrapment tibial neuropathy caused by compression of the tibial nerve by a cystic formation in the tarsal tunnel.

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**Fig. 11:** MORTON NEUROMA. Coronal (short-axis axial) T1WI through the digital metatarsals shows isointense well-defined mass on the plantar side of the deep transverse metatarsal ligament near the neurovascular bundle, in the 3rd intermetatarsal space (red arrow).

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**Fig. 1:** Normal anatomy of a peripheral nerve. Fascicles are composed of several axons wrapped in a layer of perineurium. Several fascicles form a nerve, which is surrounded by a layer of epineurium. Individual axons are covered by endoneurium, but are not visible on MRI. Fascicles are the smallest unit of a nerve visible on MRI.

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Fig. 2: 75 year old male with retroperitoneal sarcoma treated with chemotherapy, radiation therapy and surgery. (A) Axial T2 sequence shows retroperitoneal mass in the topography of the right psoas muscle showing contact with the right lateral margin of L4 vertebrae. Such mass involves the path of the right femoral nerve from the L4 plane and including the extraforaminal path of the L3 root (yellow arrow), so it is not possible to individualize the right femoral nerve. (B) Axial T1 SPAIR post contrast and (C) coronal STIR images show muscle denervation edema affecting muscles belly of the anterior compartment of the thigh (quadriceps femoris) and the sartorius (red arrows), indicating chronic compressive neuropathy.

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**Fig. 3:** YELLOW COLOR = SCIATIC innervates muscles of the posterior thigh (biceps femoris, semitendinosus and semimembranosus). RED COLOR = FEMORAL innervates anterior thigh muscles that flex the hip joint (pectineus, iliacus, sartorius) and extend the knee (quadriceps femoris: rectus femoris, vastus lateralis, vastus medialis and vastus intermedius). BLUE COLOR = OBTURATOR innervates medial compartment of the thigh (adductor longus, adductor brevis, adductor magnus, gracilis and obturator externus).

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Fig. 8: Piriformis muscle syndrome. MR neurography T1W image shows accessory piriformis muscle (red arrow) compressing branch of the sciatic nerve.

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Fig. 5: 34-year-old man. Pain on the lateral aspect of the right thigh. (A)Coronal and (B) axial T2 FAT SAT images show alteration in signal intensity and enlargement of the right lateral femoral cutaneous nerve.

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**Fig. 9:** 52-year-old man. Leg pain and difficulty in dorsiflexion of the left foot 10 days ago. (A) Axial T2 FAT SAT image show high intensity in the signal of the common peroneal nerve (red arrow). (B) Axial T2 FAT SAT image show denervation of muscles of the anterior compartment of the leg.

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Conclusion

Nerves are present on every MRI examination of lower extremity, therefore it is important to radiologists be familiar with the normal and abnormal appearances of peripheral nerves and the scope of pathologies which may produce compressive/entrapment syndromes.

MRN improves the conspicuity of the nerves and supplement the information obtained from clinical examination and nerve conduction studies.

*So keep in mind:*  
What does the referring physician need to know?  
# If the finding is in an early or chronic phase.
# Location and etiology of entrapment/compression.
# Subsidiary findings, such as concomitant osseous and soft tissue injuries.

*...and remember:* When evaluating MRI in the setting of suspected neuropathy, direct and indirect signs of nerve injury should be interpreted in the context of ancillary imaging findings and clinical evaluation!
References