Dynamic phases of peroneal and tibial intraneural ganglia formation: a new dimension added to the unifying articular theory

ROBERT J. SPINNER, M.D.,1–3 KIMBERLY K. AMRAMI, M.D.,4 ALEXANDRA P. WOLANSKYJ, M.D.,5 NICHOLAS M. DESY, B.SC.,1,6 HUAN WANG, M.D.,1,7 EDUARDO E. BENARROCH, M.D.,8 JOHN A. SKINNER, M.D.,4 MICHAEL G. ROCK, M.D.,7 AND BERND W. SCHEITHAUER, M.D.9

Departments of 1Neurologic Surgery, 2Orthopedics, 3Anatomy, 4Radiology, 5Medicine, 6Neurology, and 7Anatomic Pathology, Mayo Clinic, Rochester, Minnesota; 8McGill University School of Medicine, Montreal, Quebec, Canada; and 9Department of Hand Surgery, Huashan Hospital, Fudan University, Shanghai, China

Object. The pathogenesis of intraneural ganglia has been a controversial issue for longer than a century. Recently the authors identified a stereotypical pattern of occurrence of peroneal and tibial intraneural ganglia, and based on an understanding of their pathogenesis provided a unifying articular explanation. Atypical features, which occasionally are observed, have offered an opportunity to verify further and expand on the authors’ proposed theory.

Methods. Two unusual cases are presented to exemplify the dynamic features of peroneal and tibial intraneural ganglia formation.

Results. Two patients with a predominant deep peroneal nerve deficit shared essential anatomical findings common to peroneal intraneural ganglia: namely, 1) joint connections to the anterior portion of the superior tibiofibular joint, and 2) dissection of the cyst along the articular branch of the peroneal nerve and proximally. Magnetic resonance (MR) images obtained in these patients demonstrated some unusual findings, including the presence of a cyst within the tibial and sural nerves in the popliteal fossa region, and spontaneous regression of the cysts, which was observed on serial images obtained weeks apart. The authors identified a clinical outlier, a case that could not be understood within the context of their previously reported theory of intraneural ganglion cyst formation. Described 32 years ago, this patient had a tibial neuropathy and was found at surgery to have tibial, peroneal, and sciatic intraneural cysts without a joint connection. The authors’ hypothesis about this case, based on their unified theory, was twofold: 1) the lesion was a primary tibial intraneural ganglion with proximal extension followed by sciatic cross-over and distal descent; and 2) a joint connection to the posterior aspect of the superior tibiofibular joint with a remnant cyst within the articular branch would be present, a finding that would help explain the formation of different cysts by a single mechanism. The authors proved their hypothesis by careful inspection of a recently obtained postoperative MR image.

Conclusions. These three cases together with data obtained from a retrospective review of the authors’ clinical material and findings reported in the literature provide firm evidence for mechanisms underlying intraneural ganglia formation. Thus, expansion of the authors’ unified articular theory permits understanding and elucidation of unusual presentations of intraneural cysts. Whereas an articular connection and fluid following the path of least resistance was pivotal, the authors now incorporate dynamic aspects of cyst formation due to pressure fluxes. These basic principles explain patterns of ascent, cross-over, and descent down terminal nerve branches based on articular connections, paths of diminished resistance to fluid flow within recognized anatomical compartments, and the effects of fluctuating pressure gradients.

KEY WORDS • articular theory • cyst regression • fluid dynamics • ganglion cyst • intraneural ganglion • peroneal nerve • sciatic nerve • tibial nerve

UNTIL recently, descriptions of intraneural ganglia have centered on their static appearances. The unifying articular or “synovial” theory33 we initially proposed was based on critical analyses of clinical, operative, and imaging observations as well as on assessments of reported cases. Using this theory, we sought to explain the most common form of intraneural cyst—that affecting the peroneal nerve.32 More recently, the theory was validated with respect to the tibial nerve13,35 and corroborated by other authors as well.27 In short, we have shown that intraneural ganglia have characteristic, stereotypical appearances.34,35 For example, peroneal and tibial intraneural ganglia arise from the anterior5,32 and posterior41,42 aspects of the superior tibiofibular joint, respectively, and extend intraepineurally via their own articular branches into the parent nerve, sometimes as far proximal as the buttock.13,42

These observations, made at a single point in time and based on individual MR images and/or operative views,
provide us with important information. Admittedly, the observations are static representations, essentially a snapshot of a dynamic process. Therefore, we must take other factors into consideration, specifically intraarticular pressure and/or pressure gradients leading to dynamic fluxes over time. These could explain fluctuating clinical symptoms and signs as well as the broad spectrum of operative and imaging findings encountered.

We present three cases with multiple, apparently distinct intraneural ganglia in the popliteal fossa affecting the peroneal, tibial, sciatic, and sural nerves. These atypical features offer a unique opportunity to elucidate the pathogenesis of these cysts. Our purpose is to provide evidence demonstrating that if a peroneal or tibial intraneural ganglion arising from the superior tibiofibular joint extends proximally enough and has access to the common epineurial sheath of the sciatic nerve, it may cross over within the sciatic nerve and descend down all its terminal branches (that is, the peroneal, tibial, and sural nerves). Such a dynamic mechanism would support and extend our previously described unified articular theory of intraneural ganglion cyst formation.

Summary of Cases

Case 1

After heavy lifting in a squat position, this 41-year-old man noted severe left shin and lateral malleolar pain extending to his big toe. Two weeks later he noted a partial footdrop, and 1 month later he noted numbness in his big toe. Because the man had a previous history of low back pain and had undergone L5–S1 instrumented posterior fusion 10 years earlier, epidurography with a transforaminal injection was performed. The following day the patient noted exacerbation of pain as well as complete footdrop, which persisted. He then underwent electromyography and MR imaging of his knee. The EMG showed complex changes in the man’s peroneal neuropathy as well as L-5 radiculopathy. Interpretation of the MR images made at another institution documented a “fluid collection” around the sciatic nerve (Figs. 1A and 2A), which was deemed to be of indeterminate significance. The MR imaging report did not, however, identify the cyst as a primary peroneal intraneural ganglion (Fig. 2B) arising from the superior tibiofibular joint (Fig. 3) and having a secondary extension into the sciatic nerve (the proximal extent of which could not be seen) with a cyst involving the tibial and sural nerves as well (Figs. 1 and 2). Although the more typical cyst architecture was seen within the peroneal nerve at the fibular neck with a classic “signet ring” sign, the more proximal portions of the peroneal, tibial, and sural nerves as well as the distal sciatic nerves exhibited unusual features. These new MR images demonstrated concentric cystic expansion within the distal sciatic and proximal peroneal, tibial, and even sural nerves (Figs. 1 and 2). The maximal width of the lesion was 2.5 cm.

Examination disclosed complete deep peroneal nerve loss with essentially preserved peroneal muscle function. Asymmetric toe flexion was also seen. Other tibial nerve–innervated muscles functioned normally. Sensation was diminished, more in the deep than in the superficial peroneal nerve distributions, but was normal on the plantar aspect of the foot. A Tinel sign was elicited from the tibial nerve in the distal thigh and from the peroneal nerve over the fibular neck, where a mass could be palpated.

There was electrophysiological evidence of a predominant deep peroneal nerve lesion. There were 3+ fibrillation potentials in the tibialis anterior and peroneus tertius muscles and 1+ fibrillation potentials in the peroneus longus muscle. Electromyography of the medial gastrocnemius, posterior tibialis, and biceps femoris muscles yielded normal findings. Peroneal motor nerve conduction was absent. Tibial motor and sural sensory conductions were normal.

To our surprise, a repeated MR imaging study performed at our institution 3 weeks later showed near-complete resolution of the intraneural cyst. Only a small cyst could be seen to extend from the superior tibiofibular joint along the articular branch to the level of the sciatic nerve bifurcation (Fig. 4). There was marked abnormality of the peroneal nerve sheath extending to the sciatic nerve. It appeared thickened and showed signal enhancement on MR images. About 18 cm proximal to the knee joint, the sciatic nerve appeared normal. The tibial nerve distal to the bifurcation appeared slightly hyperintense over a distance of 2 cm. In addition, a small intramuscular, extraneural cyst was now seen (data not shown). Denervation changes in the anterior compartment were indicated by the appearance of hyperintensity and fatty changes in the muscles. Meniscal degeneration was present as was fragmentation of the tibial tubercle consistent with prior Osgood–Schlatter disease. Last, moderate degenerative changes were evident in the superior tibiofibular joint and mild changes in the knee joint.

At surgery, the abnormal-appearing medial component of the peroneal nerve was visualized. There seemed to be a nonexpanded cyst wall (Fig. 5). An enlarged articular branch connection to the superior tibiofibular joint was also seen. Cyst fluid was seen in the joint. The joint was resected, as was a portion of the articular branch. Histological analysis confirmed the diagnosis of intraneural cyst.

Postoperatively, the patient showed signs of recovering active dorsiflexion after a period of 4 months. Magnetic resonance images obtained at that time showed no persistence of cyst within the peroneal nerve or within the superior tibiofibular joint (Fig. 6). The man discontinued wearing his ankle foot orthosis 6 months after surgery and regained Medical Research Council Grade 4 foot dorsiflexion at 8 months and Grade 5- function at 1 year postoperatively.

Case 2

This 17-year-old boy injured his ankle skateboarding. Immediately thereafter he noted footdrop and complained of ankle pain and paresthesias of the dorsal foot. A diagnosis of ankle sprain and peroneal nerve palsy was made. On examination, the boy was found to have a complete lesion of the deep peroneal nerve with normal eversion but diminished sensation in the superficial peroneal nerve distribution. An EMG demonstrated marked changes in muscles supplied by the deep peroneal nerve with sparing of the short head of the biceps and marked slowing in peroneal nerve motor conduction velocity across the fibular neck. A superficial peroneal nerve sensory action potential was unobtainable. Magnetic resonance imaging performed 1 month after the injury revealed a multifoculocyst at the pe-
ripheral posterior lateral knee region, which was believed to be a ganglion and an incidental finding (Fig. 7). A review of these films at our institution revealed a peroneal intraneural ganglion cyst arising from the superior tibiofibular joint, which extended proximally to the level of the sciatic nerve. In addition there was an intraneural cyst within the tibial and sural nerves at the level of the popliteal fossa. A surgical exploration was undertaken 6 weeks after the injury. A peroneal intraneural cyst was identified and decompressed but not resected. No joint connection was identified. Within weeks after the surgery, the patient recovered Grade 2 toe extension and ankle dorsiflexion. Stability was maintained by use of an ankle foot orthosis.

The patient was referred for further evaluation 3 months after the initial injury. An additional EMG revealed a severe left common peroneal neuropathy below the branch leading to the short head of the biceps femoris muscle, which predominantly affected the deep peroneal nerve. An MR image demonstrated the peroneal intraneural ganglion cyst extending from the superior tibiofibular joint only to the level of the common peroneal nerve, approximately 1 cm superior to the fibular head. The maximal width of the

![Fig. 1. Case 1. Initial axial MR images obtained at another institution. A: A T2-weighted fast spin echo (FSE) image with fat suppression showing the sciatic nerve with the tibial and peroneal divisions within the common epineurial sheath (arrow), which is surrounded by bright cyst fluid. B: A T2-weighted FSE image with fat suppression obtained distal to the site shown in panel A. Two separate epineurial sheaths, one containing the tibial nerve (arrow) and the second containing the peroneal and lateral sural cutaneous nerves (arrowhead), are demonstrated. Note that the nerves are located posteriorly within the cyst fluid in their individual sheaths. C: A T2-weighted FSE image with fat suppression obtained distal to the site shown in panel B. The tibial (straight arrow), lateral sural cutaneous (curved arrow), and peroneal (arrow with forked tail) nerves can be seen within three individual epineurial sheaths, each surrounded by cyst fluid. Reprinted from Spinner et al, Neurosurg Focus 22(6):E17, 2007.](image)

![Fig. 2. Case 1. Initial coronal MR images obtained at another institution. A: A T2-weighted FSE image with fat suppression demonstrating the enlarged sciatic nerve (S) with surrounding cyst fluid. B: A T2-weighted FSE image with fat suppression showing the individual terminal branches of the sciatic nerve—the tibial (T), lateral sural cutaneous (Su), and peroneal (P) nerves—each in separate epineurial sheaths with the nerves in the center surrounded by cyst fluid. Available imaging did not include the most proximal extent of the cyst. The peroneal nerve has a multilaminar appearance. The joint connection to the peroneal intraneural ganglion is seen in Fig. 3.](image)

![Fig. 3. Case 1. Initial MR images obtained at another institution. A: An axial T2-weighted FSE image with fat suppression demonstrating the more classic MR imaging appearance of a peroneal intraneural cyst involving the articular branch of the peroneal nerve with cyst extension along the transverse limb of the nerve (large arrow). Note the cyst located proximally within the common peroneal nerve (asterisk), which displays a signet ring sign depicting the nerve displaced by the cyst as well as a separate outer epineurial partial ring (thin arrow). B: A sagittal T2-weighted image showing the cyst connection to the anterior portion of the superior tibiofibular joint (arrow) and extension along the ascending portion of the articular nerve branch. F = fibula; T = tibia.](image)
cyst was 4 mm (Fig. 8A). There was no cyst within the distal sciatic, tibial, or sural nerves. In addition, the cyst now extended anteriorly from the superior tibiofibular joint along a capsular vein (Fig. 8B). There was an increased T2 signal within the anterior compartment consistent with denervation. There were moderate degenerative changes in the superior tibiofibular and knee joints and evidence of an acute ankle sprain with mild injury to the anterior inferior tibiofibular ligament.

Given the persistence of the cyst, surgery was recommended but deferred for 4 weeks so that the patient could attend his high school prom. By the time of the procedure, enlargement of the lesion and an essentially complete deep peroneal nerve lesion were noted. During surgery, we identified an intraneural cyst measuring 2.5 cm within the distal common peroneal nerve. The articular branch was also enlarged, and the cyst was traced to the superior tibiofibular joint. The superior tibiofibular joint was resected, and

Fig. 4. Case 1. Axial T2-weighted MR images obtained at our institution 3 weeks after the images shown in Figs. 1 to 3, revealing spontaneous regression of the intraneural cysts. A: An FSE image with fat suppression showing a hyperintense ring of outer epineurial cyst (wedding ring sign) surrounding both divisions of the distal sciatic (S) nerve (arrow). B: An image obtained using the vastly undersampled isotropic projection reconstruction technique at the level of the distal thigh (just distal to the site shown in panel A, depicting a thickened, hyperintense rim (wedding ring sign) surrounding the peroneal (P) division of the distal sciatic nerve (arrow) with a trace of remaining cyst (arrowhead) within the tibial (T) division immediately adjacent. Both nerves are slightly enlarged and edematous. C: An FSE image with fat suppression showing an intraneural cyst within the transverse limb of the articular branch (asterisk) of the peroneal nerve. The common peroneal nerve (thin arrow) has a small residual circumferential cyst. Its connection to the superior tibiofibular joint can be seen (thick arrow indicates a tail sign). Note denervation changes in the anterior compartment musculature (plus sign).

Fig. 5. Case 1. Intraoperative photographs. A: The abnormal-appearing medial component of the common peroneal nerve (over the green background) with a nonexpanded cyst wall. B: This unexpanded cyst wall extending to involve the most medial segment of the common peroneal nerve (over the green background) and, more distally, its articular branch portion at the entrance into the fibular tunnel. C: The slightly enlarged articular branch (in the red vasoloop), which is traced to the superior tibiofibular joint. Cyst was seen in the joint.
the articular branch and capsular vein were ligated. The large cyst was then decompressed through a limited longitudinal incision. The cyst wall was not resected (Fig. 9), and the distal sciatic, tibial, and sural nerves were not exposed. The histological features of the lesion confirmed an intraneural cyst with adventitial extension (Fig. 10). An MR image demonstrated no cyst persistence at 3 months postoperatively (Fig. 11). The patient regained Grade 4+ ankle dorsiflexion and toe extension at 6 months and Grade 5− function at 1 year postoperatively.

**Case 3**

This patient was previously reported by other clinicians 32 years ago and was identified from our extensive literature review as being a clinical outlier. The patient was described as having intraneural ganglia involving several nerves without a joint connection; the pathogenesis of this anomaly was obscure.

The patient presented with left tibial neuropathy, which was localized to the popliteal fossa based on clinical and electrodiagnostic findings. No advanced imaging studies were available at that time. During surgery, he was found to harbor an extensive cyst within the sciatic nerve, which extended into the tibial nerve 9 inches distal to the knee and peroneal nerve (Fig. 12). The surgeon was able to remove the cyst while sparing the fascicles. Within 2 years postoperatively, the patient noted some mild neurological recovery.

The operative findings in this case could not be explained by our unifying theory as initially proposed. Based on our understanding of cyst pathogenesis and the patient’s symptoms and findings, we predicted that modern MR imaging would visualize a residual joint connection to the posterior aspect of the superior tibiofibular joint due to the predominant tibial neuropathy. Demonstration of this joint connection would help explain both the cyst’s unusual extension and the patient’s present clinical status.

Despite marginal image quality due to technical parameters, the postoperative MR imaging examination did succeed in demonstrating a small cyst remnant arising from the posterior aspect of the superior tibiofibular joint (Fig. 13A). In addition, a short segment of cyst extending along the expected course of the articular branch of the tibial nerve was also identified (Fig. 13A). The cyst remnant arising from the joint represented an intraneural cyst within the articular branch of the tibial nerve, an appearance identical to that seen in other joint connections in tibial intraneural

**Fig. 6.** Case 1. Postoperative axial T2-weighted FSE MR image with fat suppression demonstrating resection of the superior tibiofibular joint and no residual cyst. Note denervation in the anterior compartment muscles (plus sign).

**Fig. 7.** Case 2. Initial MR images obtained at another institution. A: Axial T2-weighted FSE image with fat suppression obtained at just about the knee joint level, showing an intraneural cyst within the outer epineurium of the common peroneal nerve that is producing the signet ring sign (large arrow) and is surrounded by a thin circumferential cystic ring (wedding ring [small arrow]). There is also a cyst present within the outer epineurium of the tibial nerve (asterisk). Note an outer epineurial cyst associated with the tibial nerve, which is enlarged and hyperintense (arrowhead). The path of the cyst travels upward from the superior tibiofibular joint along the peroneal nerve and downward along the tibial nerve. B: Coronal T2-weighted FSE image with fat suppression demonstrating the cyst extending along the course of the peroneal nerve (asterisk). C: Sagittal T2-weighted FSE image with fat suppression showing the multilocular cyst arising from the anterior superior tibiofibular joint (arrow) and extending along the course of the articular branch of the peroneal nerve. The larger, more proximal cyst extension into the common peroneal nerve (asterisk) is also visible.
ganglia arising from the superior tibiofibular joint. Magnetic resonance imaging showed prominent popliteus muscle and posterior compartment atrophy as well as mild atrophy of anterior compartment musculature (Fig. 13B), findings indicating preferential involvement of the tibial as opposed to the peroneal nerve. Severe degenerative joint disease at the knee and superior tibiofibular joint were also seen after the operation, similar to that seen in our other cases. Thirty-five years later, the patient stated that he still had moderate deficits in his tibial nerve and mild deficits in his peroneal nerve, symptoms that had remained unchanged for over three decades.

**Discussion**

Our unified theory, applied with some modification, explains the extensive cyst formation seen in the three cases described. All shared the cardinal imaging and operative features of peroneal and tibial intraneur al ganglia—a cyst extending from a degenerate superior tibiofibular joint along an articular branch via an intraepineurial dissection following the path of least resistance. In Case 1 there was also evidence of coexistent extraneural extension of the cyst into muscle and in Case 2 into vascular adventitia—patterns we have seen previously that confirm the origin of these cysts in a pathological joint capsule. Our cases also exhibited two other unusual features: atypical cyst extension and cyst regression. Although seemingly trivial, these observations needed to be explained.

The explanation for the pathological anatomy we observed is rather simple and is based on understanding the anatomical constraints of a large nerve, specifically the layers of the epineurium. Terminology has varied, but our

---

**Fig. 8.** Case 2. Magnetic resonance images obtained at our institution approximately 6 weeks after the MR images shown in Fig. 7 and 5 weeks after cyst decompression was performed at another hospital. A: Maximum intensity projection of a coronal T2-weighted FSE data set with fat suppression demonstrating the U sign of a typical peroneal intraneural cyst (arrow with dashed tail) with extension along the articular branch. A connection to the superior tibiofibular joint is also seen on this image (arrow). This image also shows the maximal proximal extent of the intraneural cyst, which is significantly smaller than that seen in Fig. 7. B: Maximum intensity projection of a T2-weighted axial FSE data set with fat suppression showing the path of the peroneal intraneural cyst along the transverse limb to the common peroneal nerve (asterisk) with anterior cystic adventitial extension (arrowhead) along the course of a small vein (arrows). The adventitial portion arises from the junction of the transverse and ascending limbs of the intraneural cyst. Note denervation changes in the anterior compartment musculature.

**Fig. 9.** Case 2. Intraoperative photographs obtained 4 weeks after MR images were obtained at our facility. A: The common peroneal nerve (against a green background). A large cystic expansion (asterisk) within the common peroneal nerve is noted just proximal to the fibular tunnel. B: The large peroneal intraneural cyst (asterisk) is mobilized; a more distal dissection allows identification and protection of the terminal branches of the common peroneal nerve in vasoloops. The red vasoloop enircles the articular branch. C: The cystic articular branch in the red vasoloop is directly adjacent to a cystic adventitial (venous) extension near the superior tibiofibular joint. D: The hollow cystic articular branch and vein have been divided and ligated. The superior tibiofibular joint is then resected (not shown). E: A small longitudinal incision is made in the peroneal intraneural cyst. F: A large amount of cyst is evacuated.
use of terms is illustrated in Fig. 14. The epineurial (adventitial) sheath is a delicate, continuous fibrous tissue layer that encircles the outer (epifascicular) epineurium, a fibrofatty layer that in turn surrounds the inner (interfascicular) epineurium, which fills the space between fascicles. The latter are surrounded by a multilaminated perineurium, the basis of the nerve–blood barrier.

The outer epineurium is the common denominator that permits us to explain the pathological anatomy in our cases. By considering pressure fluxes and the continuous layer of the outer epineurium, we can explain bidirectional flow and the apparently separate albeit connected cysts involving multiple nerves. In dye studies, injection of the outer epineurium allows observation of primary ascent, sciatic cross-over, and terminal branch descent in an experimental model and a barrier between the outer and inner epineurium.\textsuperscript{37,41} We invoke these anatomically relevant data to draw a clinical corollary. We have identified three sequential phases of peroneal and tibial intraneural ganglia cyst formation (Fig. 15) that represent a dynamic chain of events and confirm our understanding of the pathogenesis of these cysts.

Three Sequential Phases

Phase I—Primary Ascent. Primary ascent may occur in one or more layers of the epineurium. In outer epineurial (epifascicular) cysts, this initial phase consists of eccentric cyst dissection from the superior tibiofibular joint, up the articular branch of the primarily affected nerve (either the
peroneal or tibial), to the level of the division of the sciatic nerve, typically located in the distal thigh. Phase I incorporates our previous published Stages 0 to 4. Depending on pressure fluxes, the cyst may either descend down the affected nerve or regress, presumably along the same intraepineurial path it ascended. In contrast, inner epineurial (interfascicular) cysts, rather than those within the outer epineurium, can continue their primary ascent between fascicles solely within the peroneal or tibial division of the sciatic nerve.

Phase II—Sciatic Nerve Cross-Over. Cysts having access to the outer epineurium can cross over when they extend to the level of the sciatic nerve bifurcation. At that point, the peroneal and tibial nerves form the sciatic nerve, their two epineurial sheaths coalescing to form a common connective tissue sheath surrounding their individual outer epineuria. At this point the cyst may partially or completely surround the sciatic nerve, encircling the neural elements—in essence, filling a potential space with cyst fluid (producing a “wedding ring” sign). Thus transit of the cyst from the peroneal to the tibial division, or vice versa, is facilitated. A linear streak could be seen in several cases and was also produced in our anatomical study; a jet of injected ink was seen to ascend primarily within the outer epineurium of the division of the sciatic nerve even more proximal than the level of intrasciatic nerve cyst cross-over. In contrast, given the anatomical boundaries of the inner epineurium, a cyst contained within it cannot cross over unless there is a fenestration in the epineurium.

Phase III—Terminal Branch Descent. If cross-over occurs within the sciatic nerve, descent down the individual outer epineuria of the terminal branches may ensue. The process and degree of descent and circumferential filling depends on pressure gradients. Cyst fluid can pass into the peroneal or tibial nerves as well as sural nerve branches. Several cyst segments are thereby derived from one intraneural cyst and its joint connection. In some cases, Phase III may be seen without MR imaging evidence of Phase II, as this phase may not be captured in a timely fashion on MR images.

Physiologically, however, Phase III will not occur without Phase II.

Pressure, Fluxes, and Dynamic Appearances

It has become apparent to us that the size, shape, and extent of a cyst vary depending on fluid pressures. Intraarticular pressures are increased with exercise, joint motion, and in the setting of degenerative joint disease. These factors contribute to intraneural cyst propagation. The frequently seen multilobular appearances of some cysts suggest pulsatility. Multilaminar flow (as seen in Fig. 2) also highlights the pulsatility occurring along different cleavage planes within the epineurium, the fluid flowing different paths of least resistance. Similarly, a small cyst neck at the articular branch connection becomes expansive more proximally. Such is the case in the common peroneal nerve proximal to the fibular tunnel and in the tibial nerve within the popliteal fossa. With increased intraarticular pressure and perhaps associated inflammatory change, cyst fluid may extend from the proximal leg to as high as the buttok. Opposing pressures could be generated by numerous factors, including gravity, muscular contraction, external compression of the thigh, or even cyst or joint capsule rupture. The relationship of pressure to cyst formation is commonly seen in popliteal cysts (Baker cysts), which are known to be associated with intraarticular pathological conditions of the knee. Patients typically note a fluctuating course and variation in cyst size dependent largely on worsening of knee effusions.

To date, relatively few cases of intraneural ganglia with sciatic involvement have been described. We be-
lieve that these form as a result of an increase in intraarticular pressure. Although joint connections were not described in these reported cases, we believe that they were present but unrecognized. Indeed, we proved this retrospectively in one such case by demonstrating a joint connection in a “sciatic intraneural ganglion,” which the original authors failed to identify. This particular case actually represented an example of a tibial intraneural ganglion cyst extending from the posterior portion of the superior tibiofibular joint into the sciatic nerve to the mid-thigh level. It is not surprising that the farther a cyst appears to be located from a joint, the less often a connection is identified. In our experience, inability to identify a joint connection is due to the following: 1) technical limitations of resolution on MR images, 2) a radiologist’s or surgeon’s inexperience or lack of familiarity with the entity, or 3) inadequate visualization of the joint of origin. This is well illustrated in cases of peroneal or tibial intraneural ganglia as well. In one published instance, a case of a peroneal intraneural ganglion that extended to the buttock, rapid cyst recurrence was noted near the superior tibiofibular joint. These findings suggest to us that a joint connection exists in the other reported cases of tibial and peroneal ganglia extending into the sciatic nerves. Thus, the term “sciatic intraneural ganglion” is a misnomer in that it brings to mind de novo formation within the nerve rather than proximal extension of a joint-related cyst.

The presence of pressure fluxes in cysts contained within differing anatomical barriers not only can be used to explain their primary ascent but also the potential for crossover within the sciatic nerve and descent in terminal branches. The findings of multiple cysts were readily apparent in Cases 1 and 3 but were more subtle in Case 2. Although the primary intraneural lesion is typically symp-
tomatic, other intraneural lesions may be subclinical. With proximal primary ascent into either the common peroneal or tibial nerve, the cyst tends to be eccentrically located. On MR images this typically results in the signet ring sign.\(^4\) When a cyst has access to the outer epineurium within the sciatic nerve, the MR imaging appearance is completely different, resulting in a wedding ring sign pattern due to cyst encirclement of the nerve, when it is fully expressed. This pattern is maintained in the descent phase in varying degrees within the proximal tibial, peroneal, and sural nerves.

The clinical manifestations of pressure fluxes described herein are not isolated findings. The potential for cyst regression/enlargement and proximal extension with cyst cross-over and descent is underappreciated. This is likely due to failure to undertake serial imaging over time, incomplete imaging of the proximal extent of cyst involvement (as in the cases illustrated in Figs. 2 and 16), or simply to a lack of recognition of the process. We were gratified to identify these previously unrecognized, atypical clinical and imaging patterns in several of our patients as well as in published cases. We can cite several examples.

In one case in our previously published series,\(^3\) we did not recognize an apparent discrepancy between the clinical and MR imaging findings. The patient had fluctuating symptoms. An intraneural cyst extended into only a portion of the articular branch of the peroneal nerve but none-
Peroneal and tibial intraneural ganglia formation
to recurrence, perhaps even cross over and descend within
previously unaffected terminal branches. This highlights
the need for careful, long-term follow-up and suggests a
benefit to eliminating any cyst remnant. In our experience,
given that we have always disconnected and/or ligated the
joint–nerve connection, we have not observed intraneural
cyst recurrence or progression.

Could There be Another Explanation?
This unified theory is predicated on a joint–cyst connec-
tion originating either from a capsular rent, as seen with
arthrography,\textsuperscript{30} or from a synovial herniation. To us, the
finding of an intraneural cyst not connected to a joint would
be inconsistent with direct synovial herniation. We certainly
also considered the possibility that such cases could rep-
resent exceptions to the unified theory. De novo multifocal
cyst formation occurring from a degenerative process af-
factoring three neighboring nerves does not seem likely, espe-
cially at locations away from a joint. Furthermore, it does
not seem logical for two distinct pathological processes to
be involved, that is, formation of one cyst from the joint (ar-
ticular theory) and two separate cysts on the basis of some
other process. As proponents of a unified articular theory\textsuperscript{31}
and Occam’s razor, we believe that the finding of joint
pathological conditions and cyst–articular connections is
not coincidental but causal.

Conclusions
The pathogenesis of the intraneural ganglion cyst has
been an issue of controversy for longer than a century. De-
spite many reports of such ganglia arising de novo without
joint connections (degenerative theory), we believe that we
have recently demonstrated the true nature of these cysts
based on a unifying articular or “synovial” theory.\textsuperscript{33} In fact,
peroneal and tibial intraneural cysts share certain charac-
teristic clinical, imaging, operative, and histological fea-
tures that make their anatomical appearances predictable,
stereotypical, and understandable.

A careful scrutiny of our atypical cases and of the litera-
ture has expanded our appreciation of the spectrum of pre-
sentations and imaging appearances assumed by intraneur-
al cysts. It has certainly deepened our understanding of the
mechanism(s) underlying their formation. These clinical
observations have validated the articular theory. In sum-
mary, we have presented a dynamic explanation of intra-
neural cyst pathogenesis based on imaging, operative, and
experimental evidence. The common principles for per-
oneal and tibial intraneural ganglia include the following:
an articular branch connection from a degenerative joint;
cyst extension along the path of least resistance;\textsuperscript{33} and, ulti-
mately, cyst dimensions and distributions determined
largely by pressure fluxes, which in some cases can lead to
the formation of multiple intraneural ganglia.

Acknowledgments
The authors appreciate the continued intellectual support of Dr.
John L. D. Atkinson (Rochester, Minnesota); the clinical informa-
tion provided by Drs. John J. Kepes (Kansas City, Kansas), Karik G.
Krishnan (Dresden, Germany), John A. Maxwell (Medina, Washing-
ton), and Marie-Christine Petit-Lacour (Le Kremlin Bicêtre, France);
and the creative artistic excellence of David Factor and Peggy
Chihak (Medical Graphics, Rochester, Minnesota).

References
L: Intraneural cyst of the peroneal nerve. Childs Nerv Syst 14:
222–225, 1998
2. Bonar SF, Viggione W, Schatz J, Scolyer RA, McCarthy SW: An
unusual variant of intraneural ganglion of the common peroneal
3. Buijsrøgge MP, van der Meijs S, Korte JH, Fritschy WM: “Inter-
mittent claudication intermittence” as a manifestation of adventi-
tical cystic disease communicating with the knee joint. Ann Vasc
Surg 20:687–689, 2006
4. Chang H, Park JB, Kim KW: Synovial cyst of the transverse liga-
ment of the atlas in a patient with os odontoideum and atlantoax-
5. Colen CB, Rengachary S: Spontaneous resolution of a cervical
6. Coulier B, Ghoze P, Mailleux P: [Computed tomography diag-
agnosis of clinically well-tolerated bilateral vertebral synovial cysts.]
JBR-BTR 81:141–143, 1998 (Fr)
7. Davidge CM, Walker R, Brett K, Bromran RS: Spontaneous res-
olution of a spinoeardial notch cyst and associated suprascapular
2007
8. de Seze MP, Rezzouk J, de Seze M, Uzel M, Lavignolle B,
Durandau A, et al: Anterior innervation of the proximal tibio-
ganglion of the n. peroneus communis.] Ceska a Slovenska Neuro-
logie a Neurochirurgie 64:300–303, 2001 (Czech)
10. Dubuisson AS, Stevenaert A: Recurrent ganglion cyst of the per-
oneal nerve: radiological and operative observations. Case report.
J Neurosurg 84:280–283, 1996
11. Ewald C, Kalff R: Resolution of a synovial cyst of the lumbar
spine without surgical therapy—a case report. Zentralbl Neuro-
chir 66:147–151, 2005
12. Friedlander HL: Intraneural ganglion of the tibial nerve. A case
13. Harbaugh KS, Tiel RL, Kline DG: Ganglion cyst involvement of
peripheral nerves. J Neurosurg 87:403–408, 1997
14. Houten JK, Sanderson SP, Cooper PR: Spontaneous regression of
symptomatic lumbar synovial cysts. Report of three cases. J Neu-
15. Jacobs RR, Maxwell JA, Kepes J: Ganglia of the nerve. Pre-
sentation of two unusual cases, a review of the literature, and a dis-
cussion of pathogenesis. Clin Orthop Relat Res 113:135–144,
1975
and calf cysts in rheumatoid arthritis. Treatment by anterior syn-
17. Krishnan KG, Schackert G: Intraneural ganglion cysts: a case of
18. Lang CJ, Neubauer U, Quaism U, Fahrbusch R: Intraneural gan-
glion of the sciatic nerve: detection by ultrasound. J Neurol Neu-
surg Psychiatry 57:870–871, 1994
J Neurosurg 40:120–124, 1974
20. Mercader J, Munoz Gomez J, Cardenal C: Intraspinal synovial
cyst: diagnosis by CT. Follow-up and spontaneous remission.
21. Milliø K, Terzis JK: Nomenclature in peripheral nerve surgery, in
Terzis JK (ed): Microreconstruction of Nerve Injuries. Philad-
22. Morio Y, Yoshioka T, Nagashima H, Hagino H, Teshima R: In-
traspinal synovial cyst communicating with the C1–C2 facet
joints and subarachnoid space associated with rheumatoid atlanto-
23. Mortazavi SM, Farzan M, Asadollahi S: Proximal tibiofibular
joint synovial cyst—one pathology with three different presen-
J. Neurosurg. / Volume 107 / August, 2007
11


29. Spinner RJ, Amrami KK, Angius D, Wang H, Carmichael SW: Peroneal and tibial intraneural ganglia: correlation between intraneurial compartments observed on magnetic resonance images and the potential importance of these compartments. \textit{Neurosurg Focus} 22(6):E17, 2007


42. Wadstein T: Two cases of ganglia in the sheath of the peroneal nerve. \textit{Acta Orthop Scandinavia} 2:221–230, 1931


Manuscript submitted August 9, 2006.
Accepted March 16, 2007.
Address reprint requests to: Robert J. Spinner, M.D, Mayo Clinic, 200 First Street SW, Rochester, Minnesota 55905. email: spinner.robert@mayo.edu.