Peroneal and tibial intraneural ganglia: correlation between intraepineurial compartments observed on magnetic resonance images and the potential importance of these compartments

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Object. Previously the authors demonstrated that peroneal and tibial intraneural ganglia arising from the superior tibiofibular joint may occasionally extend proximally within the epineurium to reach the sciatic nerve. The dynamic nature of these cysts, dependent on intraarticular pressures, may give rise to differing clinical and imaging presentations that have remained unexplained until now. To identify the pathogenesis of these unusual cysts and to correlate their atypical magnetic resonance (MR) imaging appearance, the authors retrospectively reviewed their own experience as well as the published literature on these types of intraneural ganglia.

Methods. A careful review of MR images obtained in 22 patients with intraneural ganglia located about the knee region (18 peroneal and four tibial intraneural ganglia) allowed the authors to substantiate three different patterns: outer (epifascicular) epineurial (20 cases); inner (interfascicular) epineurial (one case); and combined outer and inner epineurial (one case). In these cases serial MR images allowed the investigators to track the movement of the cyst within the same layer of the epineurium. All lesions had connections to the superior tibiofibular joint. Nine patients were identified as having lesions with sciatic nerve extension. Seven patients harboring an outer epineurial cyst (six in whom the cyst involved the peroneal nerve and one in whom it involved the tibial nerve) had signs of sciatic nerve cross-over, with the cyst seen in the sciatic nerve and/or other terminal branches. In only two of these cases had the cyst previously been recognized to have sciatic nerve involvement. In contrast, in one case an inner epineurial cyst involving the tibial nerve ascended within the tibial division of the sciatic nerve and did not cross over. A single patient had a combination of both outer and inner epineurial cysts; these were easily distinguished by their distinctive imaging patterns.

Conclusions. This anatomical compartmentalization of intraneural cysts can be used to explain varied clinical and imaging patterns of cleavage planes for cyst formation and propagation. Compartmentalization elucidates the mechanism for cases of outer epineurial cysts in which there are primary ascent, sciatic cross-over, and descent of the lesion down terminal branches; correlates these cysts' atypical MR imaging features; and contrasts a different pattern of inner epineurial cysts in which ascent and descent occur without cross-over. The authors present data demonstrating that the dynamic phases of these intraneural ganglia frequently involve the sciatic nerve. Their imaging features are subtle and serve to explain the underrecognition and underreporting of the longitudinal extension of these cysts. Importantly, cysts extending to the sciatic nerve are still derived from the superior tibiofibular joint. Combined with the authors' previous experimental data, the current observations help the reader understand intraneural ganglia with a different, deeper degree of anatomical detail.

KEY WORDS • epineurium • ganglion • intraneural cyst • mucinous degeneration • peroneal nerve • sciatic nerve • tibial nerve • unified theory

INTRANEURAL GANGLIA are rare nonneoplastic, mucinous cysts whose underlying mechanism for their formation has been poorly understood. Recent evidence supports a unifying articular theory based on an analysis of the most common form of these lesions—cysts arising from the superior tibiofibular joint.¹² Synovial fluid dis-

sects through a capsular rent and courses proximally up an articular branch within the epineurium into the common peroneal nerve more frequently than the tibial nerve, following the path of least resistance. Depending on pressure fluxes, cyst fluid will increase or dissipate.

Recent personal experience with two peroneal nerve cysts extending to the sciatic nerve provided us with an opportunity to identify a new pattern of cyst formation, that showing sciatic cross-over and descent down terminal branches. In these clinical examples with atypical MR

Abbreviations used in this paper: MR = magnetic resonance; MIP = maximum intensity projection.

FIG. 1. Schematic drawing showing the anatomy, pathoanatomy, and classification of different types of epineurial cysts.

imaging findings, we hypothesized that the cyst fluid would dissect within the outer (epifascicular) epineurium, ascend eccentrically within the common peroneal nerve, have the potential to fill the shared outer epineurium of the sciatic nerve, and then descend down the terminal branches.¹¹ Based on an earlier anatomical study¹⁹ we confirmed this phenomenon of cross-over and defined epineurial anatomical compartments in major nerves; moreover, we demonstrated in this experimental model that cyst fluid dissecting within the inner (interfascicular) epineurium may ascend within the peroneal or tibial nerve and continue to extend within these divisions of the sciatic nerve without cross-over.¹⁵ We predicted that combinations could also occur.¹⁵ Figure 1 summarizes the terminology that we adopted,¹¹ based on the usage of others,^{2,5,9,16,17} to correlate the epineurial anatomy and pathological conditions specifically for intraneural cysts.

We believe that careful evaluation and correlation of MR imaging findings will further elucidate propagation patterns, substantiate this anatomical classification of intraepineurial compartments, and deepen our understanding and refine our characterization of the cross-sectional pathoanatomy of these cysts.

Materials and Methods

A retrospective review of MR images obtained in patients with operative and histologically confirmed intraneural ganglia arising in the knee region was conducted to analyze specifically the imaging appearance associated with involvement of the various pathological epineurial layer(s) and to identify specific patterns of dissection in these cases. The majority of MR imaging studies were performed both with and without contrast enhancement.

In the past 5 years at our institution, a 3-tesla MR imaging unit was used during most examinations performed for this indication. In all cases images were available in the DICOM (Digital Imaging and Communications in Medicine) format for review on a clinical workstation (Advantage Workstation 4.3, General Electric Healthcare).

Results

Twenty-two patients were examined by a single musculoskeletal radiologist, who is experienced in the interpretation of MR images showing intraneural ganglia. The study cohort consisted of 20 patients who were consecutively treated at our institution during the past 10 years (12 of whom have been described in publications by our group¹³) and two other patients with tibial intraneural ganglia who were treated by other surgeons but were later included in case studies published by our group.^{6,14} Eighteen patients had peroneal intraneural ganglia and four had tibial intraneural ganglia. Sixteen of the patients with peroneal intraneural ganglia presented with symptoms and signs of various degrees of deep or complete peroneal nerve palsy. The two remaining patients had a peroneal nerve palsy as well as a subtle tibial nerve lesion. Three patients with tibial intraneural ganglia had tibial neuropathy alone, and one had moderate tibial and peroneal nerve dysfunction.⁶ All the cysts arose from the superior tibiofibular joint: from the anterior portion of the joint in cases of peroneal intraneural ganglia and from the posterior portion of the joint in cases of tibial intraneural ganglia.

Patterns of Epineurial Involvement

Our analysis revealed three different patterns of intraneural cyst involving the epineurium: outer epineurial (20

FIG. 2. Axial T2-weighted MR images obtained using fat suppression, showing the typical appearance of outer epineurial cysts. A: Classic features of a signet ring sign in association with a peroneal intraneural cyst (P). The cyst (*asterisk*) is located in the outer epineurium and the fascicles have been displaced (*upward arrow*). The joint connection to the anterior aspect of the superior tibiofibular joint is clearly seen (*downward arrow*). B: Initial preoperative appearance of a tibial intraneural ganglion (T). Note: the signet ring sign representing the crescentic displacement of nerve fascicles (*arrow*) by the cyst (*asterisk*) within the outer epineurium is analogous to the peroneal nerve finding shown in Panel A.

cases; Fig. 2), inner epineurial (one case; Fig. 3); and combined outer and inner epineurial cyst (one case). Classic outer and inner epineurial cysts maintained their basic configurations throughout their longitudinal extensions; the configuration could be seen whether the cyst existed alone or in combination. In all cases, we could track the cyst within the same epineurial compartment in the parent tibial and peroneal nerves. The spatial resolution achievable at the time of the clinical examination, even at a high field strength, did not allow the distinction of outer and inner epineurial cysts within the articular branches of the nerve near the joint.

The most commonly observed pattern was the outer epineurial cyst. This pattern corresponds to the previously described “signet ring” sign, which represents an eccentrically located cyst within the outer epineurium that displaces nerve fascicles in a crescentic fashion around the cyst (Fig. 2). This typically is seen in association with peroneal intraneural cysts and is best visualized within the common peroneal nerve just proximal to the trifurcation. It may also be seen with tibial intraneural ganglia.

We also observed that rarely cyst material may lie between individual nerve fascicles within the inner (interfascicular) epineurium (Fig. 3). In this retrospective review, we observed that the classic epineurial cyst (signet ring sign) and the inner epineurial cyst may exist either alone or in combination.

Sciatic Nerve Extension

We identified evidence of sciatic nerve involvement in nine of the 22 cases. In seven patients who harbored an outer epineurial cyst (six in whom the cyst involved the peroneal nerve and one in whom it involved the tibial nerve), signs of sciatic nerve cross-over were demonstrated, with evidence of the cyst in the sciatic nerve or other terminal branches. In only two of these seven patients were the cysts identified as having sciatic nerve extension on initial review; the characteristics of these cysts were

not identified prospectively by the referring physicians and were the subject of our initial report.¹¹ One patient in whom the lesion was previously reported to be an “intraneural ganglion of the sciatic nerve,”⁶ was determined to have an inner epineurial cyst involving the tibial nerve, which ascended within the tibial division of the sciatic nerve and did not cross over. In a single case both outer and inner epineurial cysts were present; their differing imaging patterns could be distinctively identified, but the sciatic nerve extension was not appreciated by us initially.¹⁴

In the nine patients whose cysts extended to the sciatic nerve, there appeared to be two basic patterns: 1) sciatic cross-over and descent of cyst material into the terminal branches of the sciatic nerve; and 2) no cross-over of the cyst but continued ascent of this lesion within the same primary division of the sciatic nerve as the nerve affected at the level of the superior tibiofibular joint.

In those patients whose cysts demonstrated sciatic nerve cross-over, all the lesions were outer epineurial cysts. Within this group we identified different types and extensions of outer epineurial ring cyst patterns. Within the outer epineurium of the sciatic nerve, the cyst could completely (Fig. 4) or partially (Fig. 5) encircle the sciatic nerve divisions. We also observed the cyst in the outer epineurium of terminal branches not affected by the primary cyst; for example, a peroneal intraneural ganglion arising from the superior tibiofibular joint could have a cyst involving the peroneal and distal sciatic nerves as well as the sural and tibial nerves (Figs. 4, 6, and 7).

In addition to the more classic signet ring cyst pattern, there was a partial or circumferential cyst within the outer epineurium with nerve fascicles sandwiched between these two types of outer epineurial rings of cysts (Figs. 6 and 7). This combination of cyst patterns was only seen in the nerve primarily affected.

A single patient harbored a cyst with inner epineurial extension and sciatic nerve extension but no sciatic cross-over (Figs. 3 and 8). There was no evidence of the cyst within other terminal branches on available imaging stud-

ies. Another patient had both outer and inner epineurial cysts that displayed distinctive imaging patterns for each on MR images. On serial axial images it was clear that there was a small inner epineurial cyst within the tibial nerve that did not communicate with the outer epineurial cyst. The inner epineurial cyst displayed a more constrained appearance with a limited longitudinal extension compared with the outer epineurial cyst, which extended to the sciatic nerve. The cross-over of the outer epineurial cyst was evidenced by the incomplete circumferential outer epineurial cyst at the level of the sciatic nerve and a complete outer epineurial ring around the tibial nerve, indicating descent along the terminal branches of the sciatic nerve.

Discussion

In this paper we report our analysis of a relatively large number of cases in which we focused on atypical MR imaging findings seen in intraneural ganglia to support the concept of intraepineurial compartments and to highlight their potential importance. These intraneural cysts share common principles of their formation: namely, an articular branch connection from a degenerated joint and dissection of fluid along a path of least resistance dependent on pressure fluxes. The differences in the cleavage plane and subsequent longitudinal propagation leads to different phenotypes: an outer epineurial and an inner epineurial pattern. Based on our cases and a review of the literature, the outer epineurial pattern is much more common than the inner epineurial variant, from which we can infer an inherently preferred path of least resistance. As the outer epineurial cysts ascend they take on an eccentric pattern (producing the signet ring sign). These cysts may have loculations that give them a somewhat different appearance on consecutive images, whereas the inner epineurial cysts directly displace fascicles within a more constrained inner epineurium, providing a more consistent cylindrical appearance or geographic placement between nerve fascicles on serial images. Moreover, the outer epineurial cysts have the capacity of sciatic nerve cross-over and subsequent descent down different terminal branches, producing a complex appearance of multicyst intraneural involvement all derived from a single joint of origin. In contrast, inner epineurial cysts without outer epineurial involvement do not cross over and may continue to ascend (or descend) within the same affected nerve or division.

We were able to further refine our understanding of MR imaging findings and signs: the signet ring sign was present within the affected nerve in all cases of outer epineurial cysts. In cases in which the cyst did not reach the sciatic nerve, the signet ring sign was suggestive of ascent (and presumably also descent based on pressure fluxes) within the nerve primarily affected. Fascicles were displaced eccentrically in the expected pattern. The signet ring sign was not present in the one patient with an isolated inner epineurial cyst.

The outer epineurial pattern of cyst seen in patients with sciatic cross-over has a distinctive and reproducible imaging appearance. This type of outer epineurial cyst is not solely eccentrically located within the epineurium, in contradistinction to the typical signet ring sign. It can form either a complete or partial ring of cyst around the sciatic

FIG. 3. Example of an inner epineurial cyst. Axial T2-weighted image showing a cyst within the tibial nerve (T) below the sciatic bifurcation. Note: the normal common peroneal nerve (P) is at the same level. Although difficult to appreciate on this image, the cyst within the tibial nerve is an inner epineurial one, and its appearance differs from that of the outer epineurial cyst shown in Fig. 2. More proximal images obtained in this patient are seen in Fig. 8. This patient, who previously was described by Krishnan and Schackert, presented with a sciatic neuropathy. We previously hypothesized and then demonstrated (Spinner et al: *Skeletal Radiol*, 2007) that the patient had a tibial intraneural cyst and a posterior joint connection to the superior tibiofibular joint.

nerve and its divisions when sciatic cross-over is present, as well as a signet ring sign in the “primary” nerve proximal to the joint origin. We have termed this finding the “wedding ring” sign to distinguish this pattern of intraneural cyst extension in which the cyst either partially or completely encircles the nerve within the outer epineurium. When the wedding ring sign is present it can involve the sciatic, peroneal, tibial, or sural nerves in combination or alone, independent of the location of the primary cyst—the common process is outer epineurial extension to the sciatic nerve. In these cases the combination of these two cyst types’ appearances (signet ring and wedding ring) leads to axial MR imaging of a “ring-within-a-ring” appearance. We have observed a spectrum of outer epineurial cyst appearance, having the signet ring and a coexistent wedding ring of cyst within the sciatic nerve. At its most extreme representation (Fig. 4), there is a merging of the two outer epineurial types of cyst to form a very prominent ring of cyst encircling the terminal branches of the sciatic nerve. More commonly these two forms of outer epineurial cyst coexist in configurations in which the individual parts are easily identifiable on MR images (Figs. 5–7). On serial axial MR images (specifically T2-weighted images obtained with fat suppression) it is possible to

FIG. 4. Magnetic resonance images showing outer epineurial cysts. This was our first patient with atypical MR imaging in whom we recognized obvious evidence of sciatic extension of a peroneal intraneural cyst. The images demonstrate features of the progression of an outer epineurial cyst extending from the superior tibiofibular joint up the peroneal nerve into the sciatic nerve. Within the sciatic nerve, however, there is cross-over and descent. Axial T2-weighted images obtained using fat suppression at the level of the distal sciatic nerve (A), just below the bifurcation (B), and just proximal to the knee (C). The most proximal image (A) shows a cyst circumferentially surrounding the tibial and peroneal divisions within the distal sciatic nerve (*large arrow*). B: Just distal to this site two separate cysts can be seen surrounding the tibial (*thin arrow*) and common peroneal (*arrowhead*) nerves. Note the lateral sural cutaneous nerve adjacent to the peroneal nerve within the same cyst. C: On the most distal image separate cysts are seen surrounding the tibial (*thin arrow*), lateral sural cutaneous (*curved arrow*), and peroneal (*arrow with tail*) nerves. Very subtle but present is a small outer epineurial component within the common peroneal nerve, confirming that this is the primary nerve of involvement and representing the ring-within-a-ring pattern. The classic outer epineurial appearance within the peroneal nerve is better seen distally (demonstrated in Spinner et al: *J Neurosurg* 107, 2007 [in press]).

appreciate the relationship of these two outer epineurial cyst patterns because both may be seen in the same single image. Because of limitations related to spatial resolution in visualizing a cyst within the distal sciatic nerve and given the proximal aspect of its terminal branches and the challenge of imaging a dynamic process by using static imaging, the presence of sciatic cross-over was established directly when visualized or indirectly in those cases in which the wedding ring sign was appreciated to involve any of the terminal branches under discussion. In the primarily affected nerve, there was evidence of a more complex pattern of cyst within the outer epineurium that could also extend into the sciatic nerve. These findings, along with the classical signet ring sign, are best seen on axial T2-weighted images obtained with fat suppression, and the longitudinal extension of the cyst is best seen on coronal images, which may require postprocessing with MIP to be visualized on a single image. The relation of the ring-within-a-ring appearance to the primary intraneural cyst can be appreciated on images by examining them inferior to superior in the direction of cyst extension, despite the limitation of visualizing a dynamic process by using static imaging. When the wedding ring sign is present, the converse is true—the extent of this phenomenon is followed from superior (its most proximal extent in the sciatic nerve) to inferior along its path of extension after crossing over at the common point in the sciatic nerve, so that even when the two types of outer epineurial cysts are seen on a single image, it is clear that the direction of cyst extension for each is different. The primary direction of cyst propagation, therefore, is inferred from the consistently more common signet ring sign appearance, which is distal, near the joint origin, whereas the wedding ring sign

is usually more visible and more likely to be complete closer to the sciatic nerve and the sciatic bifurcation. This does not imply that superoinferior flow occurs exclusively within a specific single subtype of outer epineurial cyst. In fact, the presence of descent within more than one subtype of outer epineurial cyst seems likely, given basic principles of fluid dynamics, but this cannot be visualized without the benefit of serial imaging examinations over time. These imaging findings, from which we infer directionality, are always best appreciated on high-resolution T2-weighted images obtained with fat suppression, but complementary proton-density and T1-weighted images can help us infer the primary directional nature of the cyst extension when the ring-within-a-ring configuration is present. Viewing the images as a “stack” of serial images allowed us to make this inference due to the consistent and reproducible patterns of the course of the nerves. Even a few consecutive images may not show the complete extent of the process involving the sciatic nerve and its proximal terminal branches, or alternatively, may not reveal the presence of a “skip” lesion or demonstrate its relationship to the parent cyst.

Inner epineurial cysts have an imaging appearance that can be easily distinguished from the more common outer epineurial pattern. A cyst in this configuration has a different pattern, with displacement of the nerve fascicles within a more constrained inner epineurium, giving the appearance of a cyst between fascicles rather than displacing them eccentrically as in the signet ring sign. This appearance can be seen on axial imaging, but its longitudinal extension within the nerve may be viewed better on sagittal, coronal, or oblique images. Because of the often subtle appearance between what may be irritated and hyperintense nerve fascicles, visualization may require spe-

FIG. 5. “Ring-within-a-ring” pattern. A retrospective review of MR images, obtained in a patient thought to have a typical peroneal intraneural ganglion, revealing subtle evidence of unrecognized sciatic nerve involvement. The findings are visible despite the age and technical limitations of the MR imaging examination. A: Axial T2-weighted image, obtained using fat suppression at the level of the distal sciatic nerve (S), showing an incomplete outer wedding ring sign of sciatic cross-over from a peroneal intraneural cyst (arrow). B: A photographic enlargement of the image seen in panel A. C: Axial T2-weighted image, obtained using fat suppression at the level of the superior tibiofibular joint, demonstrating the classic signet ring sign of an intraneural cyst (asterisk) as well as an incomplete wedding ring sign (arrow) compatible with cyst extension to the sciatic nerve and cyst descent. Also seen is the transverse limb sign of a cyst along the articular branch (curved arrow) as well as the tail sign confirming origin from the joint.

cial sequences or postprocessing to best elucidate the course of the cyst within the nerve. The inner epineurial cyst may sometimes assume a crescent or elliptical shape between fascicles, potentially leading it to be mistaken for the signet ring sign of an outer epineurial cyst, but close inspection with high-resolution imaging should permit this distinction to be made. A definitive imaging characterization is not possible given the small number of cases with this pattern in our series.

In a single case this unusual inner epineurial pattern coexisted with the more common outer epineurial cyst. In this case the combined pattern was seen after an initial incomplete surgery was followed by clinical evidence of cyst recurrence. The initial preoperative images showed a classic signet ring sign and the usual appearance of an isolated outer epineurial cyst. A comparative review of the pre- and postoperative images showed a very different pattern, with a new finding of inner epineurial cyst in addition to the recurrent outer epineurial cyst. This change in appearance suggests that the pressure dynamics and the path of least resistance were altered by surgery, resulting in a different imaging pattern of cyst extension.

We believe that the sequence of events for intraneural cyst extension is as follows: First, the cyst fluid extends from a rent in the joint capsule intraepineurially within the respective articular branch from the superior tibiofibular joint of either the peroneal or tibial nerve. With increased intraarticular pressure the cyst extends and propagates superiorly along the path of least resistance to the parent nerve. The cyst constrained to the outer epineurium assumes an eccentric pattern (the signet ring sign). With sufficient superior extension, the cyst may reach the sciatic nerve, where with adequate pressure and filling of the common epineurial sheath of the sciatic nerve it may cross over to involve the opposite division of the sciatic nerve, encircling the nerve within its outer epineurium (the wedding ring sign), again following the path of least resistance within a different portion of the outer epineurium. With dynamic pressure gradients, the cyst may descend down

any of the terminal branches of the sciatic nerve within the outer epineurium, continuing a complete or partial wedding ring sign that by location and appearance must involve the outer epineurial compartment. Because of the different tracks within the outer epineurium, there may be imaging evidence of both outer epineurial processes within the parent nerve of the primary cyst involvement; for example, a cyst ascending a nerve to the sciatic nerve with cross-over may have the imaging features of both the original eccentric cyst (signet ring sign) in the primarily affected nerve and outer epineurial ring involvement (wedding ring sign) related to sciatic cross-over and cyst descent to this level of the primary cyst. This leads to a ring-within-a-ring appearance that seems characteristic of this entity, in which the nerve fascicles are sandwiched between the two rings. In contrast the inner epineurial cyst does not have the capacity or path to cross over to the other nerve and would be expected to continue to ascend or descend within a specific nerve or division of the sciatic nerve, depending on the pressure dynamics; based on this observation, if an isolated inner epineurial cyst is seen within a division of the sciatic nerve, it must necessarily arise from that same nerve more distally. The multilaminar appearance that we have observed¹⁰ could represent a cyst extending along a path of least resistance with multiple compartments within the epineurium or within a single compartment (as in the ring-within-a-ring sign) depending on the plane of section and the effects of pressure fluxes.

This work represents a refinement into further subtypes of intraneural ganglia as our understanding has been augmented by experimental studies and further clinical experience. These imaging characteristics allow us to provide an additional cross-sectional analysis of signs that we previously reported. This is most helpful for cases of peroneal or tibial intraneural ganglia extending to the sciatic nerve. The “transverse limb” sign we previously described remains a pathognomonic finding for peroneal intraneural ganglia and the “tail sign” still is the definitive imaging feature of cyst origin from the joint (although this latter

FIG. 6. “Ring-within-a-ring” pattern. Magnetic resonance images obtained in a patient with a peroneal intraneural ganglion. Careful review revealed direct evidence of sciatic cross-over. There is an outer epineurial cyst in the peroneal and tibial divisions at the level of the distal-most sciatic nerve (the highest axial image obtained). More distally, the ring-within-a-ring pattern is seen well in panels B and C, with the signet ring portion tracking upward, the wedding ring portion tracking downward within the peroneal nerve, and a wedding ring pattern in the tibial nerve. A: Axial fast spin echo (FSE) T2-weighted image obtained using fat suppression at the level of the sciatic bifurcation. B: A photographic enlargement of the highlighted area around the sciatic nerve in panel A. The enlarged image demonstrates an outer epineurial cyst (asterisk indicates signet ring sign) within the peroneal division (arrows indicate wedding ring sign) of the sciatic nerve. In addition, an outer epineurial cyst extends circumferentially around the peroneal division (arrows), including the septation dividing the peroneal and tibial (T) divisions of the nerve and incompletely along the anterior outer epineurium of the tibial division of the sciatic nerve (arrowheads). C: Axial T2-weighted image, obtained using fat suppression just above the knee, showing a ring-within-a-ring sign (asterisk indicates signet ring sign and arrow indicates an incomplete wedding ring sign) involving the peroneal nerve (P) and a wedding ring sign (arrowhead) (P) in the tibial nerve (T), confirming cross-over of the outer epineurial cyst at the sciatic nerve level and descent of the cyst to involve both nerves. D: Axial T2-weighted image, obtained using fat suppression just proximal to the superior tibiofibular joint, showing a classic outer epineurial cyst (asterisk indicates signet ring sign) within the common peroneal nerve (P) with an associated wedding ring sign (arrow) related to sciatic cross-over.

sign is present in extraneural joint-related ganglia as well).¹³ Further improvements in imaging may allow identification of these subtypes of intraneural cyst at the level of the articular branch of the nerve, which is beyond the ability of any current MR imaging technology in a clinically acceptable acquisition time.

We are gratified to have identified examples of these imaging signs in patients in our previously published experience and in the literature with unrecognized or recognized sciatic nerve involvement. In a recent case of peroneal intraneural ganglion we identified an unreported sciatic extension of a cyst with outer epineurial involvement (ring-within-a-ring and wedding ring signs) and descent down the tibial nerve, confirming cross-over at the level of the sciatic nerve (Fig. 7).¹ In two cases of tibial

intraneural ganglia,^{8,18} we identified the ring-within-a-ring pattern in published MR images from which we inferred unrecognized sciatic nerve involvement. In two cases—one in which no MR images were available but the surgical findings revealed cystic involvement of only the peroneal component of the sciatic nerve from the knee to the buttock^{3,5,20} and another in which limited computed tomography scanning available in the report showed definite sciatic involvement but the operative notes only mentioned involvement of the tibial division⁷—we can consider the following: 1) the cyst was isolated to the inner epineurium; 2) the cyst was in the outer epineurium and there was a high sciatic bifurcation; and 3) the cyst was in the outer epineurium and an unrecognized cyst was present in other nerves. The vast majority of clinical symp-

FIG. 7. Reinterpretation of a previously reported case of peroneal intraneural cyst demonstrating unrecognized sciatic nerve extension with cross-over as well as a superior tibiofibular joint connection (A–D modified from Bonar SF, Viglione W, Schatz J, Scolyer RA, McCarthy SW: An unusual variant of intraneural ganglion of the common peroneal nerve. *Skeletal Radiol* 35:165–171, 2006, with kind permission of Springer Science and Business Media; panels E and F are from a review of original films in the same case). A: Axial T1-weighted image of a site above the knee showing a low-signal-intensity cyst (*asterisk*) arising from the epineurium of the common peroneal nerve (P). The nerve fascicles are displaced by the outer epineurial cyst (signet ring sign, *arrowhead*). There is some suggestion of a subtle incomplete outer ring sign within the tibial nerve (T), which is better demonstrated on the corresponding T2-weighted images (B and C). B: Axial T2-weighted FSE MR image of a site slightly proximal to that shown in panel A, obtained using fat suppression, demonstrating a hyperintense cyst (*asterisk*) within the common peroneal nerve (P; the signet ring sign) in addition to an outer circumferential epineurial cyst (the wedding ring sign, *arrows*) related to sciatic cross-over, which together constitute the ring-within-a-ring sign of bidirectional cyst extension. Note the fascicles sandwiched between the two outer epineurial rings posteriorly (*arrowhead*). Additional fascicles are seen between the two rings anteriorly as well. Note also the presence of a cyst within the outer epineurium of the tibial nerve (T; wedding ring sign) confirming sciatic cross-over from the primary cyst within the peroneal nerve. C: A photographic enlargement of the image shown in panel B. D: Coronal T2-weighted FSE obtained using fat suppression depicting cephalad extension of the intraneural cyst along the peroneal nerve (*asterisk*) toward the sciatic bifurcation. The origin and proximal extension of the cyst are not included on this image. E: Axial T2-weighted FSE image obtained using fat suppression showing the origin of the cyst at the anterior portion of the superior tibiofibular joint (*arrow*) as well as the portion of the cyst within the common peroneal nerve (*asterisk*). The part of the cyst within the transverse limb of the articular branch could not be appreciated due to the limited inferior extent of imaging. Additional cyst fluid can be seen extending posteriorly from the superior tibiofibular joint (*arrowhead*). F: Contrast-enhanced sagittal T1-weighted image, obtained using fat suppression at the lateral aspect of the leg, demonstrating the cyst connection to the anterior portion of the superior tibiofibular joint (*arrow*).

toms associated with intraneural cysts can easily be understood by compression of nerve(s) by the cyst. In this series, those patients with intraneural cysts that did not demonstrate any imaging abnormalities suggestive of sciatic nerve extension presented with neuropathy of the primary nerve. Two patients harboring an outer epineurial cyst with MR imaging evidence of sciatic nerve cross-over had only minimal clinical signs in the “other” division of the sciatic nerve: in one case the MR images showed prominent terminal branch descent (Fig. 4) and in the other case the appearance was more subtle (Fig. 6). This fact suggests that cyst involvement in the other nerve division may often be subclinical. Moreover, we did observe that one of the patients who harbored an inner epineurial cyst without cross-over had symptoms and findings in the “other” nerve division⁶ that could not be easily explained. Although we noted that the cyst in this

patient only affected the tibial nerve and the tibial division of the sciatic nerve without evidence of an inner or outer epineurial cyst in the peroneal division (or other terminal branches), we noted hyperintensity and edema in the peroneal fascicles within the distal sciatic nerve, a finding that represents mechanical irritation of the neighboring nerve by the cyst because the alternate mechanism of cross-over would not be anticipated.

In this report, we demonstrate that cystic extension into the sciatic nerve is underreported and may go underrecognized due to inadequate visualization of the proximal extension of the cysts within the sciatic nerve and in the “other” seemingly unaffected divisions of the sciatic nerve. In previous publications, we demonstrated however, that such cysts within the distal thigh are not primary “intraneural ganglia of the sciatic nerve”^{6,7} and are not de novo in nature, but are extensions of distal cysts arising from

FIG. 8. Magnetic resonance images showing an inner epineurial tibial division cyst within the sciatic nerve (from the same patient whose images are shown in Fig. 3, whose case was previously reported by Krishnan and Schakert and reinterpreted by us (Spinner et al., *Skeletal Radiol*, 2007). A: Axial T1-weighted image, obtained at the level of the mid-thigh, demonstrating the left tibial division (T) of the sciatic nerve with a cyst and the peroneal division (P) without a cyst (arrowhead). Note the normal tibial and peroneal divisions of sciatic nerve on the right. B: T2* image showing an inner epineurial cyst within the tibial division of the left sciatic nerve (T). The peroneal division (P) does not contain any cyst; however, several hyperintense fascicles are noted that can be seen better on other images (not shown). C: Axial T1-weighted image obtained just above the knee showing a cyst within the left tibial nerve (T; arrow) and a completely normal common peroneal nerve (P). Compare the findings with those on the right side. The corresponding T2-weighted image (Fig. 3) confirms that this cyst is an inner epineurial one. D: Coronal T2-weighted FSE MIP image, obtained using fat suppression, demonstrating previously unrecognized cyst at the posterior portion of the left superior tibiofibular joint (asterisk) and a cyst within the tibial division of the left sciatic nerve (arrow) in the thigh.

joints.¹⁴ We¹¹ confirmed a previously unrecognized joint connection in three other reported cases that had sciatic nerve extension by reinterpretation of the original MR images (Fig. 7).^{1,4,6} In one of these cases, according to the operative note, there was obvious involvement of multiple nerves consistent with sciatic cross-over from an outer epineurial cyst despite the lack of intraoperative confirmation of a joint connection.⁴ In another one of these cases¹, cyst involvement of another terminal branch was far more subtle (Fig. 7). Moreover, a patient whose case was reported longer than 75 years ago, in whom a joint connection was not noticed at the operation, had recurrence at the fibular neck region confirmed at a later operation,²⁰ a finding that we have seen previously when the joint of origin is not completely treated.

The location of epineurial cysts (that is, outer and/or inner) is maintained throughout their longitudinal extension, and can be distinctively seen; however, current clinical MR imaging, even at a high field strength, does not provide sufficient resolution to see this lesion distal to the level of the trifurcation of the common peroneal nerve. Nevertheless, it can be easily identified proximal to this site, where the nerves and cysts are typically larger. Al-

though it is tempting to speculate that the cleavage occurs at the level of the joint capsule, we are unable to substantiate this based on current imaging and histological limitations. The fact that these findings could be demonstrated in different cysts of primary origin involving different nerves (i.e., peroneal and tibial intraneural ganglia) suggests a common mechanism for formation that could apply to other nerves and other joints.

The major strength of this study is also its Achilles heel. This study lends further evidence to support bidirectional flow dependent on pressure fluxes, thereby highlighting the dynamic process in the formation and propagation of intraneural ganglia. Still the presence and prevalence of dynamic phases in intraneural ganglia, as illustrated in this study, is limited by the static MR images obtained at isolated points in time, which may not reflect the full spectrum of pathology in a given patient. Other limitations include the small number of patients with documented cyst extension into the sciatic nerve; the current limitations on spatial resolution of MR imaging, even with optimally performed examinations at 3-tesla, which are achievable in clinically reasonable imaging times; and the lack of correlative surgical pathology.

Conclusions

We have identified additional subtypes of intraneural cysts that display different imaging patterns and have differing clinical significances. We have shown that cysts may extend into the outer epineurium, inner epineurium, or a combination depending on cleavage planes within the nerve. Classic outer epineurial cysts (those demonstrating the signet ring sign) may ascend to the sciatic nerve and then cross over and descend into any of the terminal branches of the sciatic nerve within the outer epineurium (wedding ring sign). Inner epineurial cysts seem to be rare and appear to be confined to the inner epineurial compartment; they may ascend to the sciatic nerve but will maintain their location within a specific division of the nerve. These findings, while complex, are reproducible on MR images and reflect a refined understanding of the pathogenesis of intraneural cyst formation and propagation. Prospective recognition of these patterns is possible and will help direct appropriate treatment.

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