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CLINICAL ARTICLE

Extreme subparaneurial ganglion cysts. Part 2: The geyser theory as a mechanistic explanation for crossover

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OBJECTIVE Extreme subparaneurial ganglion cysts are poorly understood. In Part 1, the authors demonstrated that patterns of distribution in the subparaneurial space are consistent with the principles of the articular theory for intraneural ganglion cysts (INGCs). How a cyst transfers from the subepineurial to the subparaneurial compartment remains to be determined. In this part, the authors provide evidence supporting that cyst transfer occurs at the sciatic nerve bifurcation based on MRI and histological analysis, and introduce the geyser theory as an explanation for the redistribution of cysts.

METHODS The authors analyze MR images obtained in patients with extreme subparaneurial cysts as well as newly identified cases of nearly extreme subparaneurial cysts (i.e., cysts visible in the subparaneurial compartment but not to the extreme degree as defined in Part 1) for potential crossover sites. They also analyze histological sections from 10 cadavers around the sciatic nerve bifurcation for the presence of openings in the epineurium and paraneurium.

RESULTS MRI studies performed in 8 patients in Part 1 and 8 newly identified examples with nearly extreme subparaneurial INGCs showed evidence to support communication between different compartments at the sciatic nerve bifurcation (subepineurial-to-subparaneurial and subparaneurial-to-neighboring soft tissues). Openings in the epineurium of the common peroneal and tibial nerves at the sciatic nerve bifurcation were consistently found in all 10 cadaver specimens, as were openings in the paraneurium.

CONCLUSIONS The authors expand on the evidence to support cyst redistribution at the sciatic nerve bifurcation for INGCs in the knee region. They put forth a logical explanation for the development of a spectrum of extreme INGCs (ranging from a faint amount of cyst around the epineurium [wedding ring sign] to extreme subparaneurial INGCs [owl eyes]) based on principles seen in a geyser. The authors believe that radiological occurrence of crossover can be explained by the presence of fenestrations in both the epineurium and paraneurium at the sciatic nerve bifurcation, allowing cyst crossover in two steps: from the subepineurial to the subparaneurial space ("cross") and between a shared subparaneurial space of different nerves ("over"). Finally, the frequent occurrence of extraneural rupture ("cross-out") is due to cyst transfer into the soft tissue compartment via an opening in the outermost circumneurial layer.

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KEYWORDS peripheral nerve; intraneural; ganglia; MRI; histology; pathophysiology; mechanism; tumor; neurosurgical education

Extreme subparaneurial cysts are intraneural ganglion cysts (INGCs) that have a substantial volume of circumferential cyst in the subparaneurial space around the epineurium of nerve(s) with the potential for extensive longitudinal propagation within this space. For example, a peroneal INGC arising from the superior tibiofibular joint (STFJ) can propagate up the common peroneal (fibular) nerve (CPN) and at sciatic nerve bifurcation cross over to the proximal tibial nerve (TN) through a shared subparaneurial space: crossover at the sciatic nerve bifurcation in which a cyst can extend long distances up and down (proximally in the sciatic nerve) or distally

ABBREVIATIONS CPN = common peroneal nerve; INGC = intraneural ganglion cyst; STFJ = superior tibiofibular joint; TN = tibial nerve.

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along the branches of the TN and CPN. In Part 1, we described the occurrence and MRI features of these extreme subparaneurial cysts and demonstrated the different neural layers intraoperatively (case 8, Fig. 5G and H in Part 1).[1] We explained how this extreme type of INGC follows the principles of the articular theory regarding its formation, propagation, and treatment.

In this paper, we provide radiological and anatomical data and a pathophysiological explanation to substantiate the mechanism by which crossover occurs:[2] first, transfer of cyst from the subepineurial to the subparaneurial compartment occurs, and then, transfer between different subparaneurial compartments at the level of the sciatic nerve bifurcation takes place. We liken the sequence of events to the phenomenon of a geyser (Fig. 1) to explain these unusual features of extreme subparaneurial cysts, notably their sudden expansion and quick disappearance. An ascending subepineurial cyst coming from the joint (CPN) (Fig. 1A) and under pressure bursts into the subparaneurial space at the sciatic nerve bifurcation (Fig. 1B), spreads (potentially quickly and extensively) (Fig. 1C), and disappears again (Fig. 1D).

Methods

In this paper, we designed a radiological (MRI) and histological investigation of the site of and mechanism for subepineurial-to-subparaneurial communication.

MRI Analysis

To investigate potential intracompartmental communication sites, all MRI studies of the cases presented in Part 1[1] were reanalyzed to find evidence for subepineurial-to-subparaneurial extension. The MR images of all cases presented in Part 1—4 novel cases of extreme subparaneurial ganglion cysts (3 peroneal from the STFJ and 1 tibial from the knee) and 4 previously reported cases (3 from the senior author, 2 of which were peroneal from the STFJ and 1 that was tibial from the STFJ,[3–5] and 1 case from Kim et al.[6] [peroneal from the STFJ])—were reanalyzed for evidence for and location of transfer from the subepineurial to the subparaneurial compartment on T2-weighted coronal, sagittal, or axial images. In 1 case, an MR arthrogram had been obtained, which was analyzed separately. We were inspired by a previously published case of our group[7] to demonstrate the longitudinal extent of a peroneal INGC arising from the anterior aspect of the STFJ. MRI was recognized as having a subtle wedding ring sign, suggestive of crossover at the sciatic nerve bifurcation, which, to our surprise, demonstrated years later unrecognized communication of the cyst between the subepineurial and subparaneurial compartments (Fig. 2). We suspected that there was a spectrum of extreme INGCs and a shared mechanism for crossover.

Based on our analysis of sequential MR images in several of our cases of extreme subparaneurial ganglion cysts (e.g., case 3, Fig. 3 in Part 1[1]), we recognized that there existed a subgroup of patients who had unusual radiological features, with radiological features beyond a faint wedding ring sign suggestive of crossover of extreme INGCs, but who did not meet our strict criteria for an extreme subparaneurial cyst, as presented in Part 1 (Fig. 2). From the clinical registry of the senior author consisting of 129 cases of peroneal and tibial INGCs in the STFJ/knee region, 8 cases of INGCs were identified: 3 peroneal (2 arising from the STFJ and 1 from the knee) and 5 tibial (3 from the STFJ and 2 from the knee). This cohort included several patients who were previously featured for different reasons by our group[8–10] and others.[11,12]

MR images were reviewed by neurosurgeons (G.C.W.D.R. and R.J.S.) and confirmed with radiologists with fellowship training and experience with INGCs (K.K.A. and B.M.H.). Evidence for the presence and location of a communication between the subepineurial and subparaneurial compartments was determined by the presence of a continuous cyst on MRI or contrast on MR arthrography between the compartments, including free flow connecting signet ring signs in the proximal CPN and TN and wedding ring or owl-eye signs (in the CPN and tibial and sciatic nerves). The relative dimensions of subepineurial and subparaneurial cysts near the sciatic nerve bifurcation were assessed.

Histology

An expert anatomist (M.A.R.) analyzed histopathological sections that had been obtained on the entire trajectory of the sciatic nerve and its distal branches to determine the presence of fenestrations in the epineurium of the CPN and TN at the sciatic nerve bifurcation, the sciatic epineurium, and outer paraneurial or circumneurial layers surrounding the sciatic nerve. A detailed description of the methodology has been previously reported.[13] Ten lower limbs from fresh unembalmed and cryopreserved human cadavers were studied. The sciatic nerve, CPN, and TN were then identified and the entire trajectory carefully dissected, from the middle femur region to the fibular neck. The samples included all adjacent tissue such as the concentric fat compartment, successive paraneuria, vessels, epimysium, and muscle. The study was performed by an expert in dissection (X.S.B.).

In the evaluation of the slides, specific attention was paid to the integrity and continuity of the different collagen membranes around the fascicles and nerves. Details on the interpretation of the different layers are provided in the figure legends, as well as analysis of potential fenestration sites. Potential openings in the layers were looked for, and specifically the level, in relation to the sciatic nerve bifurcation in a longitudinal plane and the location in an axial plane. The amount of fat tissue and space between the TN and CPN at the fenestration was analyzed.

Results

MRI Analysis

MRI analysis of the 8 extreme cases presented in Part 1[1] showed communications between subepineurial and subparaneurial compartments at the sciatic nerve bifurcation in 3 cases (cases 1, 5, and 7 in Part 1; Figs. 3 and 4 in the current paper). In all cases, at the sciatic nerve bifurcation, the size of the subepineurial cyst was quite diminutive compared with the subparaneurial cyst. In one of these cases (case 7 in Part 1), an MR arthrogram showed a communication slightly proximal to where it was seen on MRI a few weeks earlier. The arthrogram showed faint

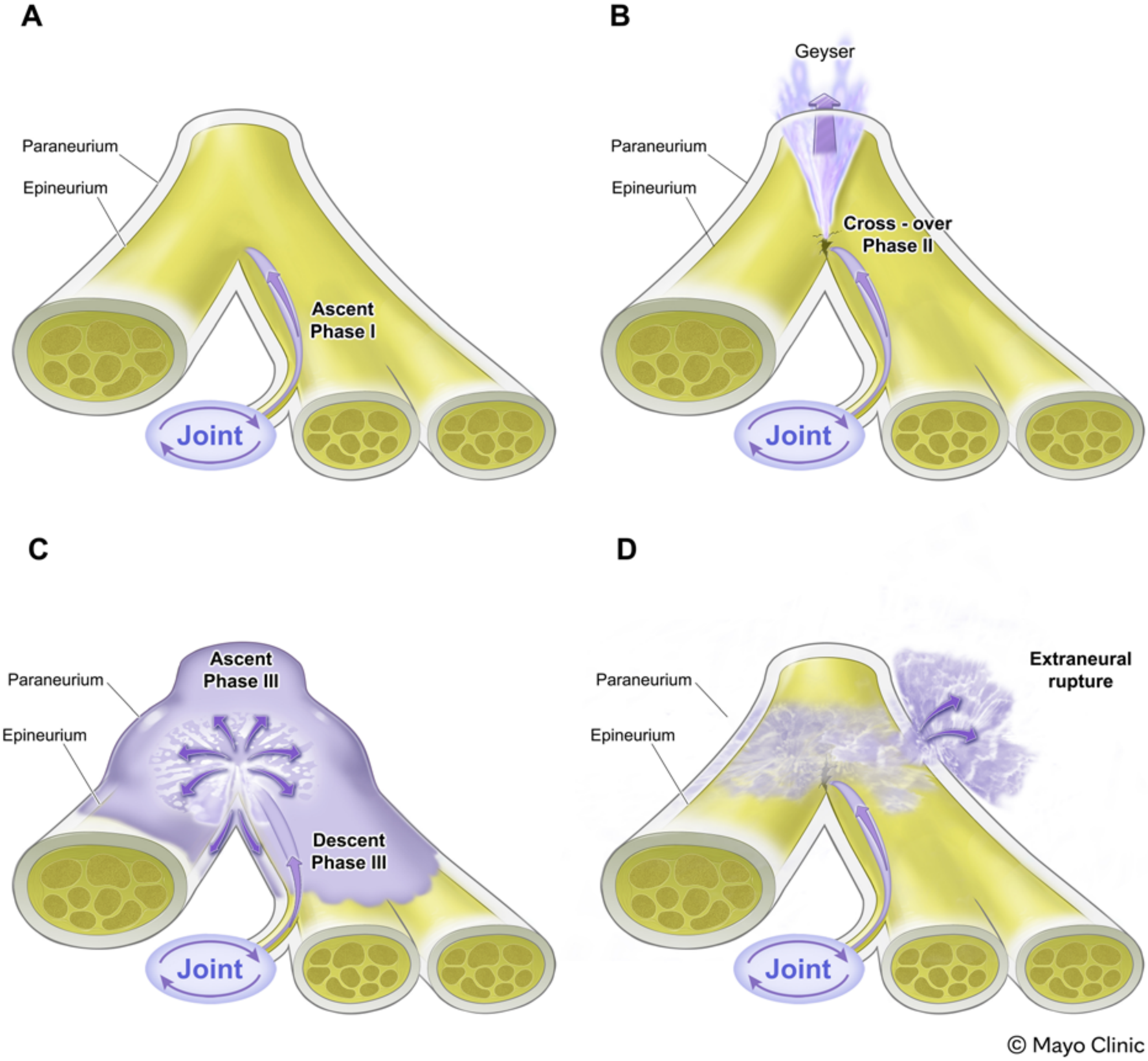

FIG. 1. Illustration of the different phases of cyst distribution from the STFJ to the CPN and the geyser theory explaining the rapid development of extreme subparaneurial cysts. As a geyser is caused by a hot spring, the source for the development of extreme INGCs is the joint—the fundamental principle of the unifying articular theory.[24] **A:** Fluid coming from the joint (either the STFJ or the knee) egresses through a capsular defect in the articular branch and is propelled upward into the CPN (or TN) (phase I). This subepineurial cyst can be compared to the ascending channel of a geyser below the earth. **B:** The buildup of pressure in the tract in the CPN leads to rapid eruption akin to a geyser. Cyst transfers from the subepineurial to the subparaneurial space at the level of the bifurcation, which also leads to crossover in phase II. **C:** The increased pressure, as in the geyser, can lead to rapid expansion and redistribution of cysts between nerve and soft tissue compartments. Pressure moves from high pressure to lower pressure, and the subparaneurial compartment (a potential space) has the ability to expand. This can lead to ascending of the cyst within the subepineurial space and/or transferring from the subepineurial to the subparaneurial compartment and between the shared subparaneurial compartments of different nerves (with cyst surrounding the nerves circumferentially)—ascent and descent in phase III. **D:** Finally, extraneural cyst rupture or transfer of cyst can occur at the sciatic nerve bifurcation, as observed in Part 1,[1] allowing the cyst to communicate between the paraneurium and surrounding soft tissues, leading to a decrease in the extreme volume of subparaneurial cyst. With the distribution of pressures, cyst deflation occurs in the subepineurial compartment.[14] The life cycle of the subparaneurial cyst (A–D) also resembles that of a geyser. It starts with a small eruption of cyst into the subparaneurial space, like the first blip of water that is sometimes seen in a geyser before it erupts. In the middle of the cycle, as in the full eruption of the geyser, there is an extreme distribution in both extension and distance. At the end of the life cycle, if the cyst has erupted into the extraneural space or if cyst fluid has been spontaneously resorbed, the cyst may disappear again, leaving only small remnants of cyst in the subparaneurial compartment and surrounding tissues, like the wet earth around an erupted geyser. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

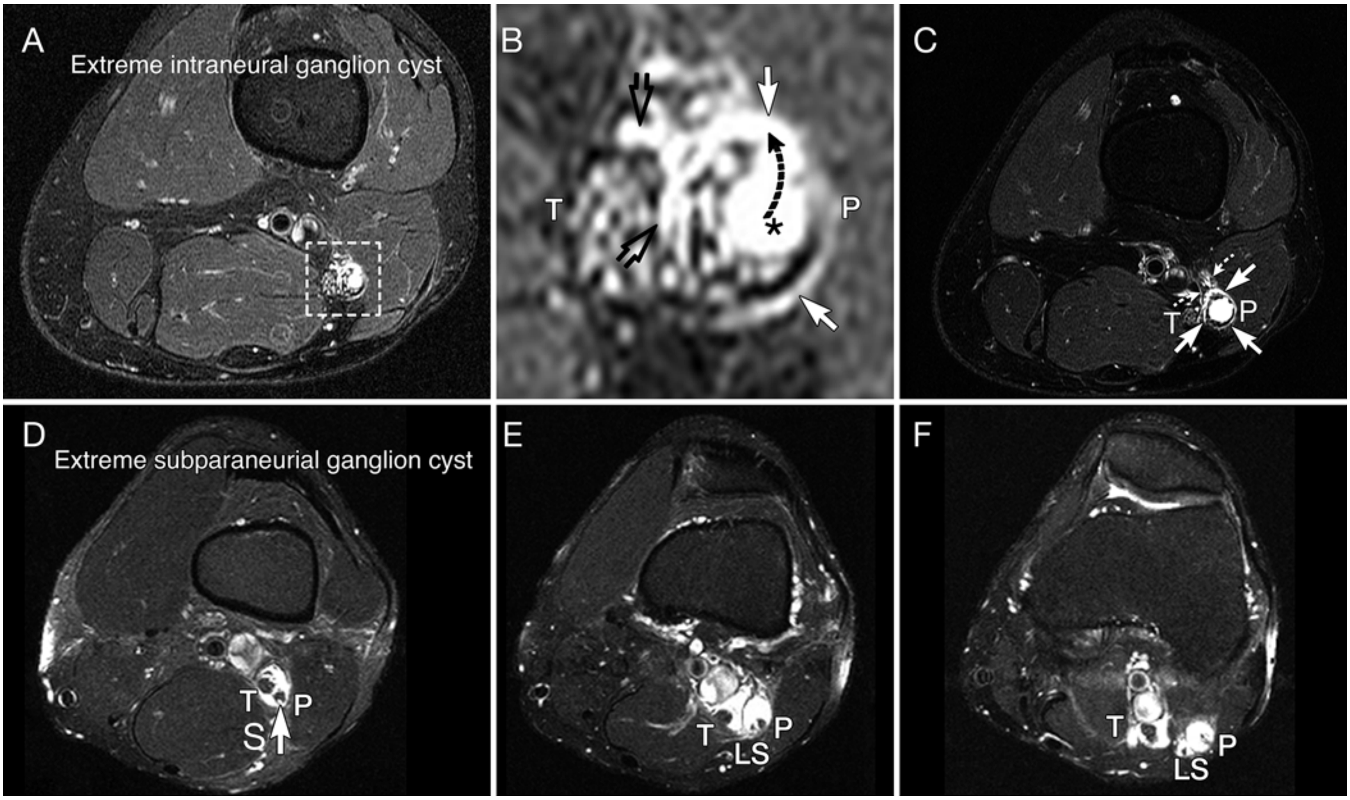

FIG. 2. Extreme INGCs (A–C) and extreme subparaneurial ganglion cysts (D–F; case 5 in Part 1[1]). A–C: Axial T2-weighted MR images show subtle evidence of crossover at the sciatic nerve bifurcation. This case was featured in early publications by our group[2,7,10] to demonstrate the longitudinal extent of a peroneal intraneural cyst from the STFJ. In this report, the same case and MR image are reinterpreted to explain the pathophysiology and expand on the radiological findings of crossover and extraneural rupture at the sciatic nerve bifurcation. **A and B:** Note the relative deflation of the subepineurial cyst (*asterisk*; signet ring) within the CPN (P) and the ring-within-ring appearance of the signet ring within the peroneal wedding ring sign (*solid arrows*) at the level of the sciatic nerve bifurcation. A subparaneurial cyst is seen around the TN (T), creating a wedding ring sign (*open arrows*) consistent with crossover. Unappreciated at the time of the original publication was the communication between the subepineurial and subparaneurial compartments (*curved dashed arrow*). Panel B is an enlargement of the *outlined area* in panel A. **C:** Just distal to the sciatic nerve bifurcation, subtle evidence of extraneural rupture is seen (*dashed arrows*). Subepineurial and subparaneurial cysts (*solid arrows*) in the peroneal intraneural cyst are demonstrated. D–F: This case with a peroneal INGC arising from the STFJ was originally included to introduce the MRI features of extreme INGCs (owl eyes with considerable circumferential cyst around the epineurium of the nerve).[3] In this paper, this cyst is referred to as an extreme subparaneurial ganglion cyst. **D:** At the sciatic nerve (S) bifurcation, a peroneal intraneural cyst ascends within the subepineurial compartment (*arrow*) and crosses over within the shared subparaneurial space so that cyst is around the epineurium of the CPN and TN. **E and F:** Just distal to the bifurcation, the extreme subparaneurial cyst is seen creating two owl eyes around the tibial and peroneal nerves (and lateral sural nerve [LS]) and then, slightly distal, three owl eyes around the tibial, peroneal, and lateral sural nerves.

increased T1 signal throughout the cyst, but no dense contrast extending superior to the bifurcation, which may be secondary to thick cyst fluid. The T2-weighted images provide more contrast to highlight the details of the cyst.

The 8 patients with nearly extreme subparaneurial cysts had relatively large, complex, multilobulated subepineurial cysts near the sciatic nerve bifurcation with evidence of crossover in the sciatic nerve but without owl-eye signs in serial axial images in major nerves. They all had MRI communication of subepineurial and subparaneurial compartments at the sciatic nerve bifurcation (Figs. 4 and 5). Seven had extraneural rupture[14] at the sciatic nerve bifurcation (Figs. 2 and 5).

Histology

An opening in the epineurium of the CPN was consistently found at the sciatic nerve bifurcation on the medial site, in between the division of the TN and CPN branches. Also, a similar opening was found in the epineurium of the TN near the sciatic bifurcation in all cases, which can explain the crossover observed in cases 4 and 7 presented in Part 1.[1] The size of the openings was variable (ranging from 0.5 to 1 mm). In addition, openings were found in the paraneurium, often at the same level. An example showing these openings is provided in Fig. 6. A further interesting observation was that openings were more frequently found at sites where there was more adipose tissue between nerves/nerve fascicles.

Discussion

To explain the occurrence of extreme INGCs, including

FIG. 3. Extreme subparaneurial cysts. A–C: Case 1 in Part 1.[1] Coronal T2-weighted MR images. **A:** A hyperintense signal around the TN (T) and CPN (P) is caused by extreme subparaneurial distribution of the cyst (giving the nerves the appearance of tram tracks). **B:** Just distal to the level of the sciatic nerve bifurcation, the *arrow* points to the crossover of cyst from the subparaneurial peroneal compartment to the subparaneurial tibial compartment. **C:** The *arrow* points to a relatively larger communication (compared with the crossover site in panel B) between the common peroneal and tibial divisions, which represents a window through which cyst fluid can transfer from the subepineurial to the subparaneurial compartment. S = sciatic nerve. D–F: Case 5 in Part 1.[1] **D:** Coronal T2-weighted MR image showing subtle evidence of peroneal subepineurial cyst communication with the subparaneurial compartments ("up and around"). **E and F:** Subparaneurial-to-subparaneurial cyst redistribution is seen around the tibial and peroneal nerves. Subtle slit-like interdigitation of the cyst in the subepineurial space with the subparaneurial space is seen in the peroneal nerve in panels D and E.

extreme subparaneurial cysts, one needs a pathoanatomical mechanism for crossover of peroneal and tibial INGCs. "Crossover," which was coined by our group in 2007, was introduced simply to describe how multiple INGCs are interconnected via a shared anatomical pathway/mechanism at the sciatic nerve bifurcation.[2] This article elaborates on that term and concept to provide evidence that cyst crossover (phase II) is more complex than previously understood. Crossover is necessary to set in motion phase III (subparaneurial cyst). Crossover occurs in two steps, allowing cyst transfer between shared compartments: via transfer from the subepineurial to the subparaneurial compartment ("cross" in crossover) and then from the subparaneurial to the subparaneurial compartment ("over" in crossover) at the level of the sciatic nerve bifurcation. Finally, cross-out can occur, also at the sciatic nerve bifurcation, due to an opening in the most outer circumneurium, which explains the extraneural rupture[14] and spread into surrounding soft tissues that is frequently observed in extreme subparaneurial ganglion cysts (Part 1[1]). These findings can all be understood by a novel pathophysiological mechanism—the geyser theory (Video 1).

VIDEO 1. Video clip showing the sequence of events that leads to the development of an extreme subparaneurial cyst and its analogy to the eruption of a geyser. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved. Click here to view.

Anatomical Considerations

We put forth an explanation for transfer of a cyst from the subepineurial to the subparaneurial compartment occurring in extreme subparaneurial cysts at the sciatic nerve bifurcation. We believe that the finding of fenestrations by themselves between the barriers at the

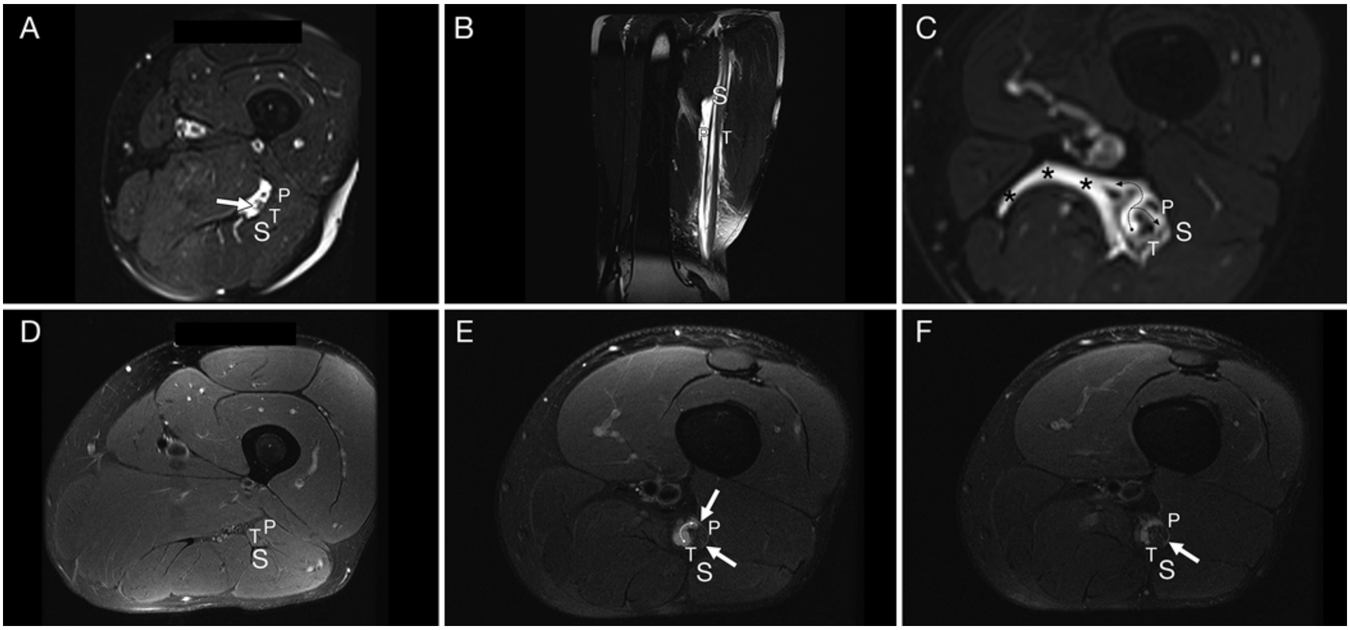

FIG. 4. MR images of a tibial INGC with extreme subparaneurial ganglion cyst formation, illustrating different snapshots of the spectrum over time. This case (case 7 in Part 1[1]), previously featured[3] to introduce the concept of extreme INGCs with cysts from the posterior aspect of the STFJ to the proximal thigh, is now being reinterpreted to demonstrate the mechanism of crossover and the dynamic changes over time. Axial T2-weighted fat-saturated images in the proximal third (A) and distal (B–F) thigh. **A:** MR image showing owl eyes in the subparaneurial layer around the sciatic nerve (S). Cyst is seen circumferentially around the TN (T) and CPN (P). A small signet ring sign from subepineurial cyst is seen within the TN (*arrow*). **B:** Sagittal T2-weighted MR image showing the extent of the subparaneurial cyst in the sciatic nerve extending to the proximal thigh. **C:** MR image from a large field of view of the bilateral thigh. At the level of the sciatic nerve bifurcation, a tapered cyst within the TN exits through a small apparent defect in the epineurium and enters the subparaneurial space (*dashed arrows*) around the tibial and peroneal nerves. Peripheral fluid extends outside of the nerve (extraneural rupture) through the most outer circumneurium. Prominent soft tissue fluid (extraneural rupture) extends from the nerve along the adjacent fascia of the hamstring muscles and the subepimyseal space (*asterisks*). **D:** MR image obtained 2 months later showing spontaneous resolution of the extreme subparaneurial cyst in the sciatic nerve in the proximal thigh. **E and F:** In consecutive T2-weighted MR images at the sciatic nerve bifurcation, the tibial subepineurial cyst, which is larger than seen on the previous MR image (see *dot* at origin of *dashed arrows*), communicates with the subparaneurial cyst. In panel F, the wedding ring sign (*arrows*) is seen around the peroneal and tibial divisions within the sciatic nerve.

sciatic nerve bifurcation allows for cyst transfer between compartments, especially in the presence of pressure gradients. This seems to be the most logical explanation for the radiological findings, including dilation of the subepineurial cyst in typical and nearly extreme cysts below the sciatic nerve bifurcation, and tapering of it in the presence of extreme subparaneurial cysts and smooth cyst flowing in the subparaneurial compartment from the sciatic nerve bifurcation. While we acknowledge the possibility of other anatomical factors, including a potential weakness at major branching points, anatomical evidence for the potential of this crossover was found from analysis of slides obtained from the entire trajectory of the sciatic nerve in 10 cadavers, which, in these cases, consistently showed openings in the epineurium on the medial side in the proximal CPN and on the lateral side in the TN, and in the paraneurium at the same level, as well as the outermost circumneurium (Fig. 6). These fenestrations can explain the crossover of a cyst from the subepineurial to the subparaneurial space, between the different subparaneurial spaces, and the cross-out into surrounding tissues. In this study, the fenestrations in all 10 cadavers were found on the inner side of the divisions just distal to the bifurcation. These fenestrations were observed in MR images in two of the extreme subparaneurial cases (Fig. 3) and in all the nearly extreme subparaneurial cases. In several cases, the crossover occurred in an anterior and posterior direction (see arrows in Figs. 2, 4, and 5). This could be explained by the fat tissue in between the TN and CPN, but it could also have been caused by a slightly different position of the fenestration compared with our histological findings. Additional experimental investigations of the sciatic nerve are needed to further investigate this.

It is possible that crossover may occur at other sites, such as the trifurcation of the CPN at the fibular neck, depending on the relative position of the subepineurial ascending cyst in relation to potential fenestrations. These potential alternate positions of fenestration, however, would not change the two-step crossover at the sciatic nerve bifurcation that we have presented in Fig. 6. Crossover from the subepineurial to the subparaneurial compartment leads to a rapid filling of the subparaneurial space, which can be explained by the higher compliance of the outer layers compared with the relatively stiff epineurium that surrounds the nerve fascicles. This increased stiffness of the epineurium compared with the paraneurium is clearly visible from observation of the thickness of the different layers in the anatomical slide presented in Fig. 6. More-

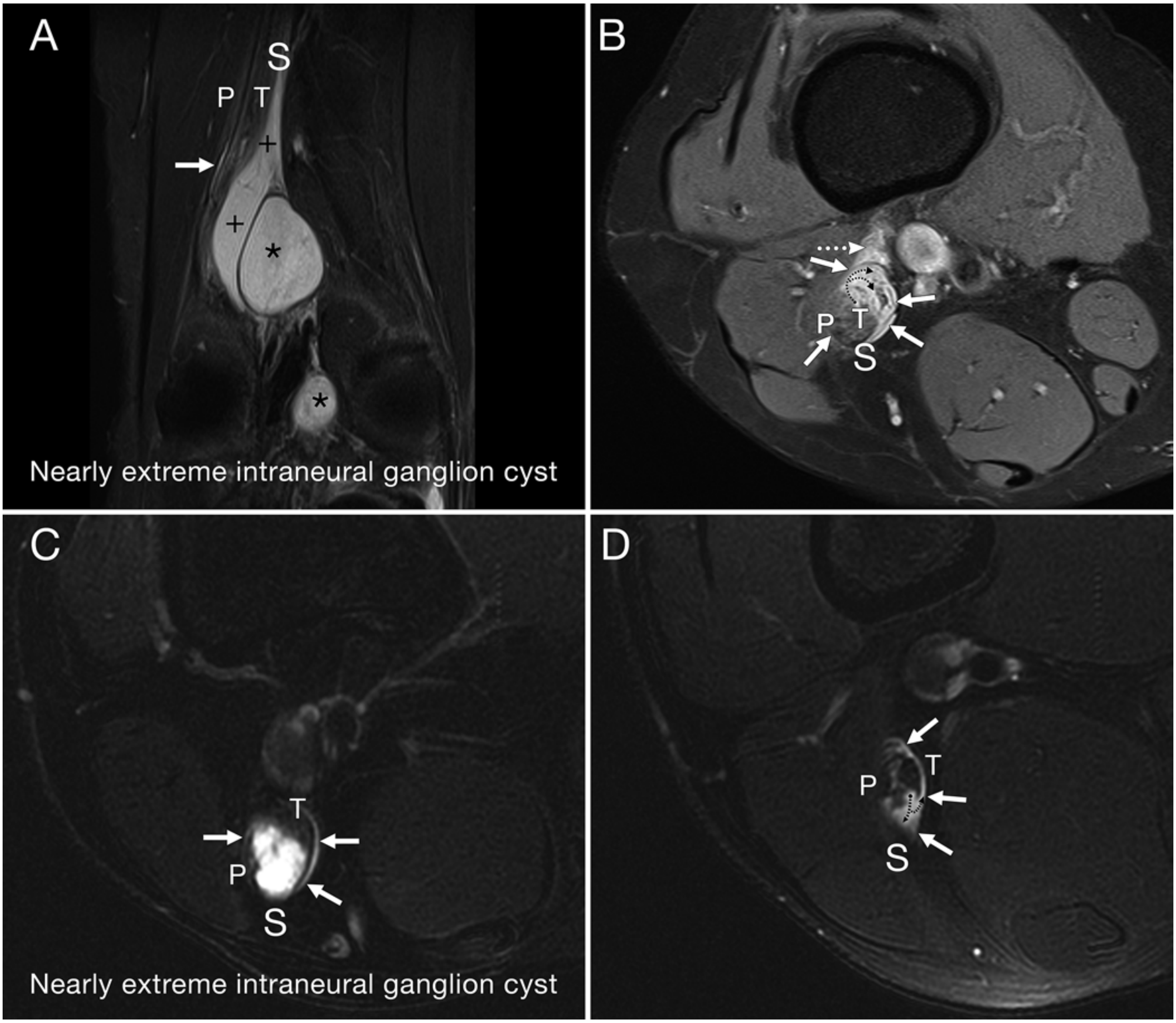

FIG. 5. MR images obtained in 2 cases of nearly extreme INGCs, illustrating that crossover precedes the formation of extreme subparaneurial ganglion cysts. **A and B:** Coronal (A) and axial (B) proton density–weighted fat-saturated MR images of the knee, demonstrating a large TN (T) INGC (*asterisks*) arising from the posterior aspect of the knee joint (not shown) with a cyst wall at the level of the sciatic nerve (S) bifurcation. Cyst fluid (+) with feathery increased T2-weighted signal is shown extending superior in the TN. In panel A, faint cyst is seen within the subparaneurial layer of the CPN (P), suggesting a tram-track sign (*arrow*) as it descends after crossover at the sciatic nerve bifurcation. In panel B, at the sciatic nerve bifurcation, cyst below the epineurium of the TN is seen communicating (*dashed curved arrows*) with cyst in the subparaneurial layer that then extends around the TN and CPN (*solid arrows*; wedding ring signs). Extraneural rupture is seen (*dashed straight arrow*) (this case was previously published by another group[12]). **C and D:** Axial T2-weighted fat-saturated images just distal to (C) and at the level of (D) the sciatic nerve bifurcation. Intraneural cyst ascends in the TN from the posterior aspect of the STFJ (not shown here, but previously published elsewhere[5] to illustrate descent), now demonstrating the mechanism of crossover. Nearly extreme INGC extends to the sciatic nerve bifurcation to the TN and CPN. A wedding ring sign is also seen around the sciatic nerve (*solid arrows*). In panel D, just proximal to panel C, the cyst tapers at the sciatic nerve bifurcation and exits through a small apparent defect in the epineurium and enters the subparaneurial space (*dashed curved arrows*). Peripheral fluid extends from this level inferiorly in the subparaneurial layer of the TN (*arrows*).

over, subepineurial stiffness is also higher than that for the subparaneurial space due to tight interconnections between fascicles, whereas the subparaneurial space consists of loose tissue.

The importance of the paraneurial layer has previously been described predominantly in studies focusing on the administration of local anesthetic solutions in the popliteal fossa to perform sciatic nerve blocks (for surgeries below the knee).[15,16] Methylene blue solution has been injected into the subparaneurial compartments distal and proxi-

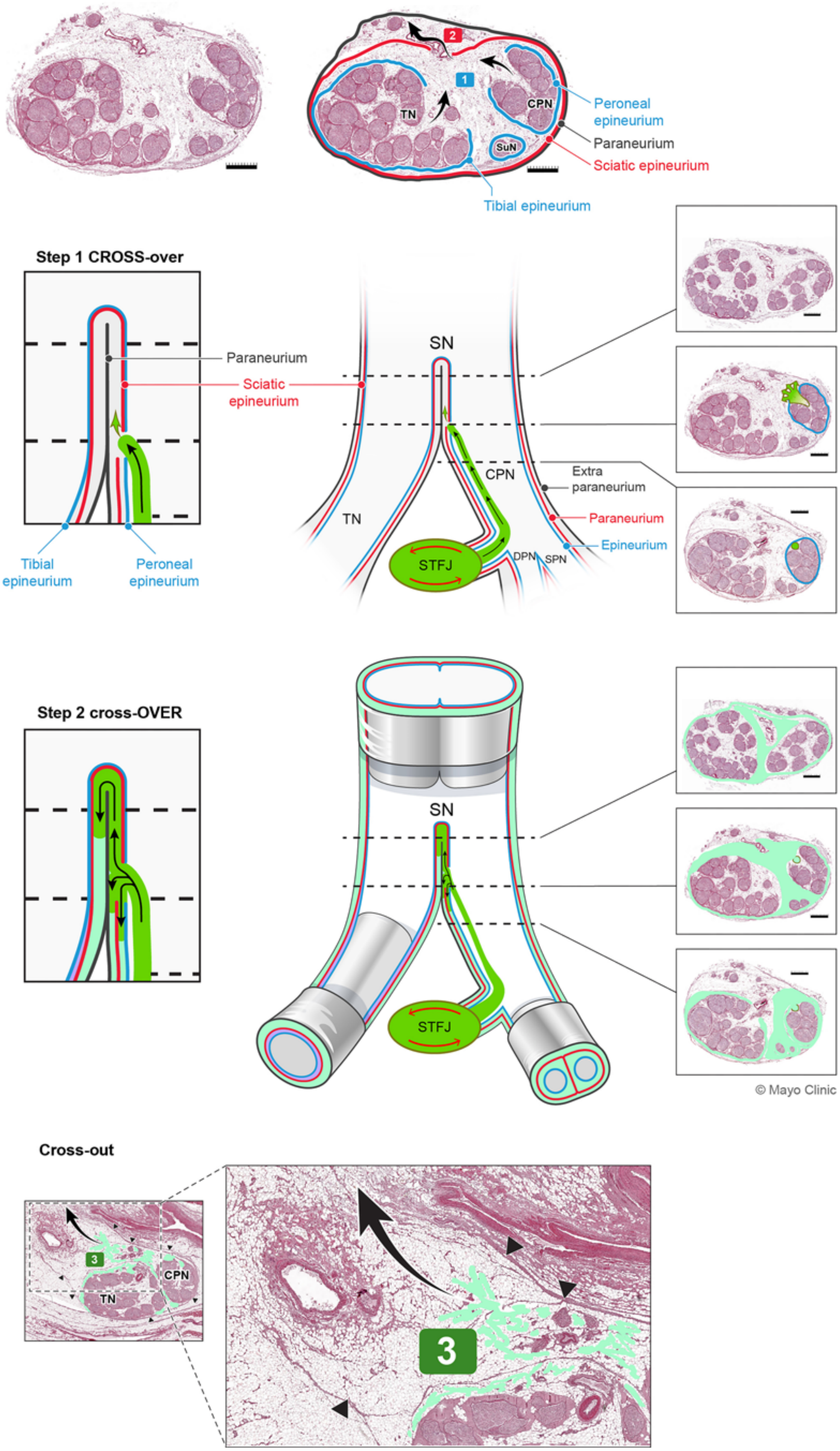

FIG. 6. Anatomical explanation for crossover and cross-out. The *upper part* of the figure shows an anatomical slide obtained at the level of the sciatic nerve bifurcation from a human cadaver, without surrounding tissue. **FIG. 6.** (*continued*)→

FIG. 6. Scale bar 1 mm is divided into 10 and 100. Original magnification ×20. Hematoxylin-eosin staining was used. Images were captured photographically (Leica DFC425, Leica SCN Microsystems), and the cross-sections were saved after scanning (Leica SCN400 Slide Scanner, Meyer Instruments and Leica SCN Microsystems). The *left upper image* is the original anatomical slide. In the *right upper image*, the different layers have been colored in *blue*, *red*, and *black*. *Black arrows* demonstrate the openings/fenestrations in the different layers: 1 (*blue*) indicates fenestration in the epineurium of both the peroneal and tibial nerves; and 2 (*red*) indicates fenestration in the paraneurium that surrounds both the peroneal and tibial nerves (and becomes the epineurium of the sciatic nerve). Both openings (in the epineurium and paraneurium) are necessary for crossover to occur. The *center part* of the figure shows the two steps of crossover that explain the potential for extreme subparaneurial distribution. Step 1 of crossover ("cross"): Once the cyst inside the channel of the CPN has reached the openings that were observed in cadaver specimens, the fluid can transfer from the subepineurial to the subparaneurial space through the *blue layer*. The layers in this figure have been given different colors to simplify the complexity of the different layers and explain the nomenclature. Distal to the sciatic nerve bifurcation, the epineurium of the peroneal and tibial nerves is *blue* and the paraneurium is *red*. An extra-circumneurial layer exists that is depicted in *black*. At the sciatic nerve bifurcation, the previous paraneurium becomes the epineurium of the sciatic nerve and the *black* circumneurium becomes the paraneurium. The cyst is depicted in *poison green* in the *center* anatomical slide (which is the same image as those in the upper part of the figure); the passage of cyst through the existing fenestration is shown with *arrows*. Step 2 of crossover ("over"): In order to get to the subparaneurial space around the sciatic nerve, cyst also has to transfer through an opening in the *red layer*. This opening was also observed in the cadaver specimens. Once this space has been reached, cyst can go up, distribute around the sciatic nerve, and cross over into the subparaneurial space around the TN ("up and over"). The distribution pattern in the subparaneurial space around the tibial and peroneal nerves, which was observed in Part 1,[1] is colored in *mint green* in the anatomical slides of the same levels as presented in the illustration in step 1. Important to distinguish is that cyst going down can thereby distribute along two different subparaneurial planes, which explains the multiple rings that are sometimes observed (as in the cases presented in Fig. 7). The theory for the two-step transfer presented in this figure is supported by the different locations of transfer observed in case 7 (presented in Part 1) for the MR images (Fig. 4 in this paper) and MR arthrogram. The *lower part* of the figure shows an example of an anatomical slide, also obtained from a human cadaver but with surrounding tissue. There is an opening (*3*, *green*) in the outermost circumneurial layer (illustrated by *arrowheads*), the paraneurium of the sciatic nerve, where cyst can cross out ("out," i.e., extraneural rupture) into surrounding tissue (illustrated in *mint green*). At this site, a large vessel is seen. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

mal to the sciatic nerve bifurcation in cadavers and has been found to distribute extensively along the course of the nerve(s).[17] The second author of this paper (M.A.R.) has performed several studies using a particulate marker such as heparinized blood solution (HBS).[18] This marker was injected into the TN at the popliteal fossa in cadavers with ultrasound guidance and was found to distribute around, but not into, the fascicles (extrafascicular intraneural spreading), and also outside the epineurium, including the subparaneurial compartment around the TN and CPN (forming a so-called donut sign on ultrasound). The advantage of the HBS marker compared with methylene blue is that it cannot leave the compartment in which it is injected unless it exits through a fenestration (like in the TN and CPN at the popliteal fossa) and the distribution patterns can later be analyzed with microscopy.[18]

Transfer of fluid (cross-out) from the subparaneurial to the subepimyseal space has also been described before in the anesthesiology literature (e.g., after ultrasound-guided popliteal sciatic nerve blocks[15]), which can also be explained by openings in the most outer circumneurium (Fig. 6). This may result in similar MRI findings,[16] as we observed in Part 1[1] (with extraneural rupture and spread of cyst into surrounding tissues in all cases of extreme subparaneurial ganglion cysts) and also in 7 of our nearly extreme cases.

These fenestrations show that both crossover and cross-out are, in fact, not actual breakthroughs, but rather transfer from one compartment to another (subepineurial to subparaneurial, subparaneurial to subparaneurial, and subparaneurial to subepimyseal) compartment.

Geyser Theory: A Pathophysiological Explanation

Currently, there is no experimental (i.e., biomechanical[19] or animal) model that explains the formation and propagation of INGCs, including the extreme subparaneurial variant. There are no reports of INGCs in animals and no extreme subparaneurial ganglion cysts in cadavers.

The geyser theory explains the pathophysiology and spectrum of extreme INGCs in the knee region and likens them to events that occur in the eruption of a geyser (Fig. 1). In phase 1, the cyst ascends in the CPN, in a relatively confined space inside the nerve beneath the epineurium. This explains why the cyst does not distribute around the other fascicles inside the parent nerve but forms a confined eccentric space visible on MRI as the signet ring sign. Pressure inside the channel in the nerve can build up, which might be visible on MRI as an enlarging signet ring sign going up proximally in the parent nerve or, in some cases, even the appearance of a balloon.[20,21] Once the cyst reaches the sciatic nerve bifurcation, the pressure buildup can lead to an eruption, which forms the beginning of phase II; as we have shown in this part, in many examples, the start of this crossover may actually be visible on MRI as a "jet" of cyst propulsion (e.g., Fig. 2A–C, which was featured in Figs. 5A and 7A in our previous publication,[7] and Figs. 4 and 5 in this paper). Near the sciatic nerve bifurcation, the cyst within the channel approaches a fenestration, which allows crossover to occur. Because of the high pressure (as in the geyser), the subparaneurial compartment, which first was only a potential space, now quickly fills and extends substantially in both width and length (phase III). The jet of pressure results in an "up and over" mechanism for crossover from the trajectory of the jet of pressure (Fig. 3). We believe that the occurrence of a disproportionate number of extreme INGCs originating from the knee joint (a rare site) rather than the STFJ (a common site) can be understood given the higher pressures of the knee joint (vs the STFJ) and the shorter distance from the site of the joint origin to the sciatic nerve bifurcation.

We believe that the subparaneurial filling occurs in a top-down manner; cyst bursts up into the subparaneurial space around the sciatic nerve and flows down, filling

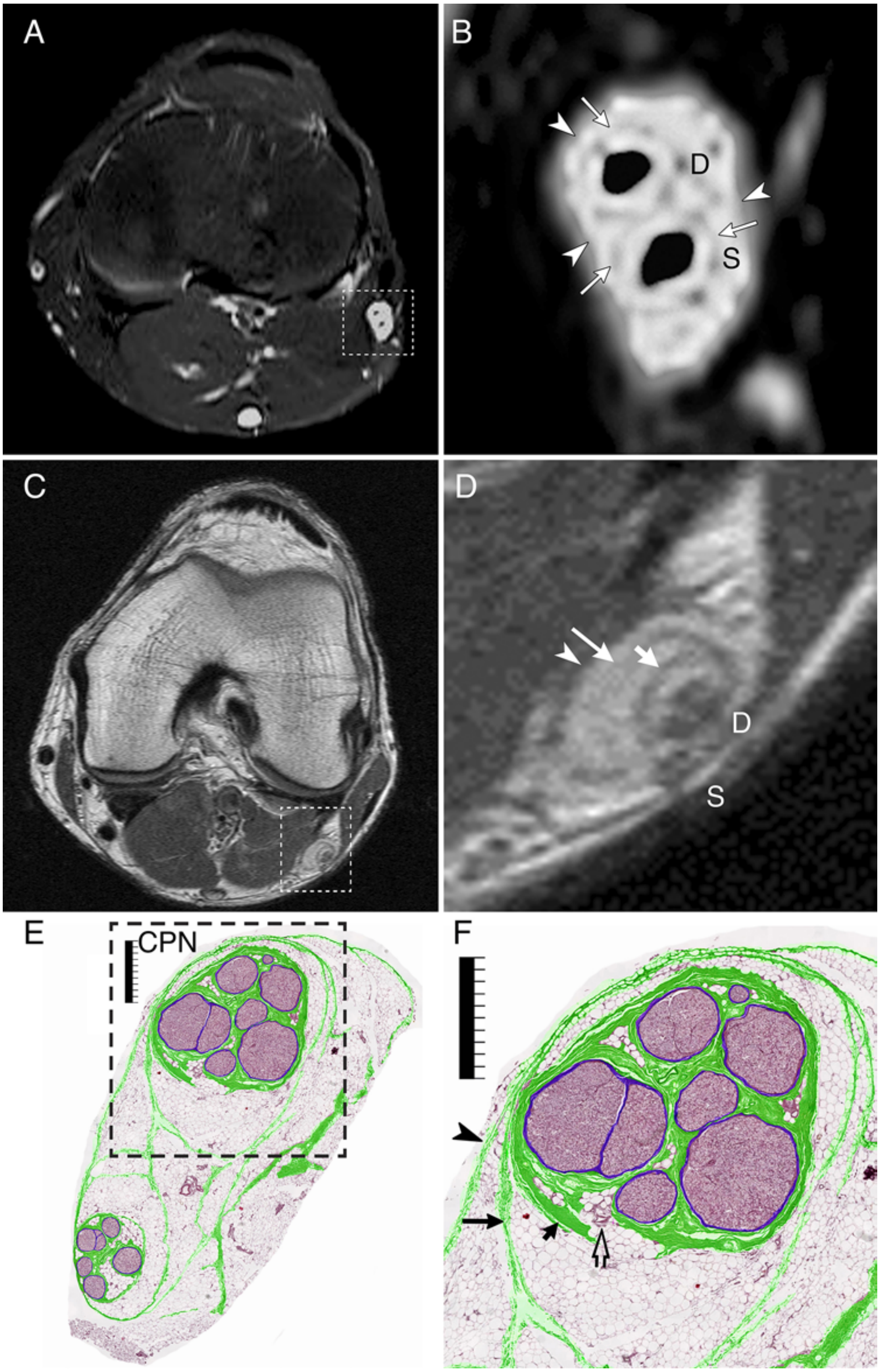

FIG. 7. MR images obtained in 2 cases of peroneal INGCs with extreme subparaneurial descent below multiple paraneurial layers and corresponding anatomical slide illustrating these different layers. A and B: Reinterpretation of case 8, previously reported by Kim et al.[6] **A:** T2-weighted MR image with fat suppression demonstrating two owl eyes of the deep and superficial nerve fascicular bundles within the CPN at the level of the knee (*outlined area*). The lateral sural communicating branch is not seen in this image but is present posteriorly on proximal slices. **B:** Photographic enlargement of the *outlined area* in panel A showing a distinct paraneurium/circumneurium (*arrows*) around the deep (D) and superficial (S) peroneal bundles within the paraneurium of the CPN at the level of the knee (*arrowheads*). Adobe level adjustment was used to enhance contrast. C–F: Case 5 in Part 1.[1] **C:** Proton density–weighted MR image without fat suppression showing separate paraneurial or circumneurial layers around the deep and superficial peroneal fascicular bundles in the CPN at the level of the knee. The lateral sural communicating branch is seen posteriorly on this image surrounded by separate cyst. **D:** Photographic enlargement of the *outlined area* in panel C. **FIG. 7.** (*continued*)→

FIG. 7. Different types of *arrows* show the three distinct paraneurial layers, with an *arrowhead* for the outermost paraneurium, a *long-stem arrow* for the second paraneurium, and a *short-stem arrow* for the third paraneurium. Of note, the epineurium in this image is not visible as a distinct layer. **E:** Corresponding histological image of the CPN and the lateral sural communicating branch at the level of the knee. **F:** Photographic enlargement of the *outlined area* in panel E showing the deep and superficial peroneal nerve fascicular groups. Several collagen fiber membranes, including sciatic nerve epineurium, CPN epineurium, and TN epineurium, were colored in *green* using Adobe Photoshop (version CC 2017.0.1, Adobe Systems Inc.). A *purple line* was drawn around the fascicular bundles of the CPN. The three distinct paraneurial layers, also visible in panel D, have again been labeled with an *arrowhead*, *long-stem arrow*, and *short-stem arrow*. Of note, a fenestration was observed in this slide in the third paraneurial layer around the corresponding superficial peroneal nerve fascicular group.

the different subparaneurial compartments of the sciatic branches, with more concentric cyst around the epineurium of nerve(s). Because the paraneurium of the TN and CPN merges with the epineurium of the sciatic nerve at the bifurcation, the cyst will have to transfer through an extra circumneurium to get "up" into the subparaneurial space around the sciatic nerve. Subsequently, in the top-down filling, as demonstrated in Fig. 6, the cyst can go down into separate subparaneurial compartments. This was observed commonly in the sural branches but also within the CPN itself in two examples (cases 5 and 8 in Part 1[1]), in which a ring within a ring within a ring appearance was observed (Fig. 7). There was no radiological evidence in these cases that communication between the subepineurium and subparaneurium occurred at other more distal sites and allowed distal to proximal subparaneurial filling. Nearly all the patients with extreme INGCs (i.e., extreme subparaneurial and nearly extreme subparaneurial ganglion cysts) exhibited evidence of cyst rupture through the subparaneurial layer into the adjacent soft tissues. The spontaneous resorption or regression is not well understood.

While the dynamic nature of INGCs has been previously described and likened to a roller coaster,[2,22,23] the present article introduces the phenomenon of a geyser to further elucidate the pathomechanics underlying the rapid and dramatic fluctuations in the appearance of extreme subparaneurial ganglion cysts. As with a geyser, what you see with an eruption is only part of the process. To identify extreme subparaneurial ganglion cysts, a single MRI study has to be performed at exactly the right moment and right place (including images of the sciatic nerve above the knee to be able to observe the proximal extension and the site of crossover at the sciatic nerve bifurcation). Sequential scans highlight the temporal evolution of INGCs, reflective in part due to pressure fluxes. Signs that may indicate extreme subparaneurial extension include the wedding ring, owl-eye, cyst-within-cyst, and tram-track signs, and sign of rupture into surrounding tissue.

It is important to realize that the life cycle of the subparaneurial cyst can result in different combinations of radiological signs involving one or multiple nerves with varying amounts of subparaneurial cyst. The life cycle of INGCs consists of different phases, and in these different phases, different nerves may be involved to varying degrees. In this study, we have expanded on the life cycle showing that a cyst can also distribute into different compartments, and especially in the subparaneurial compartment, in varying amounts. The life cycle of the subparaneurial cyst can thereby be visualized as a spectrum. At one end of the spectrum, subparaneurial cysts may be present but go largely unrecognized because of the faint appearance of a rind of concentric cyst around only the parent nerve of the primary pathway (i.e., the CPN), without the cyst being evident at the sciatic nerve bifurcation or in the nerve (i.e., the TN) of the secondary pathway. At the other end of the spectrum, prominent owl-eye signs may be seen involving long segments of the CPN, TN, sural nerve, and sciatic nerve. These varying degrees of subparaneurial cyst may make it hard to recognize the location of the cyst in some cases, but in this article we have demonstrated that in many cases, because of the availability of sequential MR images, we can connect the dots, proving that extreme cysts (wedding ring sign) and extreme subparaneurial cysts (owl-eye sign; originally called extreme wedding ring sign) differ only by the amounts of cyst in the subparaneurial compartment. The interpretation of serial MR images allows us to understand the full extent of the spectrum, ranging from a small wedding ring sign to a large owl-eye sign, or to an incomplete wedding or subparaneurial cyst,[12] and sometimes again to almost complete regression/disappearance. In fact, some cases of extreme subparaneurial cysts had imaging at another time that also could have been classified as a nearly extreme subparaneurial cyst or even a relatively small typical INGC.

Just as a geyser eruption can only be observed for several minutes (contrary to a fountain), extreme subparaneurial cysts are also present for a relatively short period of time. Sometimes only remnants of a cyst are observed, which may give the appearance of a silhouette or a faint rind of (subparaneurial) cyst (Fig. 8). This is also seen in case 2 (not shown) and case 5 of Part 1,[1,24] with repeat MRI performed 3 weeks later showing an extreme subparaneurial cyst (Figs. 2D–F and 3D–F). These findings provide insight into our cases and those in the literature. Knowledge of this life cycle of the extreme subparaneurial ganglion cyst is important because, as with a geyser, eruptions in the same trajectory may occur repeatedly. This could mean that with long intervals between sequential MR images, snapshots of different parts of the spectrum may be observed, which might not completely match with the sequence of events, including a combination of walled-off cyst and fluid (Fig. 5). It is also important to acknowledge this because with almost complete disappearance one might argue that surgery is not necessary, but as with a geyser, after a period of silence the cyst may erupt again, leading again to pain and potentially even neurological deficit.

The preferred surgical treatment is to disconnect the pressurized ascent of the geyser from the source by transection of the articular branch and preferably treatment of the joint.[1] A surgeon can perform a targeted operation at the joint origin and the articular branch connection of the INGC rather than expose and treat a lengthy, complex cyst. This shows that our novel explanation still obeys the principles of the articular theory.[24]

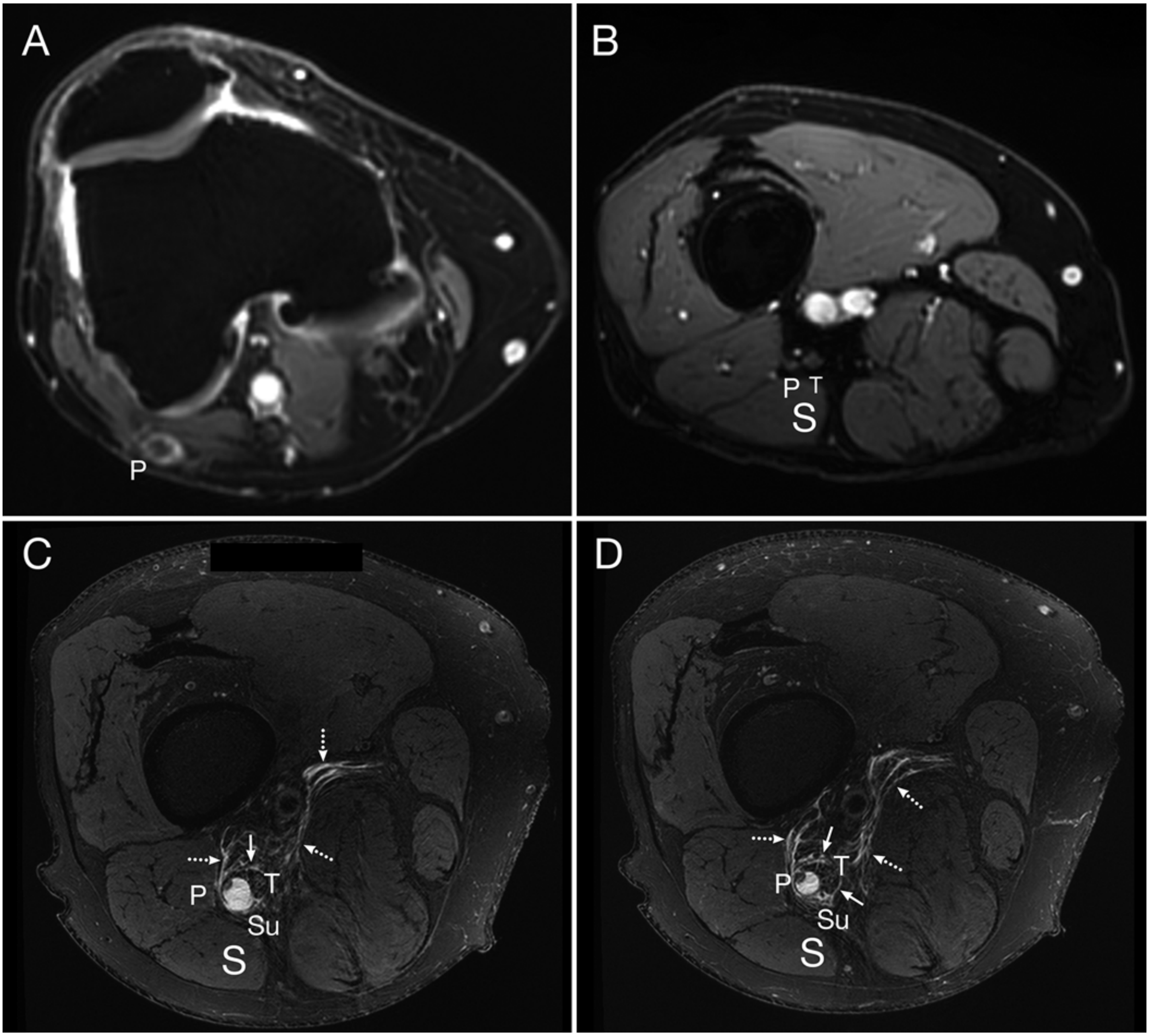

FIG. 8. Sequential MR images obtained in a case of nearly extreme subparaneurial cyst, involving the peroneal nerve arising from the STFJ, supporting the continuum of nearly extreme subparaneurial and extreme subparaneurial cysts as well as the proposed mechanism for crossover and extraneural rupture at the sciatic nerve bifurcation. **A and B:** Axial T1-weighted MR images with fat suppression after contrast at the knee level, showing a peroneal INGC with a rind of circumferential (subparaneurial) cyst around the CPN (P) at the level of the knee (A). Resolution was limited due to the bilateral examination of the entire nerve path. The faint silhouette of circumferential cyst was present on several sequential images but did not extend to the sciatic nerve bifurcation (B). At the level of the distal thigh, the sciatic nerve bifurcation was normal with no cyst identified. Without a substantial subparaneurial cyst and without extension to the sciatic nerve, this case did not qualify for inclusion as an extreme subparaneurial cyst. S = sciatic nerve; T = TN. **C and D:** Seven weeks later, repeated axial T2-weighted MR images with fat suppression at the sciatic nerve bifurcation in the distal thigh showed a peroneal INGC with an interconnection of cysts at the sciatic nerve bifurcation. There is a cyst within a cyst: a signet ring sign (subepineurial cyst) within a wedding ring sign around the peroneal nerve. There is also evidence of a wedding ring sign around the TN and sciatic nerve (*solid arrows*) and extraneural rupture (*dashed arrows*). Note the subtle owl-eye sign with circumferential cyst in panel D around the sural communicating branch (Su). An owl-eye sign was not present in the sciatic nerve on more proximal images.

Limitations

This study was intended to be a proof of concept. Although clear evidence was provided in this study for the potential cyst to transfer from the subepineurial to the subparaneurial space at the sciatic nerve bifurcation, this study has several shortcomings.

As for the MRI analysis, while clear communications between subparaneurial compartments of CPN and

TN at the sciatic nerve bifurcation could be seen in all cases of extreme subparaneurial ganglion cysts, discrete fenestrations were only identified in 3 of 8 cases. In the other 5 cases, fenestrations were not visible on MRI, because of the suboptimal quality of the scans. The defect is subtle and not definitively seen on some examples, but in those, the peripheral edema is greatest at the bifurcation. The MRI limitations for fenestrations could partly be explained by the following: the sciatic nerve bifurcation was not sufficiently depicted on the scan (particularly no transverse T2-weighted images at the sciatic nerve bifurcation), the subepineurial cyst was small/decompressed (especially compared with the nearly extreme INGCs), there were limited scans at the area of interest, and the imaging techniques were older, with low resolution. MR images may also not have been obtained at the moment of maximal distribution, during or directly after the eruption. Ideally, repeated scans may provide additional insight. Arthrograms could provide more evidence,[25] but are not routinely performed, now that the joint connections have been widely appreciated and corroborated. Limitations for arthrography would be the lack of dense contrast signal in the cyst. In contrast, the communication between compartments could be identified in all patients with nearly extreme ruptured cysts; we recognize that the definition of this group was made qualitatively and somewhat arbitrarily. Similarly, discrete subparaneurial cysts and circumneurial layers could only be appreciated in 3 of 6 cases with extreme subparaneurial cysts involving the CPN arising from the STFJ. We do not know if, in the other 3 cases, multiple paraneurial layers existed and were not visible on MRI or if the presence of discrete cysts was related to the internal topography of the CPN.

This study raises many other important questions. Although this study establishes an explanation for extreme subparaneurial ganglion cysts to cross over at the sciatic nerve bifurcation, it does not exclude the possibility of transfer between compartments at other sites, including the trifurcation of the CPN at the fibular neck. Further histological work is needed to explore other possible fenestrations in other areas of nerve(s), particularly near other branching points (e.g., sural) and variability. We do not know if the described mechanism for crossover applies to other nerves at other anatomical locations[26–28] according to the frequency with which fenestrations in the paraneurial layers in this study were found (e.g., note the fenestration in the superficial peroneal nerve fascicular bundle in Fig. 7F). However, it is important to realize that crossover depends not only on the presence of a fenestration, but also on the relation of the articular branch with respect to this fenestration. Because of the ascent of cyst through the articular branch inside the deep peroneal nerve, this ascending channel comes into close contact with a fenestration at the sciatic nerve bifurcation, which allows for the crossover to occur (Fig. 6). We wonder if multilobulated subepineurial cysts are due to intraepineurial fenestrations. We do not know the effect of gravity on the distribution of subparaneurial cysts, as to whether descent or ascent is preferred. After extraneural rupture at the sciatic nerve bifurcation, however, gravity seems to play a role, because subparaneural descent often remained compared to the ascent (most prominent in the primary compared with the secondary neural pathway; see tables in Part 1[1]), which can also be explained by the high compliance of the paraneurial layer. We do not know if transfer from the subparaneurial to the subepineurial space can occur. However, the finding of a cyst within a cyst seems to us to provide insight into the primary neural pathway; for example, analysis of a recent case of Lee et al.[29] suggests that the primary pathway is the TN (based on Fig. 4 in their report). We do not know if, in cases of large extreme subparaneurial cysts, the slit-like subepineurial cyst completely disappears. We also acknowledge that extraneural rupture of subparaneurial cysts, and even INGCs, can occur at sites besides the sciatic nerve bifurcation by different mechanisms, potentially even trauma. While we do believe that connective tissue disorders may also play a role in developing a capsular rent that leads to INGC formation and propagation, we do not know if these would predispose one to an epineurial nerve defect that would enable crossover at the sciatic nerve and facilitate subparaneurial extension.

Conclusions

This two-part study builds on several decades of research on INGCs and elaborates on the principles of the articular theory in relation to the occurrence of extreme subparaneurial cysts (Part 1[1]) and the expansive phasic mechanism (Part 2) underlying the crossover phenomenon. Detailed, iterative review of new and old cases has unveiled new MRI patterns that reveal shared mechanisms and compartments—importantly, that extreme subparaneurial cysts form from INGCs in an inside-out mechanism, and that crossover and cross-out occurring at the sciatic nerve bifurcation form via fenestrations. The geyser theory builds on the articular theory and explains how extreme subparaneurial cysts look, how they form, and how they should be treated. We believe that the geyser theory provides the next steps in understanding the distribution, compartmentalization, and spectrum of extreme INGCs.

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References

1. de Ruiter GCW, Son BC, Hayford KM, et al. Extreme subparaneurial ganglion cysts. Part 1: Principles and implications. *J Neurosurg*. Published online July 4, 2025. doi: 10.3171/2025.2.JNS242815
2. Spinner RJ, Amrami KK, Wolanskyj AP, et al. Dynamic phases of peroneal and tibial intraneural ganglia formation: a new dimension added to the unifying articular theory. *J Neurosurg*. 2007;107(2):296-307.
3. Spinner RJ, Hébert-Blouin MN, Rock MG, Amrami KK. Extreme intraneural ganglion cysts. *J Neurosurg*. 2011;114(1): 217-224.
4. Prasad NK, Desy NM, Howe BM, Amrami KK, Spinner RJ.

Subparaneurial ganglion cysts of the fibular and tibial nerves: a new variant of intraneural ganglion cysts. *Clin Anat*. 2016; 29(4):530-537.
5. Colombo EV, Howe BM, Amrami KK, Spinner RJ. Elaborating upon the descent phase of fibular and tibial intraneural ganglion cysts after cross-over in the sciatic nerve. *Clin Anat*. 2014;27(8):1133-1136.
6. Kim D, Choi JG, Son BC. Peroneal nerve palsy due to subparaneurial ganglion cyst, a rare variant of intraneural ganglion cyst. *Asian J Neurosurg*. 2018;13(4):1225-1228.
7. Spinner RJ, Atkinson JL, Scheithauer BW, et al. Peroneal intraneural ganglia: the importance of the articular branch. Clinical series. *J Neurosurg*. 2003;99(2):319-329.
8. Lenartowicz KA, Wu KY, Amrami KK, de Ruiter GCW, Desy NM, Spinner RJ. Tibial intraneural ganglion cysts arising from the tibiofemoral joint: illustrative cases. *J Neurosurg Case Lessons*. 2023;6(10):CASE23314.
9. Smith BW, Jack MM, Powell GM, Frick MA, Amrami KK, Spinner RJ. High-resolution MRI of a peroneal intraneural ganglion cyst arising from the knee joint: illustrative case. *J Neurosurg Case Lessons*. 2021;1(21):CASE21130.
10. Spinner RJ, Amrami KK, Angius D, Wang H, Carmichael SW. Peroneal and tibial intraneural ganglia: correlation between intraepineurial compartments observed on magnetic resonance images and the potential importance of these compartments. *Neurosurg Focus*. 2007;22(6):E17.
11. Jerath NU, Chen JJ, Miller BJ, Reddy CG. Teaching NeuroImages: intraneural ganglion cyst of the tibial nerve. *Neurology*. 2014;82(20):e174-e175.
12. Schlig LH, Hägele-Link S, Felbecker A, et al. Nervensonographie intraneuraler Ganglien als Ursache schmerzhafter N.-peronaeus-Paresen: eine Fallserie. *Praxis (Bern 1994)*. 2014;103(24):1433-1438.
13. Reina MA, Boezaart AP, Tubbs RS, et al. Another (internal) epineurium: beyond the anatomical barriers of nerves. *Clin Anat*. 2020;33(2):199-206.
14. Shahid KR, Hébert-Blouin MN, Amrami KK, Spinner RJ. Extraneural rupture of intraneural ganglion cysts. *J Surg Orthop Adv*. 2011;20(2):136-141.
15. Karmakar MK, Shariat AN, Pangthipampai P, Chen J. High-definition ultrasound imaging defines the paraneural sheath and the fascial compartments surrounding the sciatic nerve at the popliteal fossa. *Reg Anesth Pain Med*. 2013;38(5):447-451.
16. Büttner B, Schwarz A, Mewes C, et al. Subparaneural injection in popliteal sciatic nerve blocks evaluated by MRI. *Open Med (Wars)*. 2019;14:346-353.
17. Reina MA, Sala-Blanch X, Monzó E, Nin OC, Bigeleisen PE, Boezaart AP. Extrafasicular and intraperineural, but no endoneural, spread after deliberate intraneural injections in a cadaveric study. *Anesthesiology*. 2019;130(6):1007-1016.
18. Reina MA, Boezaart AP, Sala-Blanch X, et al. A novel marker for identifying and studying the membranes, barriers, and compartments surrounding peripheral nerves microscopically. *Clin Anat*. 2018;31(7):1050-1057.
19. Elangovan S, Odegard GM, Morrow DA, Wang H, Hébert-Blouin MN, Spinner RJ. Intraneural ganglia: a clinical problem deserving a mechanistic explanation and model. *Neurosurg Focus*. 2009;26(2):E11.
20. Spinner RJ, Amrami KK. The balloon sign: Adn M, Hamlat A, Morandi X, Guegan Y (2006) Intraneural ganglian cyst of the tibial nerve. Acta Neurochir (Wien) 148: 885-890. *Acta Neurochir (Wien)*. 2006;148(11):1224-1226.
21. Spinner RJ, Desy NM, Amrami KK, Vosoughi AR, Klaue K. Expanding on the term “balloon” sign. *Acta Neurochir (Wien)*. 2016;158(10):1891-1893.
22. Wilson TJ, Hébert-Blouin MN, Murthy NS, García JJ, Amrami KK, Spinner RJ. The nearly invisible intraneural cyst: a new and emerging part of the spectrum. *Neurosurg Focus*. 2017;42(3):E10.
23. Lenartowicz KA, Murthy NK, Desy NM, et al. Does complete regression of intraneural ganglion cysts occur without surgery? *Acta Neurochir (Wien)*. 2022;164(10):2689-2698.
24. Spinner RJ, Atkinson JL, Tiel RL. Peroneal intraneural ganglia: the importance of the articular branch. A unifying theory. *J Neurosurg*. 2003;99(2):330-343.
25. Spinner RJ, Wang H, Hébert-Blouin MN, Skinner JA, Amrami KK. Sciatic cross-over in patients with peroneal and tibial intraneural ganglia confirmed by knee MR arthrography. *Acta Neurochir (Wien)*. 2009;151(1):89-98.
26. Son BC, Choi JG, Ko HC. Ulnar neuropathy due to intraneural ganglion cyst of the ulnar nerve at the elbow. *Indian J Neurosurg*. 2018;7:260-264.
27. Isaacs AM, Midha R, Desy NM, Amrami KK, Spinner RJ. The mechanism underlying combined medial and lateral plantar and tibial intraneural ganglia in the tarsal tunnel. *Acta Neurochir (Wien)*. 2016;158(11):2225-2229.
28. Spinner RJ, Amrami KK, Wang H, Kliot M, Carmichael SW. Cross-over: a generalizable phenomenon necessary for secondary intraneural ganglion cyst formation. *Clin Anat*. 2008; 21(2):111-118.
29. Lee SH, Kim SH, Kim HS, Lee HU. Palsy of both the tibial nerve and common peroneal nerve caused by a ganglion cyst in the popliteal area. *Medicina (Kaunas)*. 2024;60(6):876.

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Spinner, de Ruiter, Reina, Howe, Amrami. Acquisition of data: Spinner, de Ruiter, Reina, Sala-Blanch, Son, Amrami. Analysis and interpretation of data: Spinner, de Ruiter, Reina, Howe, Son, Amrami. Drafting the article: Spinner, de Ruiter, Reina, Amrami. Critically revising the article: Spinner, de Ruiter, Reina, Howe, Son, Amrami. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Spinner. Administrative/technical/material support: Spinner.

Supplemental Information

Videos

Video 1. https://vimeo.com/1071117810.

Companion Papers

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