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''Flow Void Sign'': Flow Artifact on T2-Weighted MRI Can Be an Indicator of Dural Defect Location in Ventral Type 1 Spinal CSF Leaks

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"Flow Void Sign": Flow Artifact on T2-Weighted MRI Can Be an Indicator of Dural Defect Location in Ventral Type 1 Spinal CSF Leaks

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ABSTRACT

SUMMARY: Patients with spontaneous intracranial hypotension caused by type 1 dural defects typically have an epidural fluid collection on MRI. Still, the location of the defect is not usually readily identifiable on standard MRI sequences and can be at any point along the length of the collection. The most common location for type 1 leaks is ventral and, as such, these are most commonly associated with ventral predominant epidural fluid. Dynamic myelography (either digital subtraction myelography or dynamic CT myelography) is currently the standard of care for localizing the defect. We describe an imaging sign on T2-weighted images caused by CSF-flow egress at the site of the defect that may permit accurate prediction of the site of the CSF leak noninvasively. Importantly, this sign was only observed on 2D T2-weighted and STIR images and not on 3D acquisitions, which notably suppress artifacts. This has implications for optimal MRI spine protocol construction. This sign can be used to limit myelographic range, reduce radiation dose, and increase diagnostic confidence in dural defect location.

ABBREVIATIONS: dCTM = dynamic CT myelography; SIH = spontaneous intracranial hypotension

Spontaneous intracranial hypotension (SIH) is a debilitating disorder caused by spinal CSF leaks, which can be classified as type 1 (dural defect), type 2 (lateral leak with associated diverticulum), or type 3 (CSF-venous fistula).[1] Ventral type 1 leaks occur most commonly as a result of piercing of the dura by a discogenic microspur and result in a predominantly anterior spinal epidural collection of fluid.[2] These fluid collections can be longitudinally extensive and, although most ventral dural defects occur in the upper thoracic spine,[3] there is no predictable relationship between the craniocaudal extent of the collection and the vertebral level at which the causative dural defect is located.[4] Localizing the site of the defect enables targeted treatment to be performed. Current practice utilizes invasive radiographic myelographic techniques, most commonly digital subtraction myelography or dynamic CT myelography (dCTM). Myelography, for this purpose, necessitates examining the entire length of the epidural collection.[3,5] This can result in high radiation doses to the patient, particularly with multiple passes of dCTM.[6,7] These examinations are also sometimes technically difficult without relevant operator experience and sometimes necessitate repeat examinations. These can also be unpleasant experiences for the patient. It would, therefore, be desirable to be able to predict the location of the dural defect from noninvasive imaging. This may allow for a greater likelihood of successful myelography through appropriate targeting, limiting the craniocaudal coverage to reduce radiation dose and shortening procedure time.

In some patients with SIH caused by ventral type 1 leaks, we have noted a flow-related loss of CSF signal on T2-weighted MRI at the level of the dural defect that we have termed the "flow void sign." This is mainly seen on sagittal 2D T2-weighted images, either standard TSE or STIR, but also rarely on axial images at the site of the defect. This sign has also shown to be present in the ventral epidural space and/or adjacent epidural collection. In this brief report, through a series of illustrative cases, we describe the appearance of this finding, which, to our knowledge, has not been reported previously.

CASES

We identified exemplar cases of patients with dCTM-confirmed ventral type 1 spinal CSF leaks in whom a flow void sign was visible on premyelography MRI. The collective experience of the authors in our respective institutions is that the flow void sign is

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Spine MRI protocol

Parameter	Core Sequences		Optional Sequences	
	Sagittal 2D T2-Weighted TSE	Sagittal 3D Fat-Suppressed T2 SPACE	Axial 2D T2-Weighted TSE	Sagittal 3D CISS
Coverage	Whole spine (3 parts)	Whole spine (3 parts)	Epidural collection	Epidural collection
FOV (mm)	220 (cervical) 320 (thoracic) 300 (lumbosacral)	220 (cervical) 320 (thoracic) 300 (lumbosacral)	180	320
Matrix	352 × 392	320 × 310	352 × 264	320 × 380
Slice thickness (mm)	3	1	3	0.8
Interslice gap (mm)	0.3	NA	0.3	NA
TR (msec)	3000	1500	5500	5
TE (msec)	90	125	90	2.5
NEX	2	1.5	2	1
Echo-train length	16	60	16	1

Note:—NA indicates not applicable.

FIG 1. Case 1: Ventral CSF leak at T1-T2. *A*, Sagittal STIR MR image shows a slightly poorly defined CSF flow void sign in the ventral epidural fluid collection at T1-T2 (*arrow*). This finding was also visible on T2-weighted images (*not shown*). *B*, Sagittal image of prone dCTM shows split in the contrast column with leakage into the anterior epidural space at the same level (*arrow*).

identifiable in at least one-half, if not most, patients with a ventral type 1 spinal CSF leak when a 2D T2-weighted sequence is performed. Spine MRI protocols vary between institutions; our experience is that this sign is best seen on standard 2D T2-weighted TSE or STIR sequences and is not readily visible on 3D sequences as the sign is suppressed on these sequences. However, a sagittal fat-suppressed T2-weighted 3D spin-echo sequence such as SPACE (Sampling Perfection Application with optimized Contrast by using different flip angle Evolution; Siemens) remains useful for the purposes of detecting small volumes of epidural fluid as well as diverticula—the latter being relevant for their association with CSF-venous fistulas. As such, we have modified our internal institutional protocols and present an ideal combination of sequences that were obtained. While the sign is most commonly seen on sagittal sequences, it can also be seen on axial T2-weighted sequences more rarely. As such, we sometimes obtain an axial 2D T2-weighted TSE acquisition to cover the length of the epidural collection. A sagittal 3D balanced steady-state free precession sequence, such as CISS or FIESTA, that covers the length of the epidural collection is also sometimes used to try and identify dural defects (Table). For the purposes of this report, intended to introduce and describe the flow void sign, examples were grouped according to their anatomic location.

Flow Void Sign in Epidural Collection

Case 1. A 40-year-old woman presented with a 1-year history of orthostatic headache. Brain MRI showed appearances consistent with SIH, with a Bern score[8] of 8. A spinal MRI showed a ventral epidural collection from C7 to T12. On sagittal T2-weighted and STIR images, at the level of the T1-T2 disc, there was a focal area of reduced signal intensity within the epidural fluid collection. Prone dCTM demonstrated a ventral type 1 CSF leak in the midline at T1-T2 (Fig 1).

FIG 2. Case 2: Ventral CSF leak at T12-L1. *A*, Sagittal T2-weighted MR image shows a flow artifact in the ventral epidural fluid collection extending inferiorly from the level of the T12-L1 intervertebral disc (*arrow*). Note also the presence of a thin, well-defined linear hypointense septation within the collection at T10 (*arrowhead*), which appears distinct from the flow void sign. *B*, Sagittal image of prone dCTM shows contrast leaking at the T12-L1 disc level into the ventral epidural space (*arrow*).

Case 2. A 32-year-old-man presented with a 5-year history of progressive weakness and wasting of both hands. Brain MRI was normal, but spine MRI showed a ventral epidural fluid collection from C2 to L3-L4. Sagittal T2-weighted images demonstrated a prominent area of flow artifact within the epidural collection, extending inferiorly from the level of the T12-L1 disc (Fig 2). Subsequent prone dCTM confirmed the presence of a ventral type 1 CSF leak at the level of the T12-L1 intervertebral disc.

Flow Void Sign Spanning Subarachnoid Space and Epidural Collection

Case 3. A 44-year-old woman presented with a 10-year history of orthostatic headache. Brain MRI showed findings of SIH, with a Bern score of 8. Spine MRI demonstrated a ventral epidural fluid collection from C2 to T12. On sagittal STIR and T2-weighted images, there was an area of relatively poorly defined flow artifact extending from the anterior subarachnoid space at the level of the T10-T11 disc, extending into the adjacent epidural collection. This artifact was not visible on a 3D CISS sequence. Prone dCTM demonstrated a ventral type 1 CSF leak at the level of the T10-T11 disc (Fig 3).

Case 4. A 45-year-old man presented with a 5-year history of headache that was initially orthostatic. The brain MRI showed SIH features, with a Bern score of 7, and cortical vein thrombosis over the right frontal lobe. MRI of the spine showed a ventral epidural collection from C2 to L2. Sagittal T2-weighted MRI of the spine showed a linear area of low signal with poorly defined margins, oriented anteroposteriorly in the subarachnoid space anterior to the conus at T12-L1 and extending into the adjacent epidural fluid collection (Fig 4). Prone dCTM confirmed the presence of a ventral type 1 CSF leak at the level of the T12-L1 intervertebral disc.

Flow Void Sign in Subarachnoid Space

Case 5. A 48-year-old woman presented with a 3-week history of severe orthostatic headache preceded shortly by sudden onset of back pain. MRI of the brain showed features consistent with SIH and a Bern score of 9. MRI of the spine showed a ventral epidural collection from C6 to T8. On the sagittal T2-weighted fast spin-echo sequence, there was a short segment of poorly defined decrease in signal intensity of CSF in the subarachnoid space ventral to the cord, just superior to the level of the T3-T4 intervertebral disc (Fig 5). Prone dCTM identified a ventral type 1 CSF leak in the midline at T3-T4 caused by a partially calcified disc protrusion.

Case 6. A 45-year-old man presented with an 8-month history of orthostatic headache. MRI of the brain showed widespread dural thickening over the cerebral convexities; the Bern score was 2. Spine MRI demonstrated a ventral epidural fluid collection spanning C5 to T2. On the sagittal T2-weighted fast spin-echo sequence, there was a small focal area of decreased CSF signal intensity in the subarachnoid space anterior to the spinal cord at the level of the T1-T2 intervertebral disc (Fig 6). Subsequent prone dCTM confirmed the presence of a ventral type 1 CSF leak via a right paramedian ventral dural defect at the level of the T1-T2 intervertebral disc where there was a paracentral discogenic microspur.

Case 7 – Atypical Location. A 54-year-old woman presented with a 10-year history of headaches following a lumbar puncture.

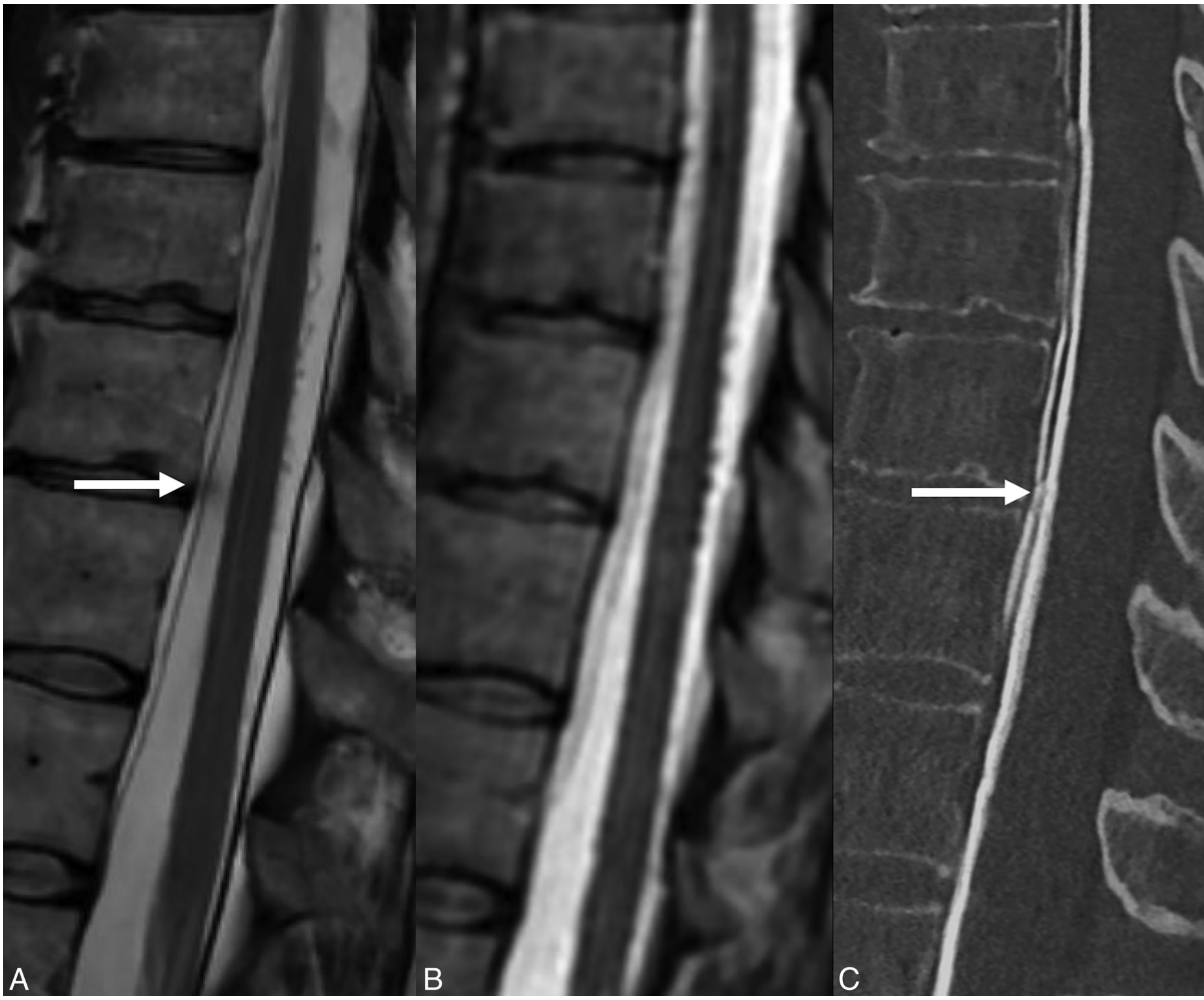

FIG 3. Case 3: Ventral CSF leak at T10-T11. *A*, Sagittal T2-weighted MR image shows a flow artifact in the anterior subarachnoid space and adjacent epidural fluid collection at the level of the T10-T11 disc (*arrow*). *B*, Sagittal 3D CISS MR image shows no flow artifact at this site. *C*, Sagittal image of prone dCTM shows splitting of the contrast column secondary to a ventral leak, originating at the T10-T11 disc level (*arrow*).

Initial brain MRI at the time of presentation showed changes of SIH, Bern score 7, which subsequently resolved. Spine MRI showed a ventral epidural collection from T6 to L5. At the level of the upper third of the L3 vertebral body, there was a subtle flow artifact in the subarachnoid space on sagittal T2-weighted MRI (Fig 7). Prone dCTM confirmed a CSF leak from a paramedian ventral dural defect, attributed to a through and through puncture at the time of the initial lumbar puncture.

DISCUSSION

We have observed that in some patients with SIH and a ventral spinal epidural fluid collection, a CSF-flow artifact occurs on T2-weighted MRI in the anterior subarachnoid space and/or the adjacent epidural fluid collection at the level of the dural defect. We have termed this the flow void sign. The appearances of this flow artifact can range from quite distinct, linear areas of reduced signal intensity oriented transversely, perpendicular to the long axis of the vertebral canal, to more subtle and ill-defined areas of only very slightly decreased signal appearing as a blur or smudge-like. These appear distinct from very thin septa that occur in chronic epidural fluid collections, which are most often very fine, well-defined, and linear and only found within the epidural collection themselves without involvement of the subarachnoid space.

This artifact most likely occurs as the result of CSF motion from the ventral subarachnoid space through the dural defect at the site of the leak into the epidural fluid collection. This flow is perpendicular to the normal craniocaudal pulsation of CSF in the subarachnoid space. This results in a reduction of signal intensity on T2-weighted images by means of time-of-flight effects and potentially also as a result of localized turbulent CSF flow.[9] Since most spontaneous ventral type 1 CSF leaks are the result of piercing of the dura by disc herniations or osteophytic microspurs arising from the vertebral endplate,[2] this artifact almost exclusively occurs at or in very close proximity to the level of the intervertebral disc. In some patients, however, neck flexion or extension during positioning for MRI might cause a dural shift with respect to the relatively fixed bony landmarks of the spine and slightly displace the dural defect and hence the flow void

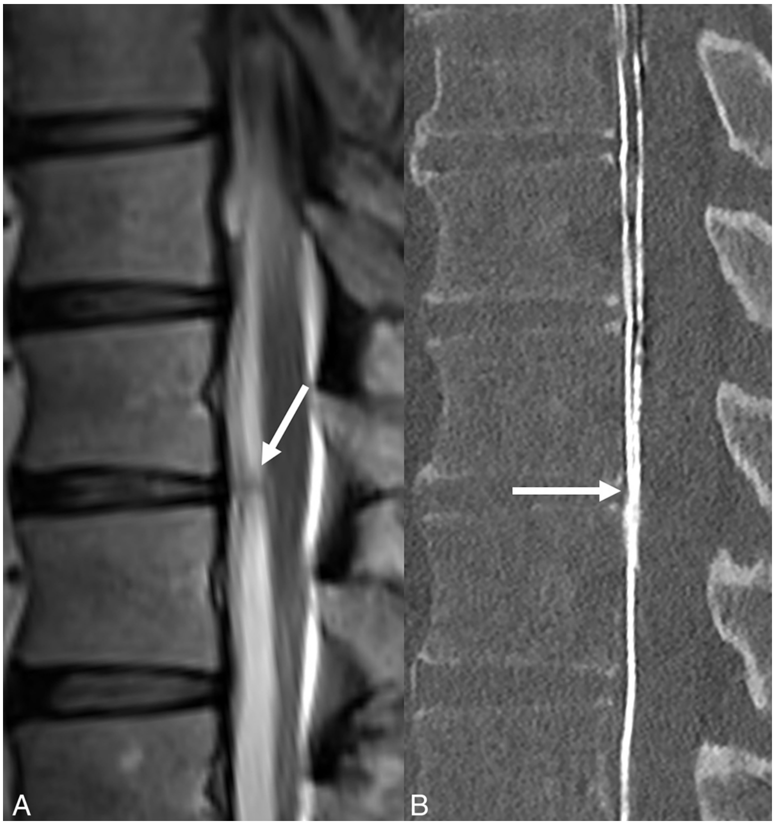

FIG 4. Case 4: Ventral CSF leak at T12-L1. *A*, Sagittal T2-weighted MR image shows a faint area of flow artifact in the subarachnoid space and epidural collection at T12-L1 anterior to the conus medullaris (*arrow*). *B*, Sagittal image of prone dCTM shows ventral leakage of contrast into the epidural collection at T12-L1 (*arrow*).

FIG 5. Case 5: Ventral CSF leak at T3-T4. *A*, Sagittal T2-weighted MR image shows CSF-flow artifact in the anterior subarachnoid space at the level of lower T3 (*arrow*) with an adjacent ventral epidural fluid collection. *B*, Sagittal image of prone dCTM shows corresponding leakage of contrast into the ventral epidural collection (*arrows*), extending superiorly from the leak site adjacent to calcification in the T3-T4 disc.

from disc or endplate level. If this appearance is not at or close to the level of the intervertebral disc, one should also consider that it may not be the flow void sign, or it could be caused by a nonspontaneous cause of ventral leak, as demonstrated in case 7. This localized flow artifact is distinct from that caused by oscillatory CSF flow within the spinal subarachnoid space that occurs synchronously with the cardiac cycle, which tends to cause signal loss over longer distances craniocaudally.[10] We have not observed the flow void sign in patients with leaks from lateral dural tears. This may be because in lateral dural tears, there is an *en face* orientation of the CSF flow through the defect with respect to the sagittal plane (and as such, would not be seen as a perpendicular artifact in the sagittal plane) or, as a result of arachnoid outpouching through the defect, as often occurs with lateral dural tears, obscuring the leak. It is likely that type 1 leaks caused by dorsal dural defects could also show the flow void sign on sagittal T2-weighted MR images given their orientation in the sagittal plane. However, we have yet to observe an example because of the relative rarity of this form of type 1 leak compared with ventral leaks.

This finding has not been reported previously, but other investigators have studied methods of attempting to localize the likely site of a CSF leak noninvasively by means of the appearances on spine MRI. Rarely, the dural defect may be visible directly on high-resolution, thin-section heavily T2-weighted steady-state free precession sequences.[11] The "crossing collection" sign denotes the level at which spinal epidural collections transition from ventral to dorsal or vice versa and has been found to occur within 3 vertebral segments of the site of the CSF leak in 90% of patients[12] and has been proposed as a putative aid to target myelography. When used in combination with other noninvasive findings, this may increase diagnostic confidence. If validated in future studies, the finding of a CSF-flow artifact in the subarachnoid space or epidural fluid collection would allow a more accurate prediction of the leak site before invasive imaging. This would enable a more anatomically focused myelographic examination with the attendant benefit of reduced radiation dose and possibly reduce the need for repeat myelography. When present, the sign may also increase confidence that otherwise potentially equivocal myelographic findings do, in fact, represent the site of the leak. In particularly challenging cases where multiple myelograms have been nonlocalizing, the sign may be useful to guide surgical exploration.

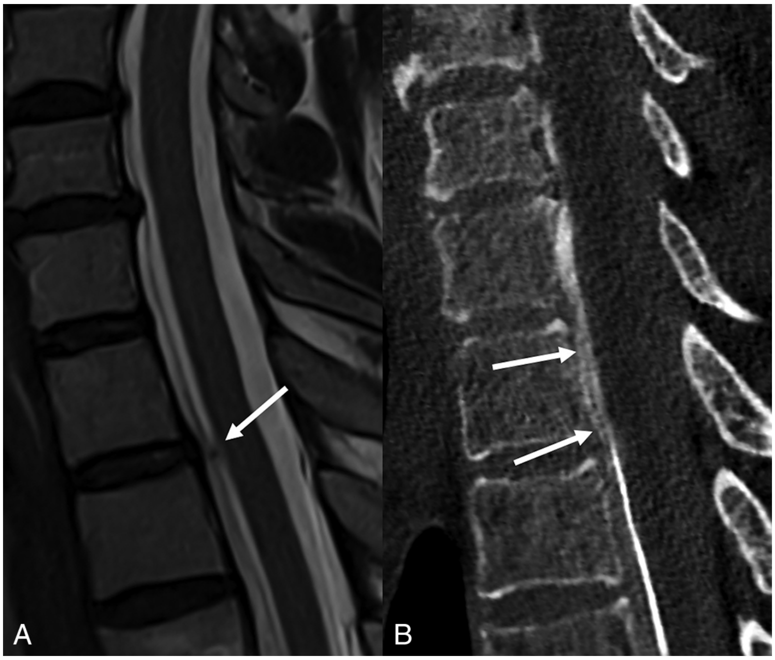

FIG 6. Case 6: Ventral CSF leak at T1-T2. *A*, Sagittal T2-weighted MR image shows a focal flow artifact in the anterior subarachnoid space at the level of the T1-T2 intervertebral disc. *B*, Sagittal maximum intensity projection image of prone dCTM shows contrast leaking at the T1-T2 disc level and extending superiorly (*arrows*).

There are a few potential pitfalls in the application of this imaging sign. First, this sign is not always present. The reasons for this are unclear but may be dependent on a number of factors, including but not limited to the volume of the collection, size of the defect, presence of a bony spur, presence of cord herniation at the defect, and adhesive membrane formation. Second is the presence of septation within the spinal epidural fluid collection, a finding that occurs in some patients with chronic CSF leaks as a result of neomembrane formation or bridging veins within the collection. Our experience is that these potential mimics of the CSF flow artifact sign are much more discrete and finely linear appearing, while the artifact associated with a CSF leak is always slightly ill-defined at

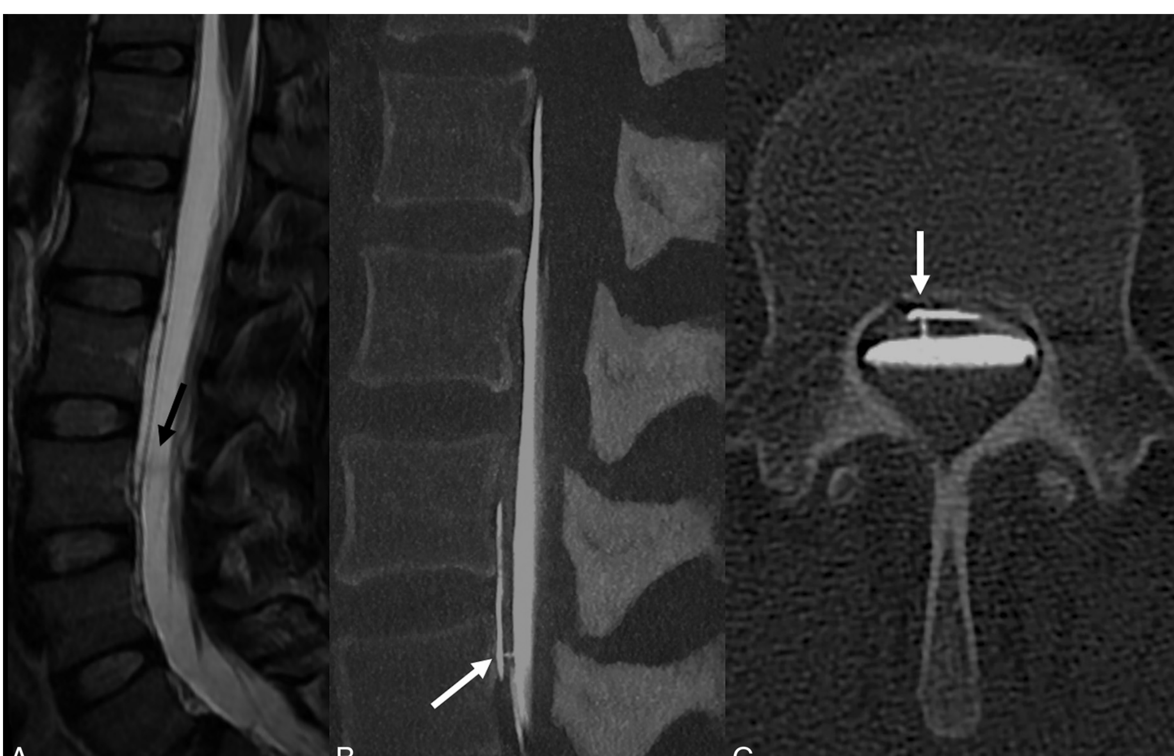

FIG 7. Ventral CSF leak at upper L3. *A*, Sagittal T2-weighted MR image shows a subtle anterior-posterior flow artifact in the subarachnoid space at the upper third of the L3 vertebral body (*arrow*). *B*, Sagittal and (*C*) axial images of prone dCTM confirm CSF leakage at the same level (*arrows*), likely the result of a through and through inadvertent ventral dural puncture from prior traumatic lumbar puncture 10 years earlier. Note the more atypical, more lateral position of the defect in the ventral dura compared with most spontaneous ventral leaks, which are in the midline/slightly paramedian.

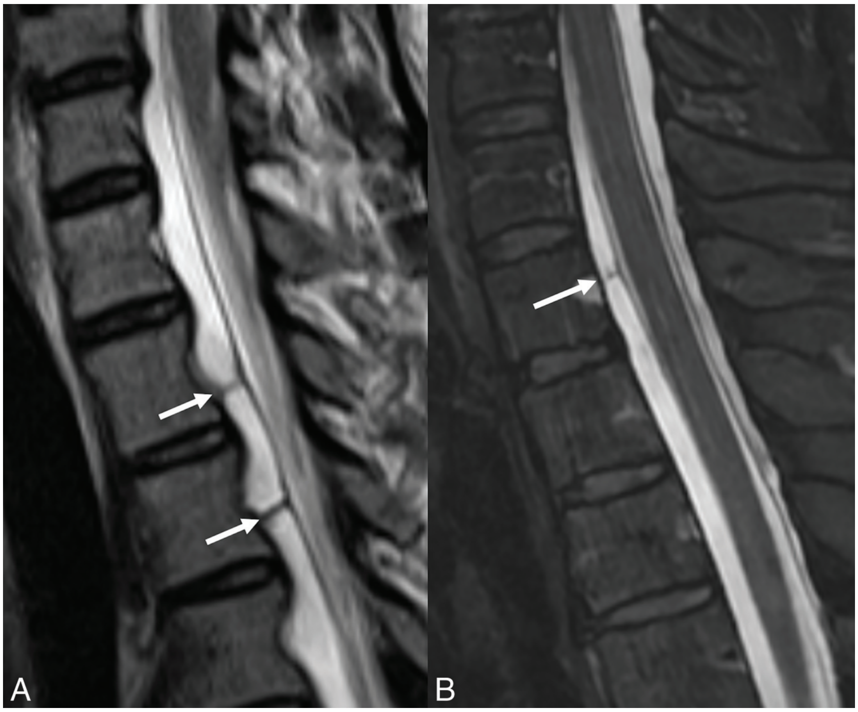

FIG 8. Septations within epidural fluid collections. *A*, Sagittal T2-weighted MR image and (*B*) sagittal fat-suppressed T2-weighted MR image in two different patients show septations (*arrows*) within ventral epidural fluid collections. In contrast to the flow void sign, which often appears to have more blurred margins or is smudge-like, septations are typically very well-defined, band-like areas of linear hypointensity, are often multiple, and traverse the anterior-posterior span of the collection from one margin to the other.

its margins to some degree (Fig 8). We have also found that there is a learning curve to recognizing this artifact, with more subtle examples being particularly easy to overlook until one becomes familiar with the appearances.

The effect of sequence types and specific parameters on the conspicuousness of this sign is not yet known, but we have so far observed it only on standard 2D T2-weighted turbo spin-echo or STIR sequences. Both time-of-flight and turbulence-dephasing signal losses are accentuated by the use of longer echo times and thicker slices, which may affect the ability to detect this sign.[9] Flow artifacts caused by spinal CSF pulsation are also more prominent on 2D than 3D sequences, so protocols that include only 3D sequences may be less sensitive to this sign.[13,14] We have observed this to be the case in our practice also. We have not encountered flow void signs on 3D T2-weighted spin-echo or heavily T2-weighted balanced steady-state free precession sequences such as CISS or FIESTA. While these sequences can occasionally, in our experience, demonstrate dural defects, this is unpredictable and often not sufficient by itself to localize the site of the leak. Therefore, we advocate for including a sagittal 2D T2-weighted sequence as part of the spinal MRI protocol in patients undergoing work-up for SIH, as the use of 3D T2-weighted sequences alone will overlook this finding. Other investigators have reported the utility of phase-contrast CSF-flow studies of the spine in patients with SIH[15] and the role of such sequences in the identification of CSF flow through dural defects is a potential avenue for future research.

This clinical report describes our preliminary observations regarding the definition and appearances of the spinal CSF-flow artifact sign in the context of SIH and thus is necessarily limited in scope. Further studies are required to determine the prevalence of this sign among patients with ventral type 1 spinal CSF leaks, measures of diagnostic accuracy including sensitivity and specificity as well as interobserver and intraobserver agreement, and correlation with intraoperative findings.

CONCLUSIONS

Patients with SIH caused by ventral type 1 spinal CSF leaks can show a localized area of CSF-flow artifact on spine MRI at the level of the dural defect, which, if correctly identified, may allow more focused and targeted myelographic examination.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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