An arachnoid web is an abnormal formation of the arachnoid membrane in the spinal subarachnoid space that blocks CSF flow and causes syringomyelia. Although the precise mechanism of syrinx formation is unknown, dissection of the arachnoid web shrinks the syrinx and improves symptoms. Precisely determining the location of the arachnoid web is difficult preoperatively, however, because the fine structure generally cannot be visualized in usual MRI sequences.

In this report, the authors describe 2 cases of arachnoid web in which the web was preoperatively identified using quantitative CSF flow analysis of MRI. By analyzing cardiac-gated phase-contrast cine-mode MRI in multiple axial planes, the authors precisely localized the obstruction of CSF flow on the dorsal side of the spinal cord in both patients. This technique also revealed a 1-way valve-like function of the arachnoid webs. Imaging led to the early diagnosis of myelopathy related to the derangement of CSF flow and allowed the authors to successfully excise the webs through limited surgical exposure.

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Key Words • syringomyelia • arachnoiditis • arachnopathy • surgery • magnetic resonance imaging • cerebrospinal fluid flow

Abbreviation used in this paper: ROI = region of interest.

If the lesion is a simple arachnoid web, we can dissect the web to restore normal CSF flow. This procedure usually shrinks the associated syrinx and improves neurological symptoms. However, precise localization of the arachnoid web is sometimes difficult preoperatively. The thin structure of the arachnoid web frequently renders it invisible in usual MRI sequences. Moreover, the topological relationship of the arachnoid web to the syrinx is variable. Myelography with CT and cardiac-gated phase-contrast cine-mode MRI in the sagittal plane are likewise not always useful. Therefore, it would be beneficial to find a better method to diagnose and localize arachnoid webs.

In this article, we describe 2 patients with a thoracic spinal dorsal arachnoid web. We used cardiac-gated phase-contrast cine-mode MRI in multiple axial planes encompassing the area of interest and quantitatively ana-
analyzed the CSF flow in those planes. This method clearly showed the blockage of CSF flow in the dorsal aspect of the spinal cord, thereby correctly localizing the lesions. It also demonstrated the 1-way valve-like pattern of the CSF blockage. We herein describe our imaging technique and discuss the importance of studying the detailed flow pattern of CSF in these patients.

Case Reports

Case 1

History and Examination. A 61-year-old woman began to have disturbed sensation in both lower extremities 7 months prior to admission. Weakness of the left lower extremity and gait disturbance developed soon afterward and gradually worsened. On examination, she had mild weakness (Medical Research Council [MRC] Grade 4/5) and markedly decreased position sense in the left lower extremity. Subsequent CT obtained after the intrathecal injection of contrast material, demonstrating the thoracic spine. No space-occupying lesion was observed in the subarachnoid space. Thoracic spine MRI revealed an enlarged dorsal subarachnoid space with ventral shifting of the spinal cord (Fig. 1A and B). Although there was some deformation of the spinal cord in the axial plane, no abnormal lesion was found in the subarachnoid space dorsal to the cord except for some attenuation of the CSF signal on T2-weighted images that probably represented an artifact related to the CSF flow. Myelography CT (via lumbar injection) failed to show a space-occupying lesion in the dorsal subarachnoid space (Fig. 1C). Suspecting a possible derangement of CSF flow, we performed cardiac-gated phase-contrast cine-mode MRI in the sagittal plane; it failed to show a distinct blockage of rostrocaudal CSF movement in the subarachnoid space (Fig. 1D).

Still suspecting CSF flow derangement, we performed a quantitative study of CSF flow in the upper thoracic levels using a 3.0-T MRI scanner (Magnetom Verio, version VB17, Siemens) with software to quantify the CSF flow (Argus Flow, version 4.02, Siemens). We selected three axial planes across the T3–4 level, the most likely area of deranged CSF flow based on the clinical presentation (Fig. 2A). At each plane, we analyzed the CSF flow moving perpendicular to the plane. Data were obtained using cardiac-gated phase-contrast cine-mode MRI: TR 26.35 msec, TE 8.46 msec, velocity encoding 15 cm/sec, flip angle 15°, slice thickness 5 mm, resolution 192 × 192, FOV 200 × 200 mm, voxel size 1.0 × 1.0 × 5.0 mm. Upward and downward flow was encoded into the image intensity, with high intensity indicating upward flow and low intensity indicating downward flow. Thus, the to-and-fro movement of CSF crossing the axial plane in synchrony with a cardiac cycle could be observed cinematographically on a monitor. We then quantitatively measured and analyzed the flow in two regions of interest (ROIs) in the subarachnoid space: one on the ventral side of the spinal cord and the other on the dorsal side (Fig. 2B).

Figure 2C shows the time course of mean CSF flow velocity (cm/sec) through planes at the T3, T3–4, and T4 vertebral levels. Positive values indicate caudorostral flow, and negative values indicate rostrocaudal flow. The corresponding planes are depicted in Fig. 2A (a, b, and c, respectively). The x axis in Fig. 2C shows the time in milliseconds after the beginning of the arterial pulse used as the trigger for data acquisition. At the two rostral levels (T3 and T3–4), CSF exhibited the normal to-and-fro pattern (Fig. 2C, a and b, respectively); however, at the T4 level (Fig. 2C, c), there was a marked reduction in rostral flow in the dorsal ROI, suggesting the existence of a 1-way valve at this level. Because of the gradual progression of the patient’s neurological deficits, we decided to surgically explore the dorsal subarachnoid space at the level of T-4.

Operation. After induction of general anesthesia, the patient was placed prone. We performed laminectomy of T-3 and T-4 and inspected the intradural structures with ultrasonography, which showed a membrane-like structure in the dorsal subarachnoid space moving to and fro in synchrony with the cardiac cycle. After opening the dura mater in the midline, we found an arachnoid membrane that coursed in a slanted angle (from rostral right to...
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caudal left) within the subarachnoid space, dorsal to the spinal cord. The to-and-fro movement of the membrane was easily seen. We dissected the membrane, which restored the pathway for CSF flow on the dorsal side of the spinal cord, and then closed the dura.

Postoperative Course. Immediately after surgery, the patient had marked improvement of the hypesthesia in her lower extremities. The position sense of her left lower extremity improved in 2 weeks, and she was walking normally within 1 month. The slight weakness of her upper extremities disappeared within 2 months. A thoracic spine MR image obtained 1 month after surgery showed slight expansion of the previously compressed spinal cord at the T-4 level (Fig. 3A and B). The flow study showed recovery of the CSF flow on the dorsal surface of the spinal cord at the T-4 level (Fig. 3C and D). No recurrence of signs or symptoms was observed on follow-up at 1 year after surgery.

Case 2

History and Examination. A 32-year-old woman had a 3-year history of bilateral upper-extremity paresthesias, pain, and weakness. On examination, she had MRC Grade 4/5 weakness of the bilateral interossei muscles and hypesthesia to pinprick in the region innervated by C-3 to T-1 bilaterally. Deep tendon reflexes were normal, and Babinski testing was negative bilaterally. Cervical and thoracic spine MRI showed a thin central syrinx in the lower cervical to upper thoracic segments (Fig. 4A) and some prominent flow-related artifacts on the dorsal side of the thoracic spinal cord. However, cardiac-gated phase-contrast cine-mode MRI did not clearly show a CSF blockage.

Using the same techniques described in Case 1, we studied CSF flow in the axial planes at the T-2, T-3, and T-4 vertebral levels and placed the ROIs on the ventral and dorsal side of the spinal cord. As shown in Fig. 4E,
we noted a significant reduction of rostral flow on the dor- 
sal side of the cord at the T-4 level. Based on these find- 
ings, we determined that the derangement of dorsal CSF 
flow near the T-4 level was responsible for the syringomy- 
elia and the patient’s symptoms, and we thus proceeded 
with surgery.

Operation. After T-4 and T-5 laminectomy, we in-
spected the intradural structures with ultrasonography 
and found a membrane-like structure on the dorsal side of 
the cord, which exhibited conspicuous to-and-fro move-
ment (Fig. 4C). We opened the dura and found two leaves 
of arachnoid webs that coursed obliquely on both sides 
of the dorsal aspect of the spinal cord (Fig. 4D). Each 
leaf was associated with a dorsal root that coursed along 
the web and was attached to the root. We incised these 
two leaves of the arachnoid web and restored the normal 
CSF pathway on the dorsal side of the cord. Pathologi-
cal examination of the arachnoid web specimen showed 
a relatively thick connective tissue membrane (Fig. 5 up-
per). Staining with CD3, which is a specific marker for 
T lymphocytes, showed a small number of CD3-positive 
cells (Fig. 5 lower).

Postoperative Course. Immediately after surgery, the 
patient noted improvement of her bilateral upper-extrem-
ity paresthesias. The weakness of her bilateral interossei 
muscles fully resolved within 1 week. A postoperative 
MR image with a CSF flow study obtained 1 month af-
fter surgery showed CSF flow normalization on the dorsal 
side at T-4 (Fig. 4E). The patient had no recurrence of 
signs or symptoms as of 1 year after surgery.

Discussion

In the two cases described above, quantitative CSF 
flow study in multiple axial planes provided a better meth-
od to analyze arachnoid pathology, which is often not visi-
ble in routine MRI sequences. As reported in the literature, 
neither myelography CT nor cardiac-gated phase-contrast
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cine-mode MRI in the sagittal plane can reliably diagnose arachnoid webs. Moreover, the location of the syrinx is not a reliable indicator of the site of arachnoid pathology. For example, Klekamp reported that the syrinx extended rostrally to the lesion in 47% of cases, caudally in 24%, and on both sides in 29%. Being able to more precisely localize the area of CSF blockage and delineate the pathology not only provided us with more confidence in establishing the need for surgery, but also allowed us to limit the extent of surgical exposure.

The imaging technique described in this paper may have a further advantage: the possibility of providing an early diagnosis of arachnoid webs. Moreover, the location of the syrinx is not a reliable indicator of the site of arachnoid pathology. For example, Klekamp reported that the syrinx extended rostrally to the lesion in 47% of cases, caudally in 24%, and on both sides in 29%. Being able to more precisely localize the area of CSF blockage and delineate the pathology not only provided us with more confidence in establishing the need for surgery, but also allowed us to limit the extent of surgical exposure.

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The oblique arachnoid webs that we found in our two cases suggested a possible mechanism for the septum functioning as a 1-way valve. As shown in Fig. 6, if there is a small opening in one end of an oblique septum, in the reverse flow, the opening will be obstructed by deformation of the web. In both of our cases, there seemed to be selective blockage of the rostral movement of CSF by the arachnoid web. This may have been responsible for the syringomyelia being rostral to the blockage in Case 2 and the symptoms in the upper extremities in both cases. A number of hypotheses have been proposed to explain the pathophysiology of syringomyelia associated with CSF flow obstruction. Heiss et al. speculated that enhanced pulse pressure proximal to the syrinx drives CSF into the spinal cord through the perivascular space. By contrast, we hypothesized in previous publications that blockage of the fast components of CSF flow causes

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**Fig. 4. Case 2.** A: Preoperative sagittal T2-weighted MR image. The subarachnoid space dorsal to the cord is expanded in the midthoracic segments. A thin syrinx is observed in the lower cervical to upper thoracic segments. B: Postoperative MR image from 1 month after surgery. Note the dorsal shift of the spinal cord. C: Intraoperative ultrasonography. Two leaves of the arachnoid web (arrowheads) were making a conspicuous to-and-fro movement. D: Intraoperative photograph showing dissection of the thick arachnoid web using scissors. The web was related to an obliquely running dorsal nerve root. E: Preoperative (left graphs) and postoperative (right graphs) analysis of CSF flow at the T-2, T-3, and T-4 vertebral levels. Caudorostral flow was depressed in the dorsal ROI at the T-4 plane in the preoperative study.
a pressure drop in the subarachnoid space distal to the blockage, thereby producing a pressure gradient between the inside and outside of the spinal cord, with the higher pressure being inside (Fig. 7); repetitive generation of this pressure gradient is the driving force of syrinx formation. In our two previously reported cases of arachnoid septum,7 syringes were formed distal to the blockage. The syrinx located in the segment distal to the blockage of rostral CSF flow in Case 2 featured in the present report further supports this hypothesis. Considering the nature of the arachnoid web functioning as a 1-way valve, as demonstrated in our current cases, we can understand that the syrinx is formed rostral to the web if the caudorostral flow is blocked, caudal to the web if the rostrocaudal flow is blocked, and possibly on both sides if both flows are blocked.

Neither hypothesis described above is entirely satisfactory. If the CSF were, as Heiss et al.10 hypothesized, driven into the spinal cord by increased pressure proximal to the blockage, it would be difficult to explain why syringes are formed at a distance from the blockage point. This would suggest that there is a CSF pathway leading from the entry point immediately proximal to the blockage to the syrinx located farther away from the blockage. To our knowledge, no reports have detected such a CSF pathway on imaging studies. On the other hand, our hypothesis also presupposes the existence of a CSF pathway inside the spinal cord, such as an open central canal.6 This type of CSF pathway is also difficult to detect. Further studies are required to more fully understand the pathophysiology of syringomyelia associated with the blockage of CSF flow.

It is currently unknown how nontraumatic arachnoid webs are formed and whether they are congenital or acquired. It is interesting that both of our cases had an asymptomatic small ossification of the ligamentum flavum at the level corresponding to the location of the arachnoid web. One previous case report also described an ossification of the ligamentum flavum associated with...
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arachnoiditis. The presence of CD3-positive cells in the pathological specimen in Case 2 suggests the possibility of an inflammatory process. We speculate that inflammation in the epidural space may have extended into the subarachnoid space, thereby leading to the formation of the relatively thickened arachnoid membrane.

If arachnoid web formation is an early stage of more advanced adhesive arachnoiditis, early diagnosis with early intervention may greatly benefit patients. Diagnosing this lesion before the development of syringomyelia is of particular importance. Therefore, a method of accurately quantifying CSF flow, as shown here, should be considered in patients with possible derangement of CSF flow to detect the presence and location of an arachnoid web.

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Disclosure

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

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