Paravertebral Cerebrospinal Fluid Exudation in Young Women with Postdural Puncture Headache: A Hypothetical Interpretation based on Anatomical Study on Intervertebral Foramen

Takashi Kawahara[1,2] Masamichi Atsuchi[2] Kazunori Arita[1,3] Shingo Fujio[1] Nayuta Higa[1] Ryosuke Hanaya[1]

[1] Department of Neurosurgery, Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan
[2] Normal Pressure Hydrocephalus Center, Atsuchi Neurosurgical Hospital, Kagoshima, Japan
[3] Department of Neurosurgery, Izumi Regional Medical Center, Akune, Japan

Address for correspondence Kazunori Arita, MD, PhD, Department of Neurosurgery, Graduate School of Medical and Dental Sciences, Kagoshima University, 8-35-1 Sakuragaoka, 890-8544, Kagoshima, Japan (e-mail: karita@m2.kufm.kagoshima-u.ac.jp).

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Abstract

Background Postdural puncture headache (PDPH) is defined as a prolonged orthostatic headache secondary to a lumbar puncture. The mechanism underlying this unpleasant complication and the reasons explaining its higher incidence in the young are not well understood. Here, we speculate on the mechanisms underlying PDPH based on spinal magnetic resonance imaging (MRI) in patients with PDPH and an anatomical study on the size of the intervertebral foramen.

Methods Brain and spinal MRI findings were examined in two young women with PDPH. The relationship between age and size of the intervertebral foramen on computed tomography was assessed in 25 female volunteers (22–89 years old) without spinal disease.

Results The causative interventions leading to PDPH were epidural anesthesia for painless delivery in a 28-year-old woman and lumbar puncture for examination of the cerebrospinal fluid (CSF) in a 17-year-old woman. These two patients developed severe orthostatic hypotension following the procedure. Brain MRI showed signs of intracranial hypotension, including subdural effusion, in one patient, but no abnormality in the other. Spinal MRI revealed an anterior shift of the spinal cord at the thoracic level and CSF exudation into the paravertebral space at the lumbar level. Treatment involving an epidural blood patch in one patient and strict bed rest with sufficient hydration in the second led to improvement of symptoms and reduction of paravertebral CSF exudation. The size of the intervertebral foramen at the L2–3 level in the 25 volunteers showed a decrease in an age-dependent manner (Spearman's rho -0.8751, $p < 0.001$).

Keywords
- postdural puncture headache
- PDPH
- orthostatic headache
- intervertebral foramen
- paravertebral space

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Conclusion We suggest that CSF exudation from the epidural space of the vertebral canal to the paravertebral space through the intervertebral foramen, which is generally larger in the younger population, is the causative mechanism of PDPH.

Introduction

Lumbar dural puncture (spinal tap) is a common procedure performed to collect cerebrospinal fluid (CSF) and measure CSF pressure, conduct spinal anesthesia, inject substances for diagnosis or treatment, and so on. Postdural puncture headache (PDPH) is usually orthostatic and often accompanied by nausea and stiff neck. The reported incidence varies widely, ranging from 2 to 40%.[1–4] This is caused by low CSF pressure due to CSF leakage from the dural hole. This condition is generally transient, often lasting several days or more, and can be debilitating or life-threatening.[5–7] Reported risk factors for PDPH include needle size, needle design, bevel direction, and number of puncture attempts.[8–11] Younger age,[12–14] female sex,[12–15] and lower body mass index are also referred to as predictive factors.[16–21]

Although it is obvious that epidural leakage of the CSF from the dural hole is the trigger, the exact mechanisms of PDPH and the reason why it is more frequent in a particular group of patients is not well understood. In this study, we investigated two young women with PDPH using spinal magnetic resonance imaging (MRI) to understand the mechanism underlying this complication. Furthermore, we tried to find the reason of the susceptibility of younger patients to PDPH by measuring the sizes of intervertebral foramen in 25 female volunteers.

Case Presentation

MRI was performed with a 1.5T Vantage Titan scanner (Toshiba, Tokyo) in both cases.

Case 1

A 28-year-old woman delivered a baby under epidural anesthesia with two puncture attempts. After removal of the epidural catheter, the patient developed an orthostatic headache that gradually worsened. She was admitted to our clinic 6 days after delivery. Cranial MRI revealed slit ventricles, bilateral subdural effusion, effacement of the cisterns, and downward displacement of the cerebellar tonsils (►**Fig. 1**).

Spinal MRI at the thoracic level revealed severe anterior displacement of the spinal cord, almost touching the vertebral body. The dura mater behind the cord also shifted anteriorly (►**Fig. 2A**). At the lumbar level, midsagittal T2-fat saturation (T2-FS) MRI showed subcutaneous CSF behind the spinous processes and a dinosaur tail sign (DTS),[22] suggesting accumulation of CSF around the posterior epidural fat pad (►**Fig. 2B**). Left paramedian sagittal and coronal T2-FS scans showed high-intensity networks suggesting CSF exudation around the dural sleeves into the paravertebral space at segments–L2–L5 (►**Fig. 2C,D**).

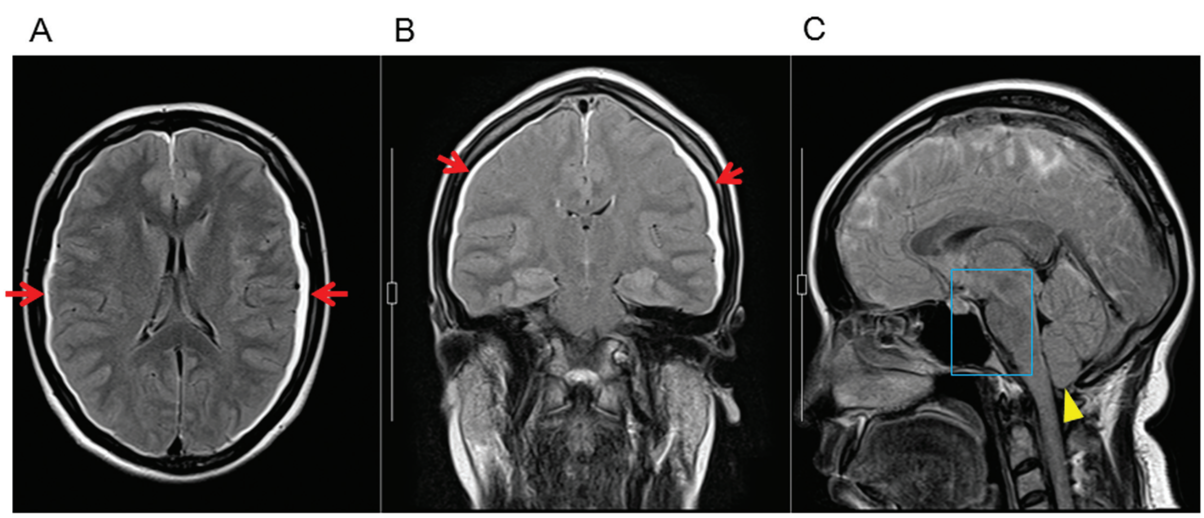

Fig. 1 Magnetic resonance imaging (MRI) of the brain at presentation using fluid attenuated inversion recovery pulse sequence in case 1. Bilateral subdural effusion (*arrows*) is observed on axial (**A**) and coronal (**B**) scans. Sagittal scan (**C**) showing effacement of the basal and prepontine cisterns (*box*) and sagging of the cerebellar tonsils (*arrowhead*).

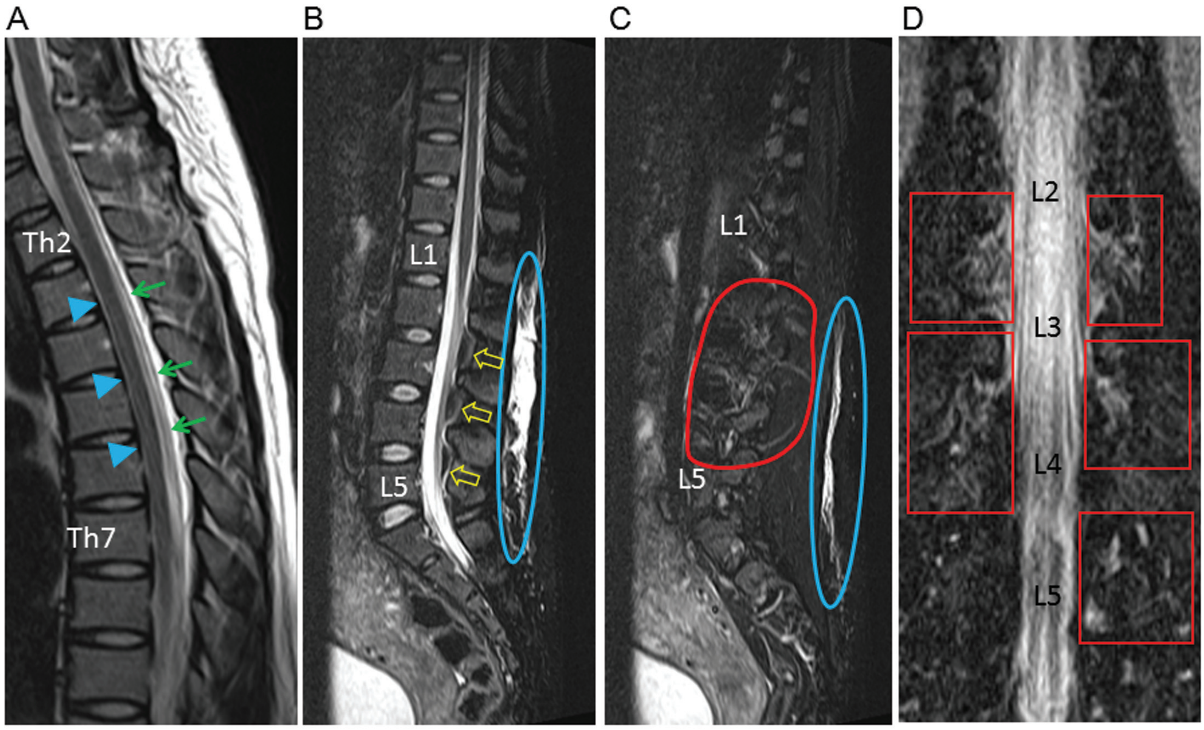

Fig. 2 Spinal MRI at presentation of severe orthostatic headache in case 1. Midsagittal T2-weighted image (T2WI) at the thoracic level (**A**) showing an anterior shift of the spinal cord (*arrowheads*) and dura mater behind the cord (*arrows*). Midsagittal T2-fat saturated (T2-FS) images at the lumbar level (**B**) show the dinosaur tail sign (DTS) (*open arrows*) and cerebrospinal fluid collection (*blue ellipse*) behind the spinous processes. The left paramedian sagittal T2-FS image at the lumbar level (**C**) shows exudation of the CSF around the dural sleeves (encircled by *red line*). Coronal T2-FS image at the lumbar level (**D**) shows CSF exudation resembling a network around the dural sleeves into the paravertebral space (*red squares*).

Based on the clinical course and MRI findings, the patient was diagnosed with PDPH caused by unintentional dural puncture during an attempted epidural catheter placement. She was administered an epidural blood patch (EBP) using 15 mL of autologous blood mixed with the same volume of saline, which quickly improved the postural headache.

Spinal MRI was performed 6 days after treatment. The anterior shift of the spinal cord improved slightly, allowing the reappearance of the CSF space in front of the cord. The dura mater behind the cord returned to its normal position (►**Fig. 3A**), and the DTS almost disappeared (►**Fig. 3B**). The CSF in the subcutaneous and paravertebral spaces was remarkably reduced (►**Fig. 3B–D**).

Case 2

A 17-year-old woman with a history of constant throbbing headache and nausea for the previous year underwent a cranial MRI study at our clinic, which revealed no abnormalities.

To determine the reason for the prolonged headache, lumbar puncture was performed through the L3/L4 intervertebral space using a 23-G needle, which demonstrated normal CSF pressure and laboratory values. Orthostatic headache and nausea developed 1 day later and gradually worsened. She was admitted 3 days after the lumbar puncture. Cranial MRI revealed no abnormalities.

Spinal MRI at the thoracic level showed severe anterior displacement of the spinal cord touching the vertebral body (►**Fig. 4A**). At the lumbar level, mid-sagittal T2-FS MRI showed a DTS (►**Fig. 4B**). Right paramedian sagittal and axial scans showed CSF networks in the paravertebral space at segments Th12 to L5 (►**Fig. 4C,D**). These findings support a diagnosis of PDPH.

Because she rejected EBP, bed rest with sufficient enteral hydration was initiated. On the sixth day after the start of conservative treatment, PDPH symptoms began to improve. MRI at the thoracic level performed 10 days after the start of treatment showed an improvement in the anterior shift of the spinal cord (►**Fig. 5A**), and the DTS at the lumbar level had almost disappeared (►**Fig. 5B**). The paravertebral CSF network also considerably reduced (►**Fig. 5C**).

Age-Related Changes in Size of Intervertebral Foramen

The intervertebral foramen size was evaluated in 25 female volunteers without spinal disease. Their median age was 61 years (range, 22–89 years). The bilateral transverse (T) and longitudinal (L) diameters at the L2–L3 level were measured on a computerized tomography (CT) scan set at

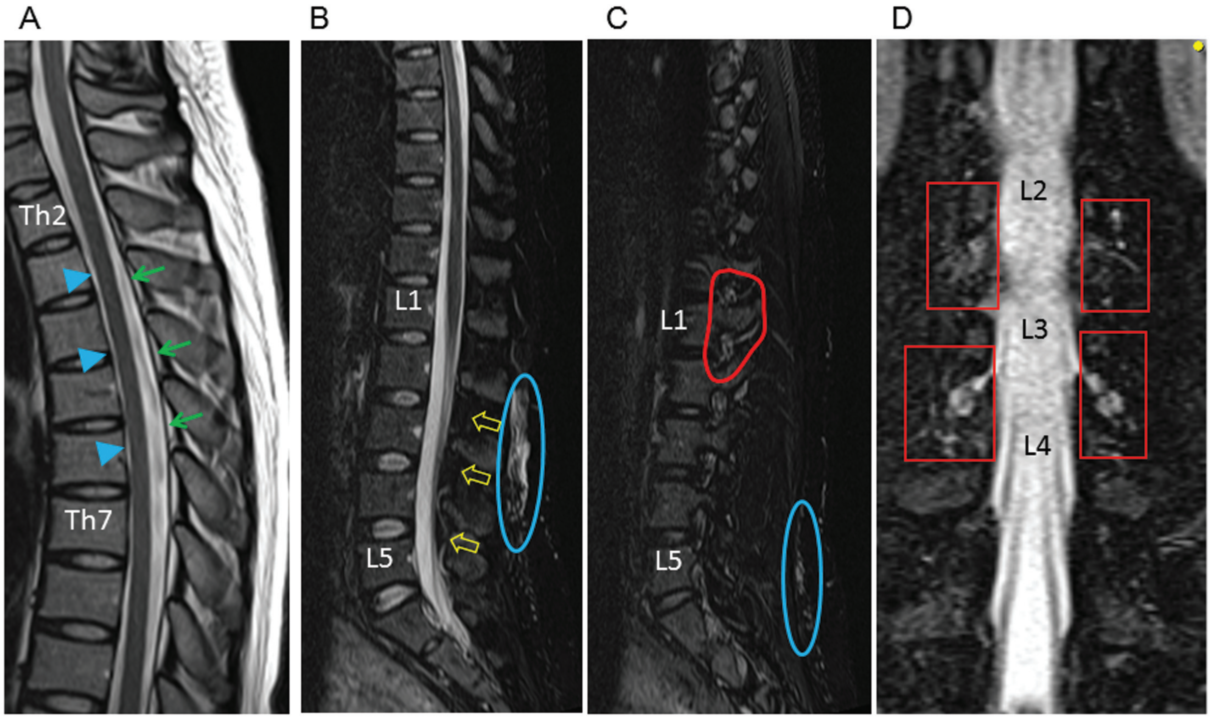

Fig. 3 Spinal MRI 6 days after the epidural blood patch treatment in case 1. Midsagittal T2WI at the thoracic level (**A**) shows improvement in the anterior shift of the spinal cord (*arrowheads*) and the normally repositioned dura mater (*arrows*). Midsagittal T2-FS image at the lumbar level (**B**) shows an almost vanished DTS (*open arrows*) and reduced subcutaneous cerebrospinal fluid collection (*blue ellipse*). Left paramedian sagittal T2-FS image at the lumbar level (**C**) shows remarkably reduced exudation around the dural sleeves (encircled by *red line*). Coronal T2-FS images at the lumbar level (**D**) also show reduced CSF exudation around the dural sleeves (*red squares*).

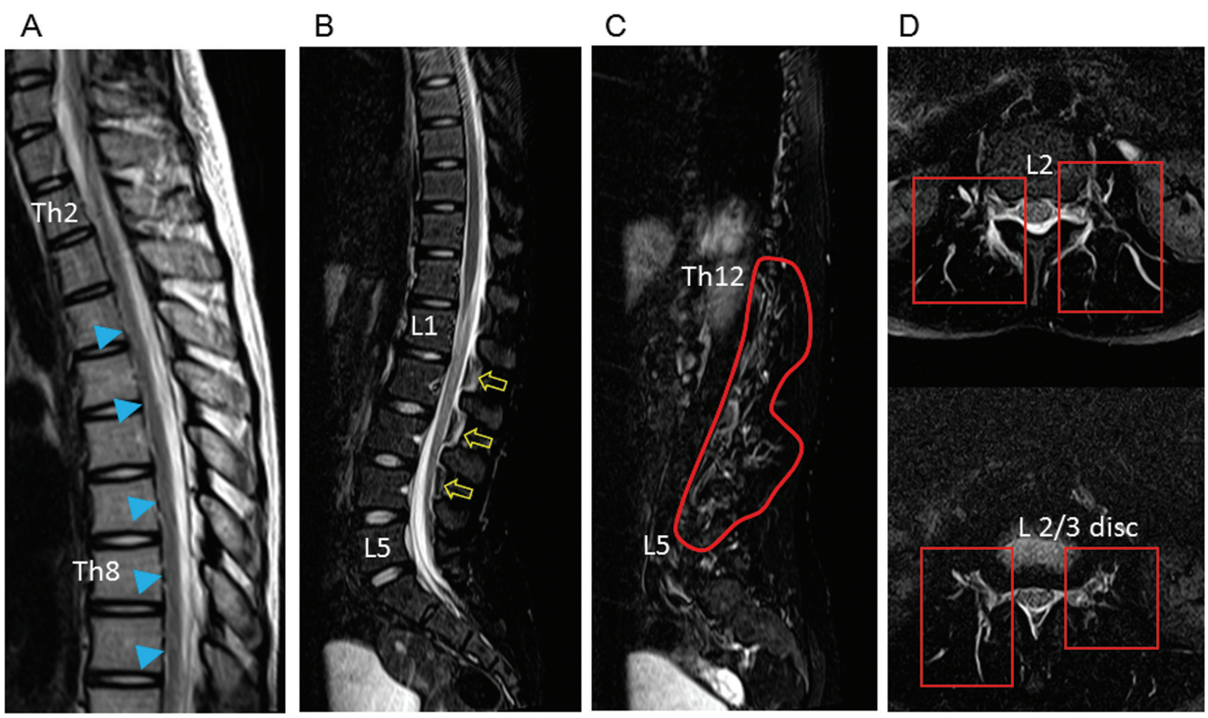

Fig. 4 Spinal MRI 3 days after lumbar puncture in case 2, who presented with orthostatic headache. Midsagittal T2-weighted image (T2WI) at the thoracic level (**A**) shows an extreme anterior shift of the spinal cord (*arrowheads*). Midsagittal T2-fat saturated (T2-FS) image at the lumbar level (**B**) shows the DTS (*arrows*). The right paramedian sagittal T2-FS image at the lumbar level (**C**) shows CSF exudation around the dural sleeves (encircled by *red line*). Axial T2-FS images at the lumbar level show CSF exudation into the paravertebral space (*red squares*).

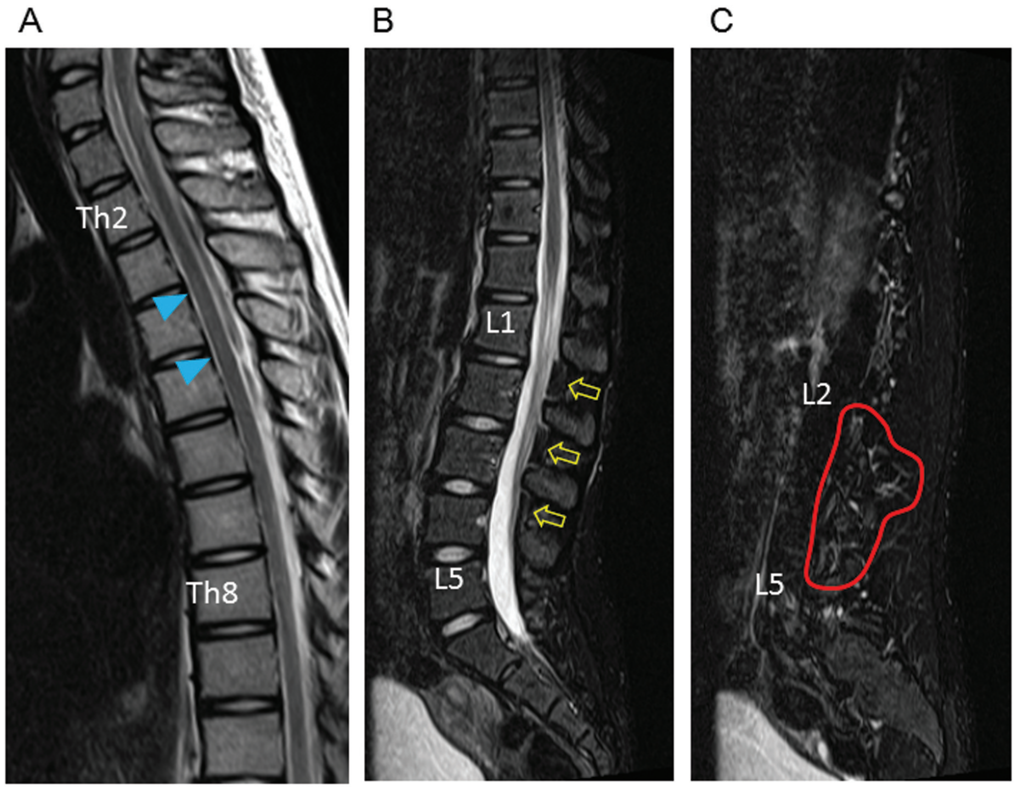

Fig. 5 Spinal MRI 10 days after the start of bed rest in case 1. Midsagittal T2WI at the thoracic level (**A**) shows improvement in the anterior shift of the spinal cord (*arrowheads*), allowing reappearance of the CSF space in front of the spinal cord. Midsagittal T2-FS image at the lumbar level (**B**) shows vanished DTS (*open arrows*). Right paramedian sagittal T2-FS image at the lumbar level (**C**) shows reduced CSF exudation around the dural sleeves (encircled by *red line*).

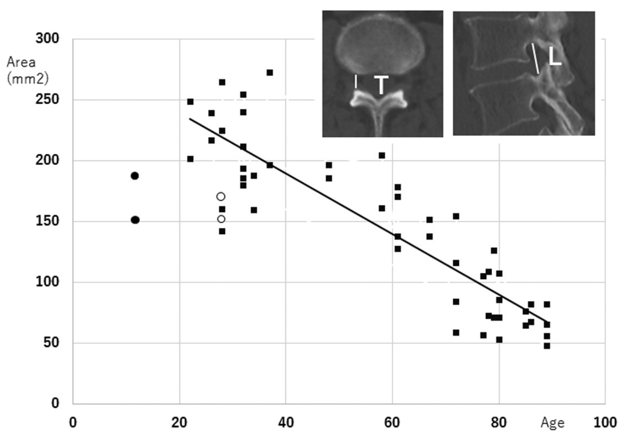

Fig. 6 Relationship between the age and the bilateral sizes of the intervertebral foramen on computed tomography scan. Squares: 25 female volunteers; open circles: case 1, 28-year-old woman; closed circles: case 2, a 17-year-old woman; T: transverse diameter; L: longitudinal diameter. The transverse area (mm^2) was negatively correlated with age.

the bone window (►**Fig. 6**, inlet). The transverse area (mm^2) of the intervertebral foramen was calculated using the following formula: area $= T \times L \times \Pi/4$. A linear negative correlation between area and age was observed (Spearman's rank correlation rho was −0.8751, $p < 0.001$) (►**Fig. 6**).

Discussion

Spinal MRI performed in these two patients with PDPH demonstrated CSF collection not only in the epidural space in the vertebral canal but also in the paravertebral space around the dural sleeves and in the subcutaneous space. Symptomatic improvement with EBP or prolonged bed rest with hydration was accompanied by a reduction in CSF collection in both the intravertebral canal epidural space and paravertebral space.

A prospective spinal MRI study following diagnostic lumbar puncture using a heavily T2-weighted image (HT2WI) showed a high prevalence of 95.7% of widespread periradicular leaks in patients with PDPH.[14] The periradicular leak observed on HT2WI in this study seemed compatible with the paravertebral CSF exudation or network on T2-FS images in our study. Periradicular leak was also observed in 31.6% of their patients without PDPH, but only in restricted areas.

Continual leakage of CSF beyond the vertebral canal may be a prerequisite for the development of symptomatic PDPH, as has been suggested in previous literature.[23–25] In this context, larger dural holes created by larger needles or multiple holes created by repeated attempts may be contributing factors.[9,10,26,27] However, even a single hole made with a small needle can occasionally cause PDPH.[28] Our observation of bone imaging CT at the lumbar level showed a negative correlation between the size of the intervertebral

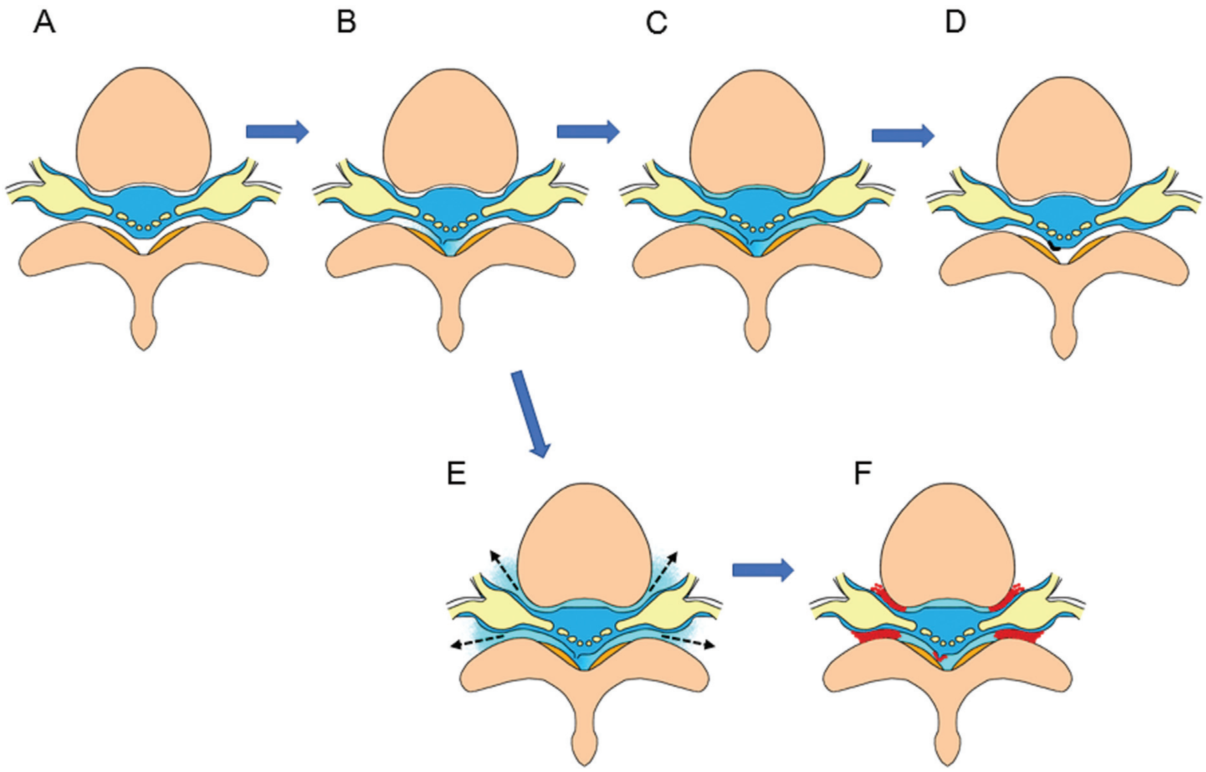

Fig. 7 Hypothesized mechanism leading to PDPH. (**A**) Before dural puncture. (**B**) CSF leaks into the epidural space from the dural hole after dural puncture. (**C**) In most cases, CSF outflow from the intravertebral epidural space does not occur. Then, intra- and extradural pressure equipoise will be established. (**D**) The pressure equipoise will result in spontaneous closure of the dural hole. (**E**) When the intravertebral epidural CSF exudes (arrows) through the connective tissue in the intervertebral foramen, the CSF leak from the dural hole will continues, eventually resulting in PDPH. (**F**) A sufficient volume of epidural blood patch seals the CSF outlets (red dots) as well as the dural hole.

foramen and age, which is comparable to previous studies.[29,30] This finding suggests that wider outlets to the paravertebral space for CSF in the intravertebral epidural space are physiologically prepared for younger patients.

►**Fig. 7** schematically depicts our hypothesized mechanism of PDPH. A hole on the dura mater causes leakage of CSF into the epidural space (►**Fig. 7A,B**). If the epidural CSF remains within the vertebral canal, transdural pressure gradient will become minimum (►**Fig. 7C**). Then, the hole will close spontaneously (►**Fig. 7D**). If the CSF in the vertebral canal exudes further into the paravertebral space through the epidural outlets surrounding the dural sleeves, it ultimately leads to PDPH (►**Fig. 7E**). The epidural space surrounding the dural sleeve is reported to be composed of ligaments, the venous plexus, connective tissue, and adipose tissue.[31–33] This space may be often wider in younger populations, as they have a wider intervertebral foramen.

Some authors have proposed that a lower body mass index (BMI) is a contributing factor to PDPH, but this is not conclusive. A large abdominal panniculus may raise the intra-abdominal and paravertebral tissue pressures, which may prevent CSF leaks around the dural sleeves.[1,3,21] The BMI in case 2 was 17.8. In case 1, the patient weighed 70 kg, with a BMI of 28.8 before delivery. She lost 7 kg body weight after delivery. The acute decrease in abdominal pressure, as well as intravenous pressure, may contribute to CSF exudation into the paravertebral space and the development of PDPH.

Autologous blood injected into the epidural space may provide quick obstruction of the CSF outlets around the shrunken dural sleeves (►**Fig. 7F**), in addition to direct sealing of the dural hole. Sufficient hydration may increase the CSF volume within the dural sleeve, as well as the spinal dural sac, and increase blood volume in the epidural venous plexus, which may result in indirect and slow obstruction of the outlets. Considering that the effect of EBP is supposed to be exerted by obstruction of the outlets around the dural sleeves, and CSF exudation was observed in several spinal segments in our two patients, sufficient volume of autologous blood is needed for EBP.

The authors recently reported that dural sac shrinkage signs (DSSSs) are good indicators for the diagnosis of spontaneous and iatrogenic intracranial hypotension.[34,35] DSSSs are composed of anterior shifts of the spinal cord and dura mater behind the cord observed on MRI at the thoracic level. A severe anterior shift of the spinal cord was observed in our two cases, which improved after treatment. An anterior shift of the dura mater behind the cord was seen in case 1, which became normally positioned after treatment. The combination of DSSSs, DTS, and paravertebral CSF leakage signs on MRI may contribute to the early detection of PDPH.

We acknowledge that the lack of control and spinal MRI studies in patients without PDPH are serious shortcomings of our hypothesis regarding the mechanism of development of PDPH. Furthermore, although the speed of CSF leakage is suggested to play a role in the development of PDPH,[14,36] the sequential dynamics of CSF shift were not investigated in our patients. Future prospective studies should involve the assessment of serial changes in spinal MRI findings in all post-spinal tap patients.

Conclusion

Our hypothesis suggests that PDPH is caused by continuous leakage of CSF from the dural hole and the outlets surrounding the dural sleeves. The relatively larger intervertebral foramen in the younger population may promote this process. A sufficient volume of autologous blood is required to obstruct outlets located over several spinal segments.

Informed Consent

The patients have given written consent to publication of their data.

Funding

None.

Conflicts of Interest

None declared.

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