The Cisterna Magna Septa
Vestigial Remnants of Blake’s Pouch and a Potential New Marker for Normal Development of the Rhombencephalon

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Objective. The purpose of this study was to show the normal sonographic embryologic anatomy of the cisterna magna septa, fourth ventricle, and cerebellar vallecula at various stages of development and our experience with their variable appearance in multiple planes and to discuss the probable relationship between the cisterna magna septa, Dandy-Walker continuum, mega cisterna magna, and persistent Blake’s pouch. Methods. Retrospective and prospective selection of examples of cisterna magna septa was performed over approximately a 12-month period. Standard and nonstandard imaging planes were adopted as necessary. Results. The septa are typically seen inferoposterior to the cerebellar vermis, usually straight and parallel, arising at the cerebellovermian angle and coursing posteriorly to the occipital bone. The cisterna magna septa become contiguous with the roof of the fourth ventricle inferior to the cerebellar vermis. The cerebrospinal fluid space enclosed between the cisterna magna septa is in direct contiguity with the fourth ventricle via the vallecula and is always completely anechoic because it develops intra- and not extra-axially. Conclusions. We propose that the cisterna magna septa represent the walls of Blake’s pouch, a phylogenetic vestigial structure observed during ontogeny. Additionally, our observations support current opinion that a persistent Blake’s pouch and mega cisterna magna represent (less severe) abnormalities within the Dandy-Walker continuum. The cisterna magna septa therefore are a marker of normal development of the roof of the rhombencephalon. Deviation from their normal appearances should prompt a closer assessment for associated abnormalities of the cerebellum, vermis, and brain stem by additional imaging in orthogonal planes with either sonography or magnetic resonance imaging. Key words: Blake’s pouch; cisterna magna; Dandy-Walker continuum; mega cisterna magna; septa.
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Ognized that there is great difficulty in seeing membranes within the posterior fossa at autopsy unless the specimen is examined under water\textsuperscript{5} and also because of specimen degeneration due to autolysis.\textsuperscript{6}

**Characteristics of the Cisterna Magna Septa**

Previous studies have shown that the cisterna magna septa are seen in 84\% to 92\% of fetuses in the second and third trimesters.\textsuperscript{3,4} The fact that they are seen in such a high number of fetuses is probably because they are normal structures.\textsuperscript{4} Their visualization is not dependent on gestational age after 15 weeks\textsuperscript{3} and is dependent on the size of the cisterna magna, being most often observed when the cisterna magna is greater than 3 mm in anteroposterior diameter.\textsuperscript{3} If they are not seen, it is often because of technical or positional issues or skull ossification.\textsuperscript{4}

These same previous studies showed that the cisterna magna septa are typically seen infero-posterior to the cerebellar vermis. They are usually straight and parallel to the anteroposterior diameter of the cisterna magna\textsuperscript{3} arising at the cerebellovermian junction\textsuperscript{4} and coursing posteriorly to the occipital bone (Figure 1). Serial follow-up imaging of the septa show them to be more difficult to discern later in gestation, and they may even disappear altogether, but the posterior fossa structures can be seen to develop normally (Figure 2).

Additional observations not previously described are that the cisterna magna septa become contiguous with the roof of the fourth ventricle inferior to the cerebellar vermis, as shown on fetal (Figure 3) and neonatal (Figure 4) sonography. The cerebrospinal fluid (CSF) space enclosed between the cisterna magna septa is therefore in direct contiguity with the CSF space in the fourth ventricle, via the vallecula. Also, the fluid between the septa is always completely anechoic, whereas the fluid outside the septa is always slightly echogenic (Figures 1–3 and 5), although this effect is reduced throughout gestation.

Often, an additional midline septum is visible in the posterior fossa on fetal and neonatal sonography, which represents the falx cerebelli (Figure 5). Therefore, 1, 2, or 3 septa can be observed depending on the scan plane: sometimes only the midline septum (falx cerebelli) straight to the occiput, sometimes only the 2 parallel septa originating at the cerebellovermian junction, and sometimes all 3 septa.\textsuperscript{4} This triple-septa appearance relates not only to the scan plane but also to the apparent variable inferior extent of the falx cerebelli.

![Figure 1. Typical appearance of the cisterna magna septa (arrows) at 20 weeks' gestation. Cb indicates cerebellum, and Cp, choroid plexus in the lateral ventricle. A, Semiaxial view. B, Coronal view.](image-url)
The Dura

At every site in the brain where the dural leaves are separated, a venous sinus exists in the space between them. This is because embryologically the sinuses develop from rich vascular plexuses within the epidural conjunctive tissue (Figure 6). Therefore, the cisterna magna septa cannot represent dural leaves because we would expect there to be vascular spaces between them, but no vascular flow is ever shown. Although there

Figure 3. Typical appearances of the cisterna magna septa (large arrows) at 13 weeks’ gestation. There was normal follow-up at 18 weeks. A. Above the level of the vallecula, the fourth ventricle (asterisk) is separated from the septa by developing cerebellar tonsils (small arrows). B. Slightly more inferiorly, the walls of the fourth ventricle are contiguous with the cisterna magna septa via the vallecula (arrowhead).
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Figure 4. Typical appearances of the cisterna magna septa (arrows) at 28 weeks on neonatal head sonography. Asterisk indicates fourth ventricle; and Cb, cerebellum. A, Above the vallecula, the fourth ventricle and septa (large arrows) are separated by the inferior vermis (small arrow). B, At the level of the vallecula, the septa (arrows) are contiguous with the walls of the fourth ventricle (arrowheads).

Figure 5. Triple appearance of the cisterna magna septa on neonatal head sonography at 27 weeks’ gestation. The falx cerebelli is separate from the midline cerebellar structures. It becomes progressively smaller in anteroposterior diameter toward the inferior aspect of the posterior fossa until it disappears, owing to its sickle shape. The visible downside “cisterna magna septum” meets the brain at the cerebellar vermis junction. Arrow indicates falx cerebelli; Cb, cerebellum; and Vm, cerebellar vermis.

The inferior roof of the rhombencephalic vesicle evaginates caudal to the developing cerebellar vermis into the meninx primitiva as an ependyma-lined diverticulum, which expands

The Roof of the Rhombencephalon

Early in development, there is focal dilatation of the central canal of the neural tube in the hindbrain. This can be shown by sonography as a cystic structure at the dorsal aspect of the fetal head (Figure 7). This is the rhombencephalic vesicle, and it eventually develops into the fourth ventricle. Normal development of the cerebellar vermis in the superior roof of the rhombencephalic vesicle has been shown on fetal sonographic \(^{11,12}\) and specimen magnetic resonance imaging (MRI) studies, \(^{13-16}\) and, allowing for some physiologic variation in timing, a “closed” (covered) fourth ventricle should usually be present by 17.5 to 18 weeks \(^{17}\) but may be as late as 22 to 24 weeks \(^{11,12}\)

are dural folds in the region of the cisterna magna, they cover tributary veins of the inferior sagittal sinus. \(^9\) Additionally, they meet in the midline at the falx cerebelli and diverge around the foramen magnum, whereas the cisterna magna septa are parallel and do not meet in the midline. For similar reasons, the septa do not represent the walls of the straight sinus, torcular Herophili, or any other vascular structure. Also, the vein of Galen and straight sinus are located above the cisterna magna. \(^10\)
dorsally to form Blake's pouch. The walls of Blake's pouch are composed of an inner layer of ependyma, an intermediate layer of attenuated neuroglial tissue, and an outer layer of pia-arachnoid. Blake's pouch fenestrates to a variable degree down to the obex (the inferior recess of the fourth ventricle), depending on whether the walls of the pouch are supported from adjacent neural and pial structures. This fenestration leaves Blake's metapore. The metapore, otherwise known as the foramen of Magendie, represents the neck of Blake's pouch, and the cisterna magna septa represent the remnants of its walls.

This explains why the fluid between the septa is always anechoic, whereas the fluid lateral to the septa is usually slightly echogenic; the fluid between the septa is intra-axial, whereas the fluid outside the septa is in the subarachnoid space of the cisterna magna. The subarachnoid space is trabeculated in multiple planes by pia-arachnoid septations, a result of its embryologic development, which give rise to the relative echogenicity compared with the intra-axial CSF spaces. The relative echogenicity diminishes throughout gestation as cavitation progresses.

Figure 6. Embryologic features of the dura. A, The brain (large arrow) is covered by a layer of meninx primitiva (small arrow) and vascular mesenchyme (double arrow). B, As the cerebral and cerebellar hemispheres expand and overgrow the developing midline structures (arrows), there is eventual apposition and fusion of the two reflected dural layers from adjacent hemispheres. The meninx primitiva starts to cavitate to form the subarachnoid space, delimited by an inner condensation of pia mater and an outer condensation of arachnoid mater. The vascular mesenchyme persists as a wedge of tissue trapped in the dural folds (double arrow). C, The reflected dural layers fuse, thus forming the falx cerebri, falx cerebelli, and tentorium. The meninx primitiva cavities coalesce to form the subarachnoid space, which is traversed by multiple pia-arachnoid septations (small arrow). Where no dural fusion takes place, the vascular mesenchyme cavitates to form venous sinuses, for example, the superior and inferior sagittal sinuses (double arrows). D, Color Doppler examination at 21 weeks showing flow in the occipital sinus (double arrow) between the diverging dural leaves of the falx cerebelli but none between or within the cisterna magna septa (arrows).
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The process of dorsal expansion also explains why the tela choroidea has been shown to extend outward beneath the vermis into the cisterna magna as it is carried in the walls of Blake's pouch as it expands dorsally. Once fenestration of the pouch occurs, it would then appear as if the tela choroidea would be within the cisterna magna and contiguous with the pia mater over the brain stem.

Lateral Displacement of the Cisterna Magna Septa

The fenestration of Blake's pouch and therefore communication of the pouch with the subarachnoid space are variable in timing but should occur by 4 months. The foramen of Luschka normally opens later than the foramen of Magendie; however, in 1% to 2% of healthy individuals, the foramen of Magendie is absent. This is understandable inasmuch as ontogeny recapitulates phylogeny, and in lower species, the pouch never fenestrates, and Blake's metapore is therefore absent. In these healthy individuals (and in lower species), it is the opening of the foramen of Luschka that leads to equilibrium of CSF between ventricles and subarachnoid cisterns.

We speculate that before fenestration of the foramen, there is transient increased intra-axial CSF pressure, and this explains the enlargement of the fourth ventricle, which is seen around 14 to 16 weeks' gestation, resolving completely by 22 to 23 weeks' gestation. It also probably explains the outward bowing of the cisterna magna septa often observed sonographically, giving the impression of a posterior fossa cyst (Figure 8).

Intraventricular Hemorrhage

Sometimes the septa are bowed laterally by the presence of intraventricular hemorrhage extending posterior to the vallecula (Figure 9). Blood in the cisterna magna has previously been shown to have a high positive predictive value for development of posthemorrhagic hydrocephalus. The likely explanation is that in the premature neonatal population, blood seen interoposterior to the cerebellar vermis is actually not in the cisterna magna but is contained within Blake's pouch and is therefore intra-axial, not extra-axial. Therefore, it has the potential to cause hydrocephalus because its intra-axial location allows it to block the foramina of Luschka and Magendie.

Figure 7 (opposite page). Embryologic features of the developing hindbrain. A, Sagittal view of an embryo at approximately 7 weeks' gestation showing the typical appearances of the rhombencephalic vesicle (arrow). The primitive dorsal pontine flexure is also clearly shown (dotted line). B, During formation of the dorsal pontine flexure of the rhombencephalon (small arrow), a transverse crease forms in the roof of the rhombencephalic vesicle (large arrow), sandwiching a layer of the meninx primitiva. The crease divides the roof of the fourth ventricle (asterisk) into the anterior (superiorly) and posterior (inferiorly) membranous areas. C, The transverse crease and its wedge of vascular meninx primitiva develop into the choroid plexus (large arrow) of the roof of the fourth ventricle. The anterior membranous area thickens and proliferates posteriorly, giving rise to the cerebellar vermis (arrowhead), which covers the posterior membranous area. The meninx primitiva (double arrow) cavitates to form the subarachnoid space. D, As a result of growth of overlying and surrounding structures, the posterior membranous area is left effectively “evaginating” posteriorly into the meninx primitiva between the inferior vermis superiorly (large arrow) and the nucleus gracilis inferiorly (small arrow), forming Blake's pouch, and carries the developing choroid plexus in its roof. The cavitations in the meninx primitiva coalesce to form the subarachnoid space trabeculated by multiple pia-arachnoid septations. The fluid contained by Blake's pouch is intra-axial, even though the pouch itself lies within the developing cisterna magna (double arrow). The pia mater (gray outline) develops as a condensation of the meninx primitiva overlying the developing neural structures. The ependyma lining the neural tube (black outline) also lines Blake's pouch. As the pouch expands, its walls and the associated tela choroidea become apposed to the medial surfaces of the adjacent cerebellar hemispheres and the undersurface of the superjacent inferior vermis. Because these also have pia mater over their outer surfaces, the two outer layers of pia mater become apposed and indistinguishable. E, Blake's pouch fenestrates, leaving an opening at its neck called Blake's metapore (dashed oval). The choroid plexus (arrow) is now in direct continuity with the pia mater over the interior surface of the cerebellar vermis and lies in the extraxial subarachnoid space, although it developed intra-axially. The remnants of Blake's pouch probably persist to a variable degree. F, In the axial plane, Blake's pouch extends dorsal to the fourth ventricle (asterisk) into the developing subarachnoid space below the vermis and between the cerebellar hemispheres. The developing choroid plexus (double arrows) in the roof of the rhombencephalic vesicle has normal caudal extensions on either side of the midline, which, once Blake's pouch fenestrates, will appear to lie on the extra-axial surface of the cerebellum. The lateral recesses of the rhombencephalic vesicle (small arrows) are also in contact with the developing subarachnoid space and fenestrate to form the foramen of Luschka. The walls of Blake's pouch (large arrows) are visible sonographically as the cisterna magna septa.
**Mega Cisterna Magna**

A mega cisterna magna (cisterna magna ≥ 10 mm; Figure 10) is known to result from a defect of the posterior membranous area during embryogenesis. We speculate that in this condition, Blake’s pouch probably persists and expands posterior to a normally formed cerebellum and vermis, but unlike a persistent Blake’s pouch (see below), fenestration occurs late, leaving behind an expanded posterior fossa, thus explaining the free communication between the “cyst,” fourth ventricle, and subarachnoid space that is seen in this condition.
Dandy-Walker Continuum

The observation that the cisterna magna septa were not seen in 16 of 18 fetuses with Dandy-Walker malformation is most likely due to the fact that the cisterna magna septa (the walls of Blake’s pouch) and the walls of the Dandy-Walker cyst are identical anatomic structures, and during expansion of the pouch within the cisterna magna, its walls become apposed to and indistinguishable from the sides of the posterior fossa (Figure 11). In those 2 of 18 cases in which the septa were seen, the size of the Dandy-Walker cyst may simply have been smaller, allowing them to be seen separately, or the diagnosis was erroneous, perhaps representing a persistent Blake’s pouch (see below).

Persistent Blake’s Pouch

In a persistent Blake’s pouch (Figure 12), there is thought to be failure of fenestration of both Blake’s pouch and the foramen of Luschka, leading to dilatation of the fourth ventricle. Although the pouch communicates freely with the fourth ventricle, there is a failure of communication between the pouch and the perimedullary subarachnoid spaces. After ventricular shunting, subtotal or total reexpansion of the cerebellar hemispheres and vermis can be seen; that is, although these structures appear to be hypoplastic, there is actually no intrinsic hypoplasia but just the mass effect of the cyst.

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Figure 8. Septa appear bowed out (arrows), giving a cystic appearance in this neonate at 24 weeks’ gestation. Asterisk indicates fourth ventricle; and Cb, cerebellum. This appearance was seen in 18% of cases in a previous study.

Figure 9. Dilatation of the space between the cisterna magna septa on neonatal head sonography at 31 weeks’ gestation, secondary to intraventricular hemorrhage. A, Semiaxial view showing a dilated space between the cisterna magna septa with blood layering on the head-down (dependent) side septum (double arrow) but not reaching the subarachnoid space over the cerebellar hemisphere (small arrow). Asterisk indicates fourth ventricle; and Cb, cerebellum. B, Axial computed tomography (different patient) showing blood in the “cisterna magna” but on closer observation can be seen to be limited in its lateral extent by “invisible walls” (arrows) corresponding to the cisterna magna septa and indirectly indicating the existence of Blake’s pouch, which itself cannot be resolved.
Figure 10. Suspected mega cisterna magna at 19 weeks’ gestation. 

A. Axial scan below the level of the vallecula showing the cisterna magna septa (arrow) bowed outward. B. Axial scan at level of the vallecula showing the fourth ventricle (asterisk) to be contiguous with space between septa via the vallecula. Arrows indicate cerebellar tonsils. 

C. Slightly oblique midline image showing evagination of the roof of the rhombencephalic vesicle forming a pouch (large arrow) containing anechoic fluid (CSF). The inferior border of the tentorium and falx cerebri is visible (double arrow), with a slightly echogenic subarachnoid space directly inferior to it. The vermis (small arrow) is slightly compressed superoanteriorly. 

D. Sagittal MRI from the same fetus showing a mega cisterna magna (double arrow). The walls of the pouch are not detectable by MRI. The vermis size and morphologic characteristics are normal for gestation with a normal primary fissure (large arrow) and fastigial point (small arrow) but an impression of slight compression inferiorly. 

E. In a mega cisterna magna, the foramina of Luschka and Magendie fenestrate late, leading to dilatation of the pouch and enlargement of the posterior fossa (double arrow). Once fenestration occurs, the vermis, which has developed normally but which may have been elevated, returns to a more normal position. An enlarged “subarachnoid” space results, but actually this enlarged space initially was intra-axial, not extra-axial.
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It has been shown that an increased angle between the vermis and tegmentum without any other abnormality of growth or structure of the vermis or abnormality elsewhere in the fetus may simply represent elevation of the vermis and does not necessarily indicate an adverse outcome, which could be explained by a persistent Blake's pouch. Unfortunately, this elevation of the vermis often leads to the false-positive diagnosis of a Dandy-Walker continuum on axial sonography and inferior vermian hypoplasia on sagittal sonography or MRI. This would explain why there has historically been a poor correlation between sonographic and autopsy findings in apparent cystic malformations of the posterior fossa.

Dandy-Walker Continuum, Persistent Blake's Pouch, and Mega Cisterna Magna: A Single Spectrum

We speculate that the spectrum of findings with respect to the posterior fossa cyst in the Dandy-Walker continuum, persistent Blake's pouch, and mega cisterna magna might depend on the degree of dilatation of Blake's pouch, which in turn depends on the relative timing of fenestration of the fourth ventricle outlet foramina. It would appear that in a persistent Blake's pouch, the vermis is fully formed, but neither the pouch nor the foramina of Luschka fenestrate, leading to elevation of an otherwise normal vermis. In the Dandy-Walker continuum, there is...
Figure 12. Persistent Blake’s pouch at 23 weeks (case courtesy of Ants Toi, MD, and Susan Blaser, MD, Department of Medical Imaging, University of Toronto, Toronto, Ontario, Canada). The fetus was stillborn at 28 weeks because of placental insufficiency in a mother with sickle cell disease. The karyotype and pathologic findings were both normal. A, Axial view with an expanded fourth ventricle (asterisk) and neck of Blake’s pouch causing a mass effect with concavity of the adjacent cerebellar hemispheres (Cb), which appear normal in size. Cp indicates cerebral peduncles. B, Sagittal MRI showing a cerebellar vermis (double arrow) with normal landmarks that has normal biometric characteristics, but it is angled away from the tegmentum (small arrow), with a large gap between the inferior vermis and brain stem (arrowhead). Because the vermic structure is normal, this gap should not be confused with inferior vermic hypoplasia. Adapted with permission from Imaging the Central Nervous System of the Fetus and Neonate. C, Sagittal histopathologic specimen showing that the vermis has returned to a normal position as Blake’s pouch has collapsed. The fourth ventricle is now normal in size (asterisk). The vermic structure is normal, with normal primary (long arrow) and prepyramidal (short arrow) fissures. It is important to note that in the fully mature vermis, there will be 3 lobules between these 2 landmarks (declive, folium, and tuber), but unlike the other vermic lobules, their white matter cores unite before reaching the fastigium (circle). On fetal MRI, this can lead to underestimation of the number of visible vermic lobules. Reproduced with permission from Imaging the Central Nervous System of the Fetus and Neonate. D, In a persistent Blake’s pouch, the cerebellar vermis forms normally. Nonfenestration of the foramina of Luschka and Magendie leads to dilatation of the fourth ventricle and Blake’s pouch and elevation of the vermis (small arrow) away from the brain stem. There is no demonstrable communication between the cyst (double arrow) and the subarachnoid space by contrast cisternography.
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variable vermian hypoplasia and elevation and variable fenestration.\textsuperscript{29} In a mega cisterna magna, the vermis is fully formed, but fenestration of Blake’s pouch and the foramen of Luschka is delayed, thus allowing sufficient CSF equilibration for the vermis not to be elevated but only after it has already caused expansion of the cisterna magna.

Conclusions

We propose that the cisterna magna septa represent the walls of Blake’s pouch, a phylogenetic vestigial structure observed during ontogeny, the remnants of which are probably present in the neonatal period and possibly even into adulthood. Additionally, our observations support current opinion that a persistent Blake’s pouch and mega cisterna magna may represent (less severe) abnormalities within the Dandy-Walker continuum.

The cisterna magna septa are therefore a potential new marker of normal development of the roof of the rhombencephalon. Deviation from their normal appearances should prompt a closer assessment for associated abnormalities of the cerebellum, vermis, and brain stem by additional imaging in orthogonal planes with either sonography or MRI.

References


