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The anatomy of the ventricular system

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An understanding of the form and detail of the ventricular system is an important point of departure when beginning to learn neuroendoscopy. Knowledge of the form and detail allows planning of the optimal entry point to enable viewing desired structures. This information also acts as a road map to direct the endoscopist to targets. It is essential to know what is just beyond the structure at the tip of the scope. Pathologic processes, such as hemorrhage, ventriculitis, and hydrocephalus, may alter the appearance of the ependymal surface of the ventricle but usually do not alter structures needed to navigate the ventricular system. Obviously, knowledge of the function of structures within the field of interest is important to you and the patient.

Detailed function of the structures forming the ventricular systems and the consequences of injuring them are beyond the scope of this article. The author assumes the reader understands the functional anatomy.

What is seen on the monitor depends on the orientation at entry to the ventricle. Structures at the immediate penetration point are difficult to see because they remain behind the lens. Noting the orientation of the patient's head before draping is critical for the endoscopist's interpretation of the structures and direction within the ventricular system. Initially, it may be helpful to have the patient's head straight brow up or lateral to limit the mental gymnastics. As one develops a three-dimensional concept of the anatomy, orientation becomes easier.

As with all neurosurgical procedures, complications are always a possibility. Only with the use of this information and practice with the scopes within the ventricular system will this become a safe and useful procedure.

Development

The cerebral ventricular system at first seems complex; however, when understood from the point of the developmental anatomy, it is much simpler. Telencephalic vesicles bud from the prosencephalon as symmetric bilateral spheres at the extreme rostral end of the embryo. The openings into the diencephalic vesicle, the future third ventricle, become the foramen of Monro. Choroid plexus develops along the dorsal raphae of the diencephalic vesicle and splits at the foramen, extending into each telencephalic vesicle. From this point, the rapidly developing cerebral hemispheres draw a group of structures that originate near the foramen out into the ventricular system. These structures become the endoscopic road maps for the lateral ventricles. Structures that originate near the foramen and end up in the temporal horn include the caudate nucleus, hippocampus, fornix, choroidal fissure, and choroid plexus. In lower mammals, the hippocampal structures move posteriorly along the paramedian with advancing phylogeny to end up in primitive forms near the foramen and, in rodents, over the posterior third ventricle.

As the hippocampal structures move posteriorly, the single large bundle of fibers is drawn out and trails behind as the fornix. Columns of the fornix fuse together as they pass over the foramen of Monro. At the anterior commissure, they again separate and each side splits into a precommissural tract and postcommissural tract. These two tracts pass ventrally and laterally, one to the septal area and the other to the mamillary body, thalamus, and midbrain.

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In primates, especially man, the parietal lobe has evolved from a structure principally for sensory function of the face to a structure serving intellectual functions. This has caused a large expansion of the parietal lobe driving the temporal lobe with its contents inferiorly and anteriorly. Rapid enlargement of the cortex of the frontal, parietal, and temporal lobes opercularizes the insular cortex.

The choroidal fissure with the choroid plexus wraps around the thalamus, passing into the temporal horn along its medial surface. The hippocampus moves with the choroidal fissure into the medial temporal lobe. This process creates a lateral ventricular system that has the form of a ram's horn. The head of the caudate nucleus begins anteriorly and laterally in the anterior horn of the lateral ventricle. The body and tail of the caudate wrap around the lateral portion of the thalamus, again like a ram's horn. The venous drainage comes out of the caudate nucleus and thalamus in the groove between the caudate and thalamus, the thalamostriate vein, and ends at the foramen of Monro, where it joins the internal cerebral veins in the roof of the third ventricle.

The corpus callosum originates as a commissural bundle anterior to the foramen of Monro and then expands superiorly and posteriorly as the cerebral hemispheres blossom. Obviously, this large midline commissure cannot continue into the temporal lobe because of diencephalic structures occupying the midline. Thus, the caudal end of the corpus callosum, the splenium, comes to rest at the posterior end of the third ventricle above the habenular commissure, the pineal gland, and the Galenic venous system.

The columns of the fornix are connected to the corpus callosum by paired thin membranes. As the hippocampus moves posteriorly with the corpus callosum, these membranes are drawn out as the septum pellucidum. This creates two potential cavities. One, located between the leaves of the septum, is the cavum septum pellucidum and its posterior extension, the cavum verge. Below the fornix, the arachnoid and choroidal fissures are folded back over the roof of the third ventricle, creating the second potential space, the cavum vallum interpositum. In children with poorly developed brains, these potential cavities can be large spaces that can either obstruct the ventricular system and cause hydrocephalus or participate with the ventricles in the expansion caused by hydrocephalus. These cavities are also the sites where missed directed shunts or endoscopes can end up, which presents a confusing picture to the endoscopist.

The diencephalic vesicle becomes the third ventricle, and the mesencephalic vesicle, which is the largest portion of the embryonic ventricular system, becomes the relatively small aqueduct.

The fourth ventricle is created by the development of the cerebellum from the lip of the rhombencephalon. This lip runs from side to side in the coronal plane. Also developing along the edge of this lip is the choroid plexus of the fourth ventricle. The expansion of the cerebellum rolls the choroid plexus under the caudal edge. Thus, the choroid plexus runs from side to side from one foramen of Luschka to the other in the inferior roof of the fourth ventricle.

Anatomy of the lateral ventricles

In considering the lateral ventricular system, it is helpful to use the designation of the portions of the ventricle that was employed by neurosurgeons when pneumoencephalography was in common use.

- Portion 1: the frontal tip of the lateral ventricle to the anterior edge of the foramen of Monro
- Portion 2: the anterior edge of the foramen of Monro to its posterior edge
- Portion 3: from the posterior edge of the foramen of Monro to the posterior edge of the thalamus
- Portion 4: the trigone of the lateral ventricle from the posterior edge of the thalamus to the beginnings of the occipital and temporal horns
- Portion 5: the occipital horn
- Portion 6: the temporal horn

Portion 1 of the lateral ventricle, with the occipital horn and the tip of the temporal horn, are portions of the ventricle without choroid plexus. The absence of choroid plexus and its immediate proximity to the foramen of Monro are the major identifying characteristics of this portion. Medially is the septum with the septal vein. Inferiorly is the septal area, and laterally is the head of the caudate nucleus. The anterior limit and the roof are formed by the anterior fibers of the genu of the corpus callosum. These fibers pass obliquely anterior and lateral to the frontal lobe; thus, the anterior horn slopes anterior lateral.

Portion 2 of the lateral ventricle is essentially the foramen of Monro and is the structure for orientation within the anterior lateral ventricle. The anterior and superior edge of the foramen is the fornix. Above the fornix is the septum pellucidum, which forms the medial wall of this portion of the ventricle and extends superior to the corpus callosum. The corpus callosum forms the roof, which joins laterally with the head and the beginning of the body of the caudate nucleus. The anterior thalamus forms the floor. The anterior inferior edge of the foramen is the septal area. Turning in the groove between the caudate and thalamus is the thalamostriate vein, which enters the foramen of Monro to join the internal cerebral vein. With the thalamostriate vein, the choroids plexus passes into the foramen and forms the posterior boarder.

Portion 3 of the lateral ventricle is that portion of the ventricle located above the thalamus. Its main identifying characteristics are that it is the only portion with the choroid plexus on the medial floor and it is immediately behind the foramen of Monro. The presence of the choroid plexus on the medial floor orients the endoscopist when the approach is posterior from the trigone. The body of the caudate and the roof form the lateral wall by the corpus callosum. The thalamostriate vein is usually a prominent vessel running in the groove between the thalamus and caudate. The septum diminishes rapidly posteriorly so that the most caudal part of the medial surface of portion 3 is formed by the choroid plexus, which covers the fornix. When approaching posteriorly, the choroid plexus and the thalamostriate vein are the road map to portions 1 and 2. The anterior thalamus is at the foramen of Monro, and the fornix and choroid plexus are closely applied to the thalamic surface in portion 3. The distance to the contralateral thalamus through the septum pellucidum is short when the contralateral ventricle is not dilated. Septostomy directed posterior to the foramen and at a small contralateral ventricle risks injury to the contralateral thalamus and internal capsule, especially the genu.

Portion 4 of the lateral ventricle is the confluence of portions 3, 5, and 6, often referred to as the trigone. It lies behind the thalamus and contains the glomus of the choroid plexus. Medially, the visual radiations pass to occipital pole, whereas ventrally and laterally is the white matter of the occipital and temporal lobes. It is important to be familiar with the characteristics of the entry into portions 3 and 6 from this portion because this determines whether you enter into the frontal or temporal horns.

Portion 5 of the lateral ventricle is the occipital pole and the most variable in size of all the ventricular portions. Again, it is one of the portions without a choroid plexus. Medially and inferiorly are the visual radiations passing to the medial occipital lobe. Superiorly and laterally are the fibers from the splenium of the corpus callosum passing to the lateral and inferior occipital lobe.

Portion 6, the final portion of the lateral ventricular system, is located within the temporal lobe. When approaching the trigone posteriorly, the temporal horn is slightly more lateral than portion 3 and the choroid plexus is on the medial roof rather than on the floor. Medially and superiorly are the choroid plexus and hippocampal structures. The deep white matter tracts of the temporal lobe form the lateral wall.

Malformations of the lateral ventricles

Many of the malformations of the cerebral hemispheres are associated with hydrocephalus, and ventriculostomy may be a treatment option. Hydrocephalus is a sign that the malformation has created an underlying obstruction causing problems with the circulation of cerebrospinal fluid.

As in all good medical practice, a through review of the patient's history and physical examination and study of the neuroimages before the procedure are essential.

Holoprosencephaly results from a lack of division of the prosencephalon into the two telencephalic vesicles. Hydrocephalus with an expanding large dorsal cyst may be present, requiring management of the hydrocephalus. Abnormalities of the face, such as extreme hypotelorism, reveal the underlying brain malformation. Children with this malformation lack intellectual development. Holoprosencephaly is common with trisomy.

Schizencephaly is a defect in the cerebral mantle. It is most common in the third and fourth portions of the ventricular system but can occur in the other portions. The ventricular system may communicate directly with the subarachnoid space, which is referred to as open-lipped schizencephaly. In closed-lip schizencephaly, the lips of the cortical defect are fused. This may be an incidental finding in normal children or associated with seizures or intellectual delay. Hydrocephalus is occasionally present.

Hydranencephaly is an extreme form of schizencephaly in which most of the cerebral hemispheres are absent bilaterally, precluding intellectual development. Hydrocephalus is often present. It is essential to distinguish this entity from maximal hydrocephalus, because the outlook is quite different.

Porencephaly is a cavity within the paraventricular white matter. Most communicate with the ventricular system. They may be congenital or occur secondary to injury, either vascular or traumatic. Premature infants with intraventricular hemorrhage often have such a cavity located in the frontal lobe, but it may be located anywhere along the germinal matrix. Poorly controlled hydrocephalus can cause a porencephalic cyst to develop along the shunt tract.

Diverticula of the ventricular system are rare, but it is essential that they be recognized for what they are. Most often, they occur in cases of hydrocephalus in which the supra- and infratentorial compartments are isolated from each other. Differential pressures allow a portion of the medial lateral ventricle to herniate into the parasellar or quadrigeminal cisterns. These "tics" usually arise along the choroidal fissure from portions 3 and 4.

Agenesis of the corpus callosum results in a major decrease in the amount of white matter in each cerebral hemisphere. Because the third ventricle is not constrained by the corpus callosum, the fornix moves laterally, causing the frontal tips of the lateral ventricles to diverge. Portions 3, 4, and 5 are usually large, so-called "copocephaly," expanding to fill the space left by the absent white matter. Only rarely is agenesis of the corpus callosum accompanied by hydrocephalus.

Ependymal and choroidal cysts are not uncommon within the lateral ventricles. They are usually small and can spontaneously disappear. Occasionally, they are large and obstruct the ventricular pathway, causing hydrocephalus proximal to the obstruction. These cysts can be managed by endoscopic fenestration.

Loculations of the ventricular system are rare. What is common is for paraventricular cysts to coalesce and expand, producing what seems to be a loculated portion of the ventricle. When entering these cavities, the absence of ventricular elements, choroid plexus for intense, reveals their nature. Biopsy of the wall reveals it to be composed of white matter containing myelinated axons. Hydrocephalus is almost invariably present. The hydrocephalus has usually been complicated by ventriculitis or ventricular hemorrhage.

Anatomy of the third ventricle

A clear understanding of the structures that comprise the limits of this ventricle is extremely important to the neuroendoscopist. Even more importantly, the structures just beyond the walls of this ventricle must be clearly understood.

Anteriorly, the two fornices come close together in the midline with only a small groove between them, forming the anterior and superior margin of the third ventricle and of the foramen of Monro. As the columns pass ventrally, each splits into an anterior and posterior limb over the anterior commissure and moves laterally, with the anterior limb ending in the septal area and the posterior limb ending in the mamillary bodies. Ventral to the anterior commissure is the lamina terminalis, which ends in the optic chiasm. The superior optic chiasm actually forms a portion of the anterior third ventricle.

The roof of the third ventricle is composed of the choroid plexus, internal cerebral veins, and columns of the fornix. As the most caudal portion of the fornix, the columns move laterally, and an interconnecting band of tissue, the fimbria, forms the posterior superior roof of the third ventricle. Below these structures are the choroid plexus, internal cerebral veins, and velum interpositum.

The pineal recess and the pineal gland form the posterior limits of the third ventricle superiorly. Below the recess are the posterior commissure and the aqueduct of Sylvius.

The paired mamillary bodies and the hypothalamus form the floor of the third ventricle. The floor slopes downward from the mamillary bodies into the infundibulum and pituitary recess. The mamillary bodies are usually prominent structures that are easily seen. The floor of the ventricle immediately in front of the mamillary bodies is often not transparent, and structures under it cannot be seen. Usually, when hydrocephalus is present, the floor is thinned and the vascular structures are visible. More anteriorly, the floor of the hypothalamus may be slightly pigmented. Below, exterior to the third ventricle is the posterior clinoid, and between the clinoid and the interpeduncular fossa runs the membrane of Liliequist. If one passes through the floor of the third ventricle in the midline anterior to the mamillary bodies and the basilar artery tip, the prepontine cistern is entered. As one move more rostrally and passes through the floor of the hypothalamus, the suprasellar cisterns anterior to the membrane of Liliequist are entered. The floor of the third ventricle is the hypothalamus, and injury can lead to endocrinopathies. Moving too far forward may cause the scope to pin the floor against the posterior clinoid.

There are three recesses that can increase greatly in size during hydrocephalus. They are the optic, pituitary, and pineal recesses. When distended, the optic recess leaves the anterior commissure as an obvious structure in the anterior third ventricle. The pituitary recess can become large and thinned to the point of being almost transparent, revealing the structures in the parasellar cisterns. The pineal recess expands into and often fills the quadrigeminal cistern.

The lateral walls of the third ventricle are formed by the medial surfaces of the thalami. Passing posteriorly along the superior margin of the medial thalamus is the stria terminalis, which ends in the habenular nucleus and commissure. Because this structure is often obscured by the choroid plexus of the third ventricle, it is usually not visible through the ventriculoscope. The massa intermedia usually occupies the middle portion of the third ventricle. This is a noncommissural structure of variable size connecting the medial portions of the thalami. In the Chiari II malformation, the massa intermedia occupies a major portion of the third ventricle.

Some important vascular structures are located external to the third ventricle in the subarachnoid space. Below the posterior floor of the third ventricle in the interpeduncular cistern are the tip of the basilar artery and the two mesencephalic portions of the posterior cerebral arteries. There are also a number of smaller penetrating arteries that branch from these main trunks. Anteriorly, just above the optic chiasm are the anterior cerebral arteries and the anterior communicating artery. Running up the anterior surface of the lamina terminalis are the paired anterior cerebral arteries.

Malformations of the third ventricle

Severe hydrocephalus can significantly alter the appearance of the structures at the foramen of Monro. Even in these cases, the basic structures of the road maps are available to locate the area for ventriculostomy.

In the Chiari II malformation, the third ventricle is usually remarkably different from normal. A large portion is occupied by the massa intermedia, but, more importantly, the floor is quite different. The distance between the mamillary bodies and the pituitary recess is extremely short, and the floor is thickened. This malformation often precludes any attempt at fenestration of the floor, especially in infants.

Agenesis of the corpus callosum allows the third ventricle to expand superiorly between the cerebral hemispheres. The foramina of Monro are displaced laterally.

Anatomy of the cerebral aqueduct

The aqueduct is the small portion of the ventricular system that connects the third and fourth ventricles. Superior to the aqueduct is the quadrigeminal plate. Inferiorly is the tegmentum of the midbrain. Nuclei of the third cranial nerve are located bilaterally near the anterior portion of the aqueduct.

Anatomy of the fourth ventricle

The normal fourth ventricle is a difficult target for endoscopy. Its size and orientation do not allow easy access. More importantly, the floor of this ventricle is the brain stem. The sixth cranial nerve nucleus, the tract of the seventh cranial nerve, and the medial longitudinal fasciculus are located superficially just below this floor. Although the cerebellum tolerates penetration, minor trauma to the floor inflicts significant neurologic deficits. In pathologic conditions in which the fourth ventricle is enlarged, however, access is possible.

The floor of the fourth ventricle is diamond shaped. The anterior point begins at the aqueduct, the lateral points hook slightly posterior to form the lateral recesses, and the posterior point ends at the obex. The normal floor is relatively flat with some identifying structures in it. Running in the midline is the median sulcus, and near the midpoint, the stria medullaris runs from the sulcus toward each lateral sulcus. The facial colliculus is located on either side near midline just rostral to the stria medullaris.

The walls of the fourth ventricle are formed by the superior and inferior cerebellar peduncles. The fourth ventricle has a pyramid shape, with the apex tilted slightly posterior. The anterior and posterior medullary velum forms the roof. The posterior side of the pyramid is convex because of the cerebellar vermis bulging inward. The vermis also splits the apex into two recesses: the posterior superior recesses. The midline apex is the vestigium. The choroid plexus is located on the posterior surface of the fourth ventricle and runs in the coronal plane from one lateral recess to the other. Foramina that drain the fourth ventricle are located bilaterally in lateral recesses: the foramina of Luschka and, in the midline, the foramen of Magendie. The choroidal fissure runs with the choroid plexus from one lateral recess to the other, separating the inferior cerebellum from the brain stem.

Malformations of the fourth ventricle

Dandy Walker cysts represent a group of anomalies in which a portion of or the entire cerebellar vermis is absent and the fourth ventricle communicates with or becomes a large cyst. When it occurs early in development, the torcula is located high, often near the midparietal region. Hydrocephalus may or may not be present. In its most severe form, it is associated with other brain malformations, such as agenesis of the corpus callosum, and intellectual delay is common in this form.

Loculation of the fourth ventricle, or a trapped fourth ventricle, like loculations in the lateral ventricles, is usually a complication of hydrocephalus. Ventriculitis is the most common cause.

The Chiari II malformation is a malformation that affects the entire brain. It has a major impact on the contents of the posterior fossa. Because the size of the embryonic posterior fossa is much too small to contain the rhombencephalic and metencephalic structures that will develop, derivatives of these embryonic portions of the brain extrude out of the posterior fossa. A portion of the (occasionally the entire) cerebellum and fourth ventricle is displaced into the cervical canal. In other individuals, the deficient tentorium allows a major portion of the cerebellum and fourth ventricle to herniate upward into the middle fossa between the cerebral hemispheres. When the ventricular shunt fails or the fourth ventricle becomes trapped or isolated, the fourth ventricle expands, increasing the pressure on the surrounding hindbrain. This is usually manifested as a dramatic increase in the patient's symptoms. When the isolated fourth ventricle in the Chiari II malformation expands superiorly, endoscopic access is available from above in a plane parallel to the floor of the fourth ventricle. This affords the opportunity to fenestrate or shunt the fourth ventricle endoscopically without endangering the floor of the fourth ventricle.

Summary

The embryology of the ventricular development of the brain assists in understanding the final relations between structures forming these cavities. An accurate concept of this anatomy allows the endoscopist to maneuver within the ventricular system.