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Techniques of endoscopic third ventriculostomy

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Modern techniques of endoscopic third ventriculostomy (ETV) are based on the concept of establishing a natural conduit for cerebral spinal fluid (CSF) flow through the floor of the third ventricle. Through the years, a wide variety of techniques have been used as a means to this end and have included both open and closed approaches. The relatively recent application of endoscopic technology to intraventricular surgery has allowed neurosurgeons to perform third ventriculostomies in a minimally invasive fashion, however. Advances in third ventriculostomy technique have been based on a detailed understanding of third ventricular anatomy, surgical trajectories, and improved instrumentation. The goal of this article is to discuss these issues in detail and to point out the relevant risks and known complications associated with them.

History

An understanding of the current state of ETV is not complete without an appreciation of its history. Briefly, in 1922, Walter Dandy originated the concept of third ventriculostomy by performing a craniotomy and fenestrating the lamina terminalis for the treatment of hydrocephalus [1]. This was quickly followed by Mixter [2], who, in 1923, used a urologic endoscope to puncture the floor of the third ventricle, thus ushering in the era of ETV at an early stage. In 1936, Stokey and Scarrf [3] and, in 1951, Scarrf [4] described their own procedures for third ventriculostomy. In the 1970s and 1980s, a host of authors described various techniques for third ventriculostomy, both open and closed [5–12]. Notable among these series is the Toronto experience as reported by Hoffman et al [13], which describes a percutaneous third ventriculostomy technique in the management of noncommunicating hydrocephalus. Significant experience with closed stereotactic techniques was reported by Kelly in 1991 [14]. During this period, neurosurgeons began taking advantage of smaller and smaller endoscopes; eventually, the routine use of fiberoptic or rod-lens ETV was accepted. Multiple studies were published in the 1990s reflecting considerable success with endoscopic techniques [14–27]. The current state of the art in ETV obviously reflects significant new concepts brought out by these pioneering neurosurgeons.

Relevant anatomy

A brief review regarding the anatomy relevant to ETV is useful. The recognition of critical landmarks and structures is vital to the overall success of ETV. In addition, complications may be avoided when important anatomy is identified early and respected throughout the procedure.

Choroid plexus

The choroid plexus lies along the floor of the lateral ventricle in the choroidal fissure and is oriented in an anterior/posterior direction. Early recognition of the choroid plexus within the lateral ventricle is a powerful navigational tool because its anterior extent leads to the foramen of Monro and the third ventricle. Thus, if one's initial endoscopic trajectory does not lead directly to the foramen of Monro, the choroid plexus can act as a "road map" to lead one to the proper site quickly and efficiently. Even in patients with

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distorted ventricular anatomy, such as those with spina bifida, the choroid plexus remains in the choroidal fissure and still leads to the third ventricle. In patients with large ventricles, this point is not much of an issue, but when the ventricular size is small, early recognition of the choroid plexus is sometimes the only navigational guide a neuroendoscopist has.

Fornix

The fornix forms the superior and anterior margin of the foramen of Monro. It is important that every effort is made to avoid its injury during endoscopic neurosurgery. Because of its location, however, it can easily be injured during passage of the endoscope from the lateral ventricle into the third ventricle. The risk of injury is multiplied when multiple passes through the foramen of Monro are made. For that reason, the number of passes of the endoscope through the foramen of Monro should be kept to an absolute minimum. In addition, it is important to recognize that the endoscope's camera port is only a small percentage of the cross-sectional area of the endoscope tip. For that reason, it is easy to assume that if one passes the endoscope easily through the foramen of Monro, the fornix is not injured. This may not be the case, however, because the edge of the endoscope tip near the light source or working chamber may inadvertently cause injury. Potential solutions for this problem are to be aware of the orientation of your endoscope's camera in relation to the cross-sectional area of the tip and to make appropriate adjustments in the approach trajectory. In addition, if one guides the scope in a handheld fashion, exquisite tactile feedback can be obtained and the surgeon could be alerted to "hanging up" the edge of the endoscope on the fornix.

Hypothalamus

The paired hypothalami form the lateral walls of the third ventricle. The supraoptic and paraventricular arcuate nuclei are the structures that are at the most risk during third ventriculostomy (Fig. 1). Injury to these structures may have significant endocrinologic consequences. Although some evidence suggests that the supraoptic nucleus is related mainly to vasopressin (antidiuretic hormone) and the paraventricular nucleus to oxytocin, both hormones are found in each nucleus. Therefore, surgical trajectories to the third ventricular floor must be planned with the idea that hypothalamic damage must not occur. Although surgical trajectories are presented in a later section, this concept is important when discussing hypothalamic anatomy. These issues are especially important when spina bifida patients with distorted hypothalamic anatomy undergo ETV.

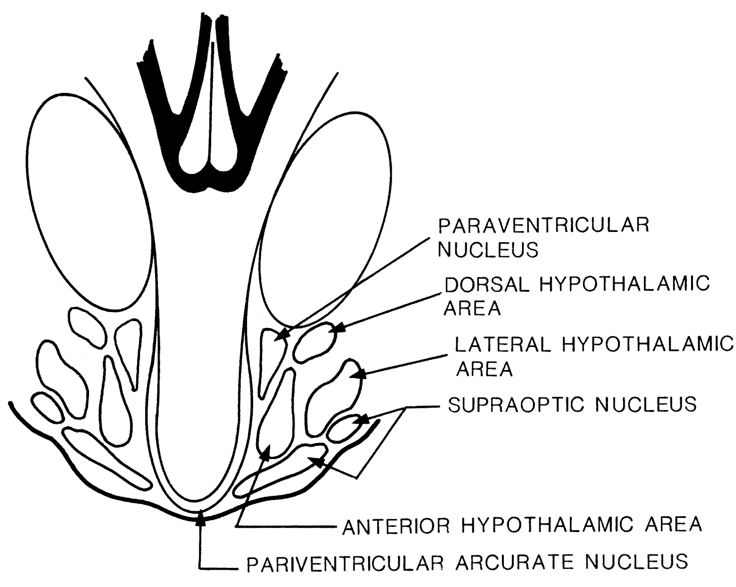

Fig. 1. Hypothalamic nuclear anatomy adjacent to the third ventricle. Note that the supraoptic and paraventricular nuclei are in close proximity to the third ventricle.

Third ventricular floor

The floor of the third ventricle is essentially a thinned out portion of the hypothalamus and can potentially have functioning hypothalamic nuclei (eg, supraoptic and paraventricular nuclei) within it. As noted previously, this consideration is especially important in patients with spina bifida. The traditional boundaries of the third ventricular floor include the mamillary bodies posteriorly, the walls of the hypothalamus laterally, and the optic chiasm/infundibular recess anteriorly. Within this area is a relative "safe zone" where the third ventricular floor may be entered (Fig. 2). This consists of the area just anterior to the midway point between the mamillary bodies and the infundibular recess. If one penetrates the third ventricular floor posterior to this point, the basilar artery tip or proximal portion of the posterior communicating artery may be encountered. If the floor is penetrated anterior to this point, the clivus is encountered . Obviously, if a choice has to be made, entering slightly more anterior to the midpoint is the safer than entering more posterior to the midpoint. Usually, within the midportion of a thinned-out third ventricular floor, there is a translucent bluish-appearing area that corresponds to a safe zone in which to make the initial opening. How the opening is actually made is discussed in later in this article.

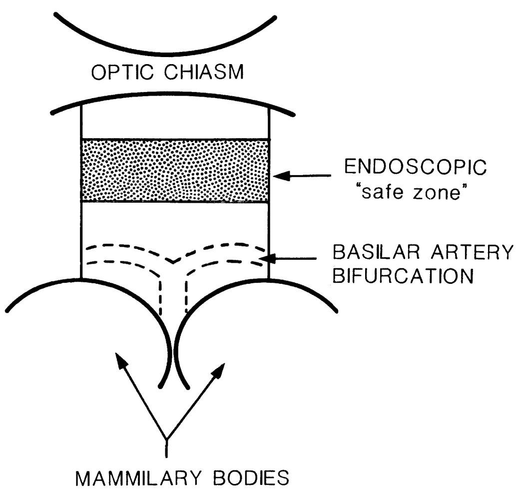

Fig. 2. Line drawing depicting the floor of the third ventricle and the "endoscopic safe zone," where initial dissection during endoscopic third ventriculostomy should begin.

Lillequist's membrane

Lillequist's membrane is an arachnoid plane that contains within it the basilar artery complex and separates the posterior fossa arachnoid cisterns from the suprasellar cisterns. Once a neuroendoscopist penetrates through the floor of the third ventricle, Lillequist's membrane is frequently encountered and hides the basilar artery complex and prepontine cistern from view. It is important that Lillequist's membrane be opened to have a successful third ventriculostomy. The goal is to communicate the fluid of the third ventricle to the prepontine cistern area. A clear view of the basilar artery complex, pons, pontine perforators, and clivus must be obtained before an ETV can be considered successful. Failure to recognize this anatomic point may lead to endoscopic failures.

Endoscopic approaches to the third ventricle

Trajectories

For a typical patient with enlarged ventricles undergoing ETV for the first time, a standardized trajectory to the third ventricle should be used. One such trajectory that yields excellent results consists of an entry site at the intersection of the coronal suture and the midpupillary line, with the trajectory of the endoscope slightly medial and oriented in line with the external auditory meatus in an anterior/posterior direction (Fig. 3A). This approach yields an endoscopic trajectory toward the foramen of Monro and into the floor of the third ventricle. The consistency and excellent results of this approach cannot be overemphasized.

A standardized approach is particularly important when previously shunted patients become candidates for ETV. The existing shunt entry site or ventricular catheter trajectory is sometimes positioned so that a safe approach to the third ventricular floor is not feasible. In this situation, a separate burr hole, and sometimes a separate incision, must be made in the standard location, and the standard approach should be employed. It is also possible in this situation to use a flexible endoscope to navigate into the third ventricle. In this author's experience, however, orientation may be difficult, and the acute curve of the scope may injure brain structures or preclude passing instruments safely down the working chamber.

The endoscope trajectory can also be changed based on the preoperative ventricular size. If the

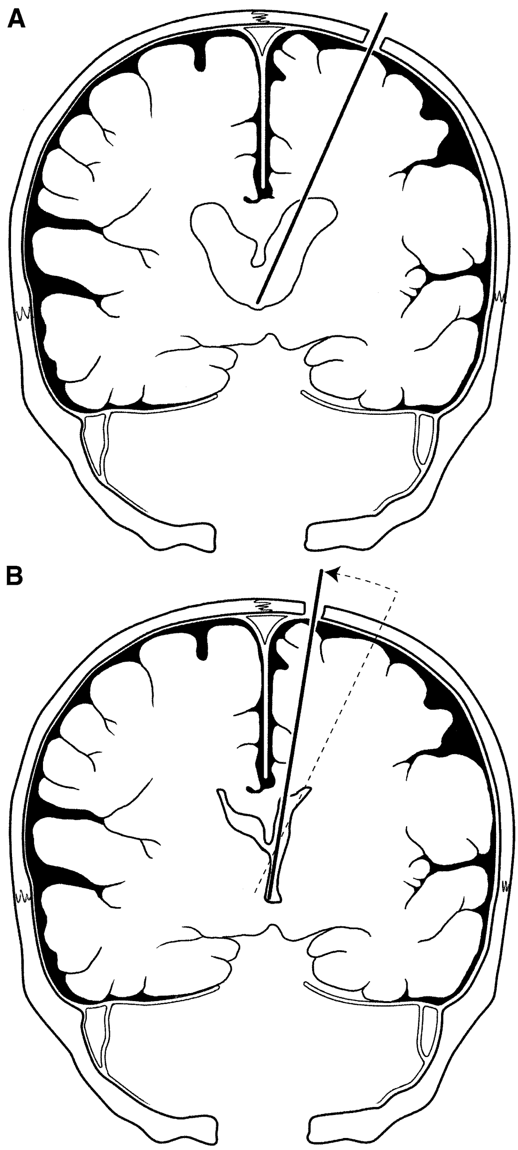

Fig. 3. Line diagrams depicting trajectories to third ventricle. (*A*) Traditional trajectory toward the third ventricle floor beginning at the midpupillary line. (*B*) Modified trajectory because of the small ventricle size. Note that the entry point is moved slightly medial compared with the standard trajectory.

ventricles are generous, the traditional trajectory described previously may be used. If the ventricles are small, however, the burr hole placement should be slightly medial to the midpupillary line, facilitating an easier approach into a narrow third ventricle (see Fig. 3B).

Type of endoscope to use

There are two basic types of neuroendoscopes that are available: rod-lens and fiberoptic. These scopes may be further subdivided into rigid, semirigid, and flexible. Understandably, there is no single endoscope that is adaptable enough to be superior in all applications and situations. Therefore, the neuroendoscopist must be flexible in his or her choice of endoscopes. For instance, if one encounters an adolescent patient with late-onset aqueductal stenosis and large ventricles, a good argument could be made for being as minimally invasive as possible, and a small, 1-mm, semirigid endoscope could be used for the entire procedure. In that case, the tip of the scope is used to perform the fenestration. The optics of the 1-mm endoscope are sufficient to allow positive identification of critical structures and rapid and safe performance of the third ventriculostomy.

A school-aged spina bifida patient with distorted anatomy in the third ventricular floor requires maximum visibility and adaptability, however. This situation requires either a rod-lens system or one of the larger fiberoptic scopes. In either case, anticipating the anatomy of the patient and maximizing visibility must be weighed against potential risks. For the experienced endoscopist, the proper endoscope choice may vary from patient to patient.

Techniques of endoscopic third ventriculostomy

In discussing techniques of endoscopic third ventriculostomy, it is logical to begin with the simplest technique available and then to proceed toward more complex or sophisticated procedures. The list that is included here is by no means meant to be all-inclusive; however, it is meant to cover most of the more commonly used techniques of ETV and serves primarily as a guide or reference for further reading.

Endoscope tip

Perhaps the easiest and most straightforward way to perform the fenestration for third ventriculostomy is using the tip of the endoscope itself (Fig. 4). Multiple case series have documented its safety and efficacy over time [15,19–21,26,28,29]. In essence, the tip of the endoscope is used as a dissecting tool to penetrate the floor of the third ventricle and Lillequist's membrane. Obviously, the smaller the tip of the endoscope, the easier the dissection becomes. This technique's

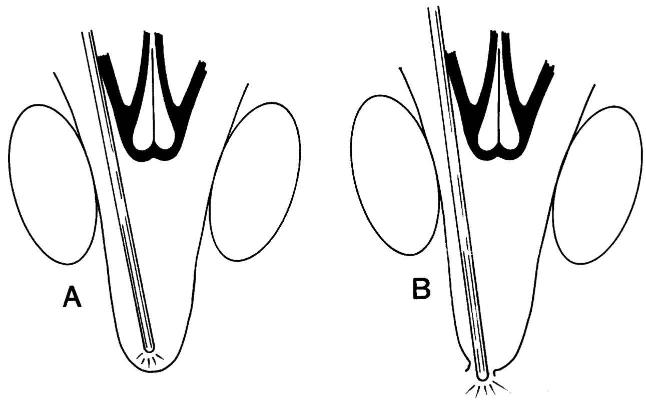

Fig. 4. (*A*, *B*) Line drawing depicting the use of the endoscope tip to perform the fenestration through the floor of the third ventricle.

critical drawback is that during the moments of dissection, one's visualization is completely obscured by the tissue in front of the scope. The lack of visualization is made up for by tactile feedback during manual opening of the third ventricular floor. Sometimes, a "windshield wiper" technique may be used to gently dissect the floor of the third ventricle and Lillequist's membrane, much like arachnoid dissection in other parts of the brain. With practice, this technique is a safe and effective way of performing a large opening of the floor of the third ventricle. In addition, the scope tip can be placed into the prepontine cistern to inspect the surrounding anatomy. Obviously, this technique has a rather steep learning curve, and the risk of basilar artery injury is a very real threat during this procedure. Only endoscopists confident with their dissecting technique using the tip of the endoscope should employ it.

A variation of this technique was reported by Wellins et al [30]. They describe preloading a ventricular catheter over the endoscope. Once the ETV is performed, the ventricular catheter is used to dilate the opening.

Dissection/balloon dilatation

Perhaps the most widespread and safest technique to open the floor of the third ventricle is to pass some type of semiblunt dissector down the working channel of the endoscope first and then to open a small hole in the floor of the third ventricle (Fig. 5A, B). Next, the dissector is withdrawn, and a 2- or 3-French balloon-tipped catheter (or similar device, such as a wire stone extractor [30]) is passed through the endoscope and through the initial fenestration in the floor of the third ventricle (see Fig. 5C). The balloon is slowly inflated at the site of the fenestration to enlarge the opening gradually and gently (see Fig. 5D) [15,20,25]. Once the balloon has been opened to its widest diameter, it is deflated and removed and the endoscope is placed through the opening to inspect and confirm that Lillequist's membrane has been opened (see Fig. 5E). If not, the procedure is repeated until Lillequist's membrane is open. Several endoscope manufacturers supply small dissecting tools that are ideal for making the initial opening. The author's preferred technique is to use the tip of an endoscopic bipolar coagulator.

This technique, used either with a rod-lens or fiberoptic endoscope, is safe, simple, and effective. The floor of the third ventricle is under direct visualization during the entire act of fenestration. For these reasons, the dissector/balloon dilatation technique and its variations deserve to be at the top of the list for recommended fenestration techniques. One notable exception is placing a fully inflated balloon-tipped catheter all the way through the third ventricle and pulling it back through the membrane in a fully inflated fashion. It is quite easy to injure the hypothalamic nuclei or to cause significant bleeding with this technique.

Saline jet

Saline jet irrigation has been used in performing ETV and cyst wall fenestration. The technique involves deploying and then directing a strong jet of saline irrigation in the region of the proposed dissection. The fluid forced from the saline jet atraumatically performs the dissection, at least theoretically. Although this technique has its merits and probably deserves more widespread

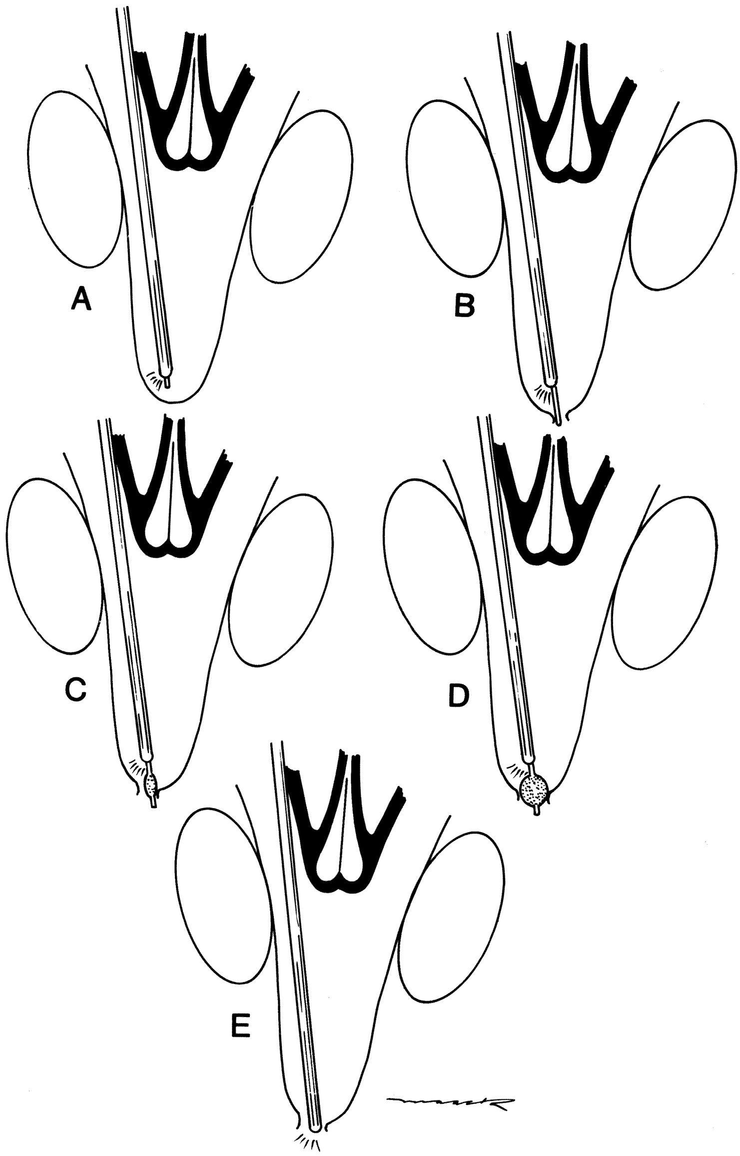

Fig. 5. (*A–E*) A series of line drawings depicting the use of an endoscope, blunt dissector, and Fogarty catheter to perform endoscopic third ventriculostomy (see text for details).

use, a saline jet apparatus is not readily available to most operating rooms and would need to be specifically requested. Further work and investigation of this technique are probably warranted before more widespread use is recommended.

Saline torch

Manwaring [31] has previously described the use of the saline torch. As a result of the fact that a potentially dangerous form of active energy is used during the fenestration, most neuroendoscopic surgeons have moved away from this technique toward blunt dissection of the third ventricular floor.

Laser energy

The application of laser energy or some other type of active energy source to perform ETV is mentioned here only to discourage its use [32]. When using a laser or other type of thermal energy source to perform the fenestration of the third ventricular floor, absolutely no tactile feedback is available and spread of the energy may easily injure or rupture critical neurovascular structures. Several significant complications, some reported and some unreported, have occurred using this type of technique [33]. Until safer sources of energy are developed to provide for third ventricular fenestration, these types of techniques should be avoided.

Stereotactic approaches

Over the years, several authors have reported closed and endoscopic stereotactic approaches to third ventriculostomy [11,13,14,19]. One such approach describes guiding a rigid rod-lens scope through the lateral and third ventricle using a predetermined stereotactic trajectory [19]. Although this type of technique has its merits, it does not allow much room for flexibility, a key factor that may represent a critical margin of safety in ETV. In addition, because of the extra expense of the preoperative stereotactic scan, extra operative time for stereotactic registration, and extra expense for the stereotactic apparatus, using a stereotactic technique is most likely not a cost-effective way to perform this procedure. Further cost-benefit analysis of this procedure would be important.

Doppler ultrasound

In 1998, Schmidt [34] described the use of a micro-Doppler technique to identify the basilar apex before performing the fenestration in the third ventricular floor. In his report, two third ventricular floors were mapped out before fenestration with a high degree of accuracy of predicting the position of the basilar artery. Although perhaps not necessary in all cases, this type of technique may be extremely useful in performing third ventriculostomies in patients with thick opaque floors or in those patients with distorted anatomy (eg, spina bifida).

Complications

Vascular

The most important vascular complication to avoid during ETV is injury to the basilar artery and its nearby branches. Two reports have documented injury to the basilar artery or the posterior cerebral artery by the tip of the neuroendoscope or a laser [33,35]. In one case, a pseudoaneurysm developed at the site of arterial injury, which later required further surgery and trapping [35]. Obviously, a careful look at the preoperative MRI to identify the position of the basilar artery in the prepontine cistern is extremely helpful in potentially avoiding vascular injury. In addition, placing the initial third ventricular floor fenestration in the safe zone also may prevent an arterial catastrophe.

If major arterial injury does occur, several techniques may help in avoiding disaster. One is the preplacement of a Sheath dilator in the lateral ventricle, through which the endoscope is passed. If arterial injury does occur, expression of blood through the Sheath dilator may help to decompress the intracranial compartment during the episode of rapid bleeding before arterial spasm. In addition, the ventricular cavity should be irrigated copiously with saline irrigation for perhaps as long as 20 or 30 minutes. Placement of an external ventricular drain and performance of a postoperative CT scan are mandatory. It is important to remember that although major arterial injuries may occur, most can be avoided by careful planning and meticulous technique.

This type of major arterial bleeding should be distinguished from the small amount of bleeding that frequently occurs from the floor of the third ventricle once the fenestration is performed. This bleeding is typically capillary in nature and subsides after 1 to 2 minutes of continuous irrigation. Further bleeding almost always requires only more patience and irrigation. If the CSF is not clear enough to see with an endoscope, the procedure should be abandoned, an external ventricular drain placed, and an emergency head CT scan obtained.

Occlusive hydrocephalus

The occurrence of acute occlusive hydrocephalus by blockage of the foramen of Monro with the endoscope during continuous irrigation has been described previously [36]. Recognition and prevention of this potentially lethal complication are important. The size of the endoscope versus the size of the foramen of Monro should be judged during surgery; if the endoscope plugs the foramen of Monro, the irrigation should be shut off. This problem should be in the endoscopist's mind if sudden vasomotor instability occurs during ETV.

Endocrine

Because the third ventricular floor is in direct continuity with the hypothalamus, endocrine dysfunction may occur after ETV. In 1996, Teo et al [37] reported four endocrine complications in 55 ETVs. Their complications included diabetes insipidus, increase in appetite, loss of thirst, and amenorrhea. The first two complications resolved completely over time. In a separate report, Teo and Jones [38] described transient endocrine complications in 2 of 69 spina bifida patients who underwent ETV. In contrast, reports of other large ETV case series [15,25] have reported no endocrine complications.

Obviously, any patient who undergoes ETV is at potential risk for damaging critical neuroendocrine structures, such as the supraoptic or paraventricular nuclei. Although it is difficult to prove with the existing data, it makes sense that patients who are at the most risk for endocrine complications during ETV are probably those with spina bifida or a thick third ventricular floor. As expected, the treatment of an endoscope-caused endocrine complication is supportive and hopefully transient. Therefore, careful attention to the regional anatomy as well as willingness to stop a procedure if the anatomy is unfavorable may help to avoid this complication.

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