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Optimal entry point and trajectory for endoscopic third ventriculostomy: evaluation of 53 patients with volumetric imaging guidance

Clinical article

Fangxiang Chen, M.D.,[1] and Peter Nakaji, M.D.[2]

[1]Department of Neurosurgery, University of Iowa Hospitals and Clinics, Iowa City, Iowa; and [2]Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona

Object. An optimal entry point for endoscopic third ventriculostomy (ETV) helps protect critical structures from undue manipulation. A commonly accepted ideal entry point is 3 cm from the midline and 1 cm anterior to the coronal suture. The authors of this study reexamine this ideal entry point.

Methods. Trajectory views from MR images or CT scans used for cranial image guidance in 53 patients (age range 3–85 years) who had undergone ETV were retrospectively evaluated. The trajectory from the tuber cinereum back through the center of the foramen of Monro was projected to the surface of the head. The relation of the entry point to the midline and the coronal suture was established.

Results. The mean perpendicular distance from the ideal entry point to the midline was 30.1 ± 7 mm (median 31.9 mm, range 12.5–42.2 mm). The mean perpendicular distance to the coronal suture was 8.9 ± 14.1 mm posterior (median 10.4 mm), ranging from 30.6 mm anterior to 35.8 mm posterior. The entry point tended to be located more posteriorly in women and adults: 5.8 ± 15.4 mm posterior in males versus 13.1 ± 13.2 mm posterior in females ($p = 0.08$) and 9.1 ± 14.8 mm posterior in adults versus 8.2 ± 11.7 mm posterior in children ($p = 0.84$).

Conclusions. While the entry point may need to be modified from the ideal trajectory for other anatomical reasons, such as a trajectory through the motor cortex, in general, the authors found that the optimal entry point for ETV was more posterior than previously published and highly variable. Using image guidance or a customized trajectory based on analysis of a patient's own imaging is highly preferable to using an empirical ideal trajectory.
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Key Words • **endoscopic third ventriculostomy** • **image guidance** • **entry point** • **endoscopy** • **diagnostic and operative techniques**

Over the past 2 decades, the popularity of ETV for the treatment of hydrocephalus has increased. It is now the approach of choice for treating certain forms of obstructive hydrocephalus. With technological advances in endoscopy and the accumulation of practical experience, a high success rate has been reported.[13,15,18–21] Although the complication rate associated with ETV is still relatively high, most complications are minor and transient.[2,5,10,18]

One particularly pernicious complication is damage to the fornix during the approach to the floor of the third ventricle. The effect of such damage on memory can range from imperceptible to disabling. Using an optimal entry point that traverses the center of the foramen of Monro, which decreases the need to move the endoscope from side to side, can reduce the frequency of this complication. Therefore, it is essential to define the ideal entry point and trajectory from a technical perspective so that the risk of traumatizing important anatomical structures around the pathway can be minimized. Naturally, the surgeon will have to account for other neuroanatomical concerns as well, such as whether the entry point endangers the premotor, supplementary motor, or motor cortex. However, in the majority of patients, the primary structures at risk are those bordering the foramen of Monro.

Based on a study of 17 patients, Kanner et al.[12] proposed that the optimal position of a bur hole for the entry point for ETV was 3 cm lateral to the midline and 1 cm anterior to the coronal suture. Common practice is to choose an entry point empirically 3 cm away from the midline and at or immediately anterior to the coronal suture. However, we routinely use image guidance to define the entry point for each individual. The variability that we have encountered suggests that an ideal entry point and trajectory have not yet been adequately defined. We hypothesized that an analysis of data obtained from a commonly used volumetric image-guided navigation system could provide a method of identifying an anatomically defined optimal entry point. Therefore, our objective in this study was to define the optimal position of the entry site and the ideal pathway for ETV on volumetric images obtained preoperatively from patients who underwent ETV procedures.

Abbreviation used in this paper: ETV = endoscopic third ventriculostomy.

Methods

The institutional review board of St. Joseph's Hospital and Medical Center in Phoenix, Arizona, approved this study. All patients were treated at Barrow Neurological Institute.

The images of 53 patients, 30 males and 23 females, who underwent an ETV procedure with preoperative volumetric image guidance brain MRI or head CT between April 2004 and August 2010 were retrospectively analyzed. The mean patient age was 37 years (range 3–85 years). Eleven patients were 16 years or younger (mean age 11 ± 5 years); 42 patients were older than 16 years (mean age 44 ± 18 years). The cutoff age between children and adults was set at 16 years based on the finding that the growth of head circumference ceases after the age of 16 years.[17]

Data Acquisition

Volumetric images were reloaded onto a Medtronic StealthStation Treon workstation. The thin-cut scans with axial, coronal, and sagittal views were displayed on the workstation. A target point on the tuber cinereum one-third the distance back from the top of the infundibulum to the mammillary bodies was selected (Fig. 1A). Another point was chosen at the center of the right foramen of Monro (Fig. 1B). The 2 points were connected with a straight line. The straight line was extended until it encountered the scalp. The meeting point of the scalp with the straight line was designated as an entry point, while the spot on the tuber cinereum was designated as a target point.

The simulated tip of the wand was advanced along the straight line between the entry point and the target point to ensure that the tip did not violate important surrounding anatomical structures, such as the caudate nucleus, fornix, thalamus, lateral wall of the third ventricle, and hypothalamus. The simulated tip of the wand running between the entry point and the target point was carefully observed in 3 dimensions. The trajectory was adjusted by relocating the entry point until none of the aforementioned structures were in contact with the line. The final trajectory was regarded as an "ideal trajectory," and the intersecting point of the ideal trajectory with the scalp was considered the "ideal entry point" (Fig. 1C).

The perpendicular distance from the ideal entry point to the sagittal suture or midline and to the coronal suture was obtained (Fig. 2). The sagittal plane was identifiable on axial images, and the coronal suture was reproducibly identifiable by the break in signal from the bone marrow (Fig. 1D). The center of the marrow break at the point where the trajectory crossed the skull was used as the index coronal suture point. The distance from the entry point to the target point on the tuber cinereum was also calculated. For descriptive data analysis and for comparison of the selected trajectories between males and females and between children and adults, we used IBM SPSS Statistics 19 software. The independent samples t-test was used for comparison. The confidence interval was set at a 95% confidence level ($\alpha = 0.05$).

Results

The mean perpendicular distance from the ideal entry point to the midline was 30.1 ± 7 mm (mean ± SD, median 31.9 mm) and ranged from 12.5 to 42.2 mm. The mean perpendicular distance to the coronal suture was 8.9 ± 14.1 mm (median 10.4 mm) posterior to the coronal suture and ranged from 30.6 mm anterior to 35.8 mm posterior to the coronal suture (Fig. 2). The distance from the external skull table to the target on the tuber cinereum was 90.5 ± 5 mm.

There was no significant difference in the location of the optimal entry point between males and females or between adults and children. The distance from the midline in males was 29.9 ± 7.8 mm compared with 30.3 ± 5.9 mm in females ($p = 0.84$, independent samples t-test). The distance from the coronal suture was 5.8 ± 15.4 mm behind the coronal suture for males compared with 13.1 ± 13.2 mm ($p = 0.08$) behind the coronal suture for females. In children, the distance from the midline was 26.7 ± 8.9 mm versus 31.0 ± 6.2 mm ($p = 0.07$) in adults, whereas the distance from the coronal suture in children was 8.2 ± 11.7 mm posteriorly versus 9.1 ± 14.8 mm ($p = 0.84$) behind the coronal suture in adults. Finally, the distance from the external cranial table to the target point on the floor of the third ventricle was 90.7 ± 5.3 mm for males compared with 90.3 ± 4.9 mm ($p = 0.79$) for females and 91.6 ± 5.6 mm in children versus 90.2 ± 4.9 mm in adults ($p = 0.42$).

Discussion

In 1923 Mixter[16] pioneered ETV, but the procedure lost favor until the quality of illumination and the endoscopic image began to improve in the 1990s. Compared with traditional shunting for the treatment of hydrocephalus, ETV establishes a normal physiological CSF pathway and does not require the implantation of shunt hardware.

The success rates for ETV have varied widely. In 1990 Jones et al.[11] reported a shunt-free success rate of 50%. A few years later, the success rate reported by these same authors in the treatment of another 103 cases had increased to 61%. In a recent summary of 368 ETV procedures, the success rate in adults was 77%;[18] the procedure was especially effective in cases of aqueductal obstruction or compression. When treated with ETV, as many as 80%–95% of these cases will not require a shunt.[15,20,21]

Given its effectiveness, ETV is an attractive alternative to shunting. However, ETV-related morbidity is often encountered and has ranged from 10% to 14%.[2,18] Fortunately, most of the complications, such as CSF leakage, mild hemorrhage, and infection, are transient or manageable without serious sequelae. Although uncommon, serious complications caused by direct trauma to surrounding key structures along the trajectory can still occur. Diabetes insipidus, cardiac arrhythmia, and respiratory distress result from damage to the hypothalamus; fatal hemorrhage or a traumatic aneurysm can result from injury to the basilar artery, its branches, or the thalamostriate vein; and the caudate nucleus and thalamus may suffer contusions from pressure from the position of the endoscope.[1,3,5–9]

An important complication encountered in patients

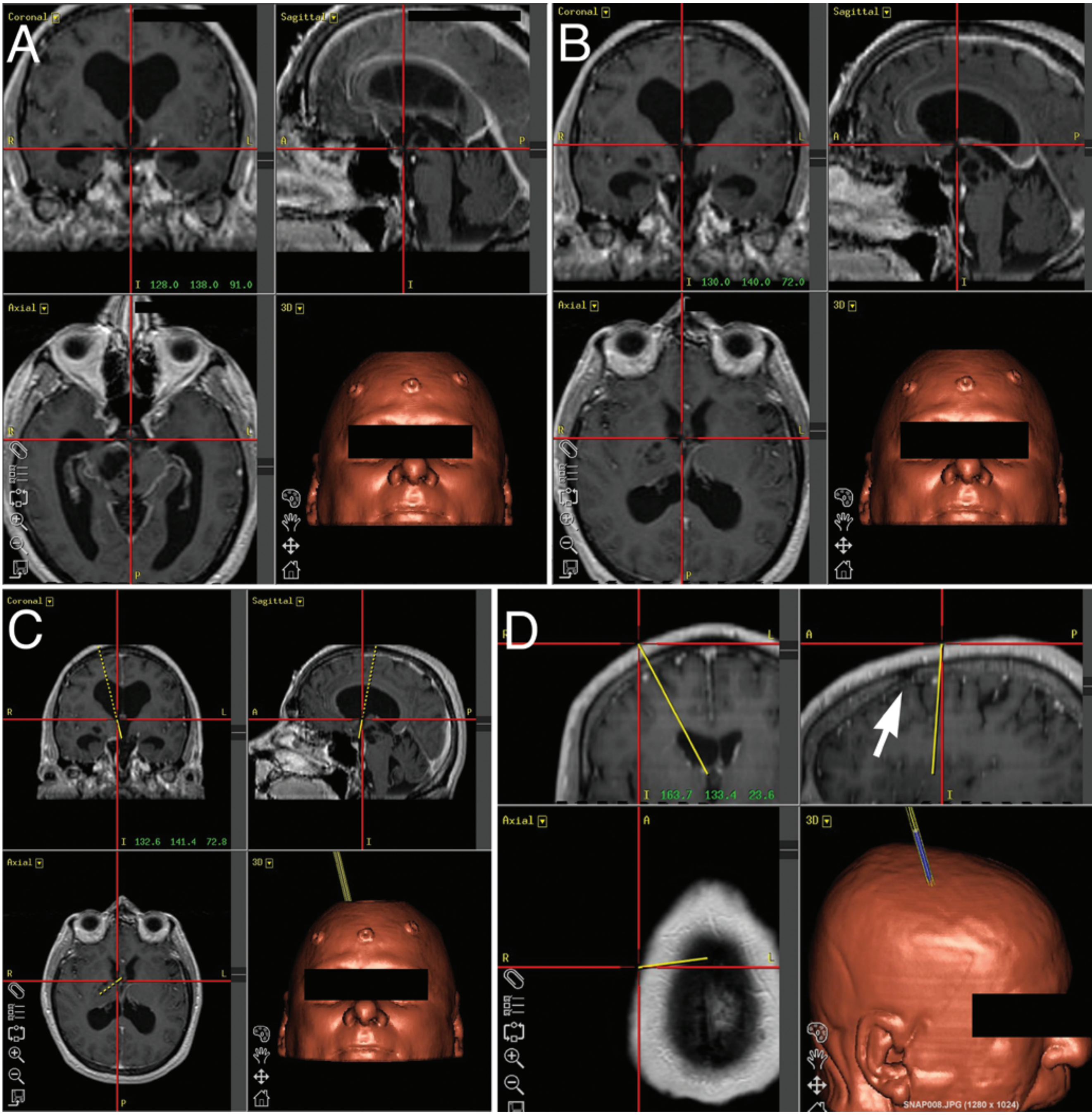

Fig. 1. Images used to determine the trajectory and entry point. **A:** Selection of the penetration point between the infundibulum and the mammillary bodies. **B:** Selection of a point at the foramen of Monro. **C:** Selection of the target point and its connection with the point at the foramen of Monro to determine the trajectory and entry point. **D:** The sagittal plane identified by axial imaging and the coronal suture identified by the break in the marrow signal *(arrow)*.

with ETV procedures is cognitive deficits, such as loss of short-term memory and executive functions. In a retrospective study on the effect of ETV on cognitive function, 4 of 10 patients had postoperative memory deficits. The deficiency in short-term memory persisted even when the size of the ventricles returned to relatively normal.[14] Trauma to the fornix caused by the endoscope passing through the foramen of Monro appears to account for such deficits.[4]

To avoid these major complications, it is essential that the trajectory through which the endoscope advances provides minimal contact with surrounding key structures. In 2000 Kanner and colleagues[12] reviewed 17 patients who underwent ETV using frame-based stereotactic guidance. They first chose 2 targets. The first was at the foramen of Monro on a slice of CT scan. On a different slice, the other point was chosen from the floor of the third ventricle between the dorsum sellae and basilar

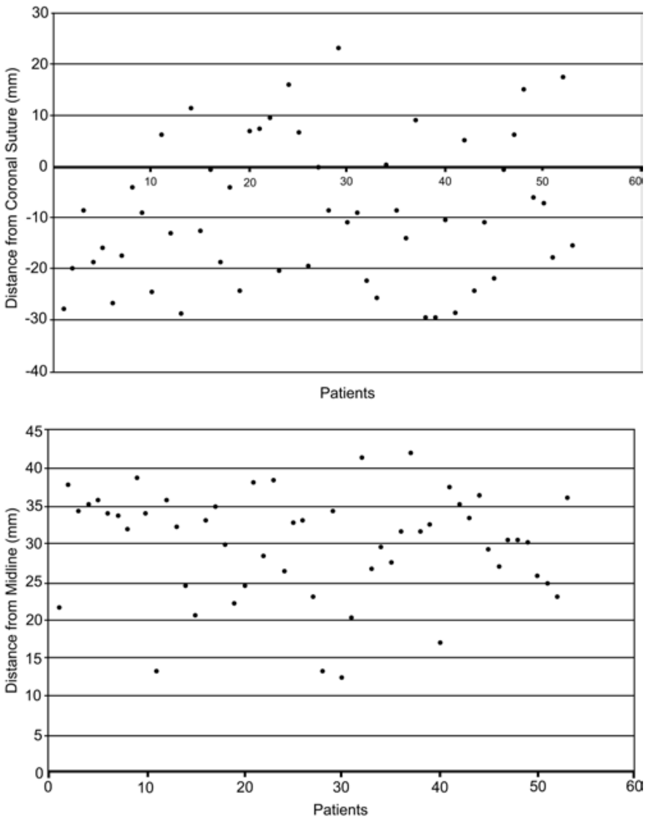

Fig. 2. Distribution of the entry points in 53 patients. **Upper:** Graph showing distribution of the entry points relative to the coronal suture. **Lower:** Graph showing distribution of the entry points relative to the midline.

artery. The coordinates of the 2 selected targets were calculated using a localization frame. The line between the 2 targets determined the trajectory and trephination point on the trajectory. They proposed that the optimal trephination point was 30 mm lateral to the midline and 10 mm anterior to the coronal suture.

Based on our data, the optimal endoscope entry point for the ideal trajectory is 30 mm (30.1 ± 7 mm) lateral to the midline and 9 mm behind the coronal suture (8.9 ± 14.1 mm). The difference between our findings and those of Kanner et al.[12] may reflect the difference in sample size as well as the method by which the trajectory was determined and adjusted. In the study by Kanner and colleagues, 17 cases were reviewed and the trajectory was either adjusted empirically or not adjusted. In fact, simply selecting 2 points to determine the trajectory without making readjustments will very likely result in the endoscope running into key structures. We simulated the actual planned trajectory of the endoscope with the navigation system by using the image guidance workstation. The relationship with the surrounding structures at all parts of the trajectory was visualized 3 dimensionally. This 3D perspective is an essential consideration, because the trajectory is not the same as the trajectory that would be calculated from a midline sagittal or simple coronal MR image. We intentionally did not analyze the actual entry points used by the surgeons for the ETVs performed in the patients whose scans were analyzed in this study, because our goal was to determine an ideal trajectory and entry point. However, we did choose patients who actually underwent the procedure to better simulate the anatomy involved in patients undergoing ETV.

The ideal entry point across the 53 patients in our study varied considerably. The distance of the entry point from the midline ranged from 12.5 to 42.2 mm and from 30.6 mm anterior to 35.8 mm posterior to the coronal suture. In contrast to the ideal entry point proposed by Kanner et al.,[12] we found that the optimal entry point was posterior to the coronal suture in 75% (40 of 53) of the patients. This finding has important implications for surgeries performed without image guidance and with the coronal suture as a guide instead. Once the ventricle is entered, the only way to redirect the trajectory is to swing the endoscope through the brain. Furthermore, an entry point too far anteriorly means that a rigid endoscope must be swung anteriorly, which, in turn, means that the fornix must be stretched. The undesirability of such maneuvers and the high degree of variability in the calculated ideal entry point argue for customizing the entry point for each patient. Ideally, intraoperative stereotactic image guidance would be used. If image guidance is unavailable, the entry point should be estimated from the patient's own imaging studies. Although a preoperative calculation is possible, it may be challenging due to a difficulty in identifying the coronal suture and calculating the angles from pure sagittal MR images or pure axial CT scans.

The substantial variation we found in the entire group was also found between males and females and in the relatively small number of children in the study population. Another study including a larger number of children, especially younger children, would be a useful next step. In any case, enough variation occurs within each group to support our point that customization of the entry point to the patient's specific anatomy is preferred.

We recognize that other anatomical considerations may force modification of the actual entry point from the calculated trajectory determined by using our method. An entry point that is too far posterior may require movement anteriorly to avoid traversing the motor, premotor, or supplementary motor area. For the majority of patients that we studied, the entry point should not place these structures at risk. A planned entry point may be seen to traverse a cortical vein and therefore must be moved. However, we submit that an entry point that takes a path as close to the one determined using our method should be preferred.

The distance from the external skull table on the trajectory to the target on the floor of the third ventricle was far less variable than the location of the ideal entry point. In any case, this distance is of minimal clinical relevance because it does not affect the procedure as it is performed with any of the commercially available neuroendoscopes.

There are weaknesses to the present study. All entry points were analyzed on the right. We did not examine the actual entry points used in the patients whose images were analyzed, and we did not evaluate the actual surgical impact on anatomical structures, the success of procedures, or neuropsychological outcomes. Our sole purpose was to assess the ideal entry points that should have been used while taking into account the surgical and anatomical priorities we identified. We also recognize that the calculated ideal trajectory may need to be modified based on other anatomical factors unique to the patient, such as the presence of a prior bur hole or tract, the eloquence of overlying cortex, and the need to perform other concomitant procedures, such as cyst fenestration, fenestration of the septum pellucidum, or tumor biopsy. Furthermore, even with an ideal entry point, a foramen of Monro smaller than the diameter of the endoscope may still need to be stretched somewhat. If so, it is even more essential to plan to traverse the very center of the foramen of Monro en route to the target on the floor of the third ventricle. Regardless of whether future prospective studies validate the clinical significance of this planning, it becomes clear that a neuroendoscopist's goals should include minimal contact with these critical structures.

Conclusions

Our study suggests that the optimal point for ETV entry is 30.1 ± 7 mm perpendicular to the midline and 8.9 ± 14.1 mm behind the coronal suture. However, the crucial finding is that this point is highly variable; therefore, its empirical use should be avoided. Given the large variation in the ideal entry point and trajectory across patients, we propose that intraoperative stereotactic navigation should be used for all ETV procedures whenever it is available. If intraoperative guidance is unavailable, the entry point should be estimated from a patient's own preoperative imaging studies.

Disclosure

Dr. Nakaji serves on an advisory board for Medtronic Navigation, Inc., is a consultant for endoscopy for Aesculap, Inc., and has received research support from the Barrow Neurological Foundation.

Author contributions to the study and manuscript preparation include the following. Conception and design: Nakaji. Acquisition of data: both authors. Analysis and interpretation of data: Chen. Drafting the article: Chen. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of all authors: Nakaji. Statistical analysis: Chen. Administrative/technical/material support: Nakaji. Study supervision: Nakaji.

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Address correspondence to: Peter Nakaji, M.D., Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, 350 West Thomas Road, Phoenix, Arizona 85013. email: neuropub@chw.edu.