Research Article

The Study of the New Occipital Ventricle Entry Point Using 3D-CT Simulation

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Abstract

Background: Cerebrospinal fluid diversion procedures are perhaps the most common procedure in neurosurgery, which is sometimes accessed via a posterior approach. However, there are many variations either in entry points, trajectories, and questions for their clinical outcomes. This study aimed to reevaluate commonly used posterior approach entry points based on 3-dimensional computed tomography (3D-CT) technology.

Method: A total of 180 patients who were diagnosed with hydrocephalus were retrieved and craniometric evaluation was done with reconstruction technique for thin cut 3D-CT. Cartesian coordinates of the new entry point for posterior ventricular catheter insertion (or the "New occipital entry point" in this study) were calculated and the brain parenchymal thickness that is traversed by the catheter via three approaches (Keen's, Frazier's, and our New occipital entry point) were compared.

Result: The New occipital entry point for posterior ventricular catheter placement is approximately 4 cm above the inion and 6 cm from the midline for both the right and left sides. The traversed brain parenchymal thickness for the New occipital entry point was statistically significantly less than Frazier's point on both sides ($P < 0.001$) but more than that of Keen's point, with statistically significance on both sides ($P < 0.001$ for right side and $P = 0.006$ for left side). Keen's point may have the least traversed brain parenchymal thickness but it might be difficult to access when the patient is set in a prone position.

Conclusion: Our study showed that the New occipital ventricle entry point for the posterior ventricular approach may decrease the amount of brain parenchymal traversed from catheter insertion. Clinical trials in real patients are needed for further evaluation of this entry point.

Keywords: Occipital parietal point, Frazier's point, Keen's point, ventriculostomy, computed tomography, 3D reconstruction

บทคัดย่อ

การศึกษาเพื่อหาตำแหน่งทางเข้าสู่โพรงน้ำสมองส่วนหลังตำแหน่งใหม่ โดยการใช้ภาพเอกซเรย์คอมพิวเตอร์สามมิติ

บทนำ: การผ่าตัดเพื่อระบายน้ำในโพรงน้ำสมองส่วนหลังของ lateral ventricle เป็นหัตถการทางศัลยกรรมระบบประสาทที่สำคัญ แต่ในทางปฏิบัติแล้วมีความแตกต่างกันค่อนข้างมาก ทั้งในแง่ของตำแหน่งที่ใช้เป็นทางเข้าและวิธีที่จะเข้าสู่โพรงน้ำในสมอง การศึกษานี้เพื่อต้องการทราบถึงตำแหน่งที่เหมาะสมที่สุดที่จะใช้ในการผ่าตัดเข้าสู่โพรงน้ำในสมองส่วนหลัง โดยใช้ภาพเอกซเรย์คอมพิวเตอรสามมิติ

วิธีศึกษา: โดยการนำข้อมูลภาพเอกซเรย์คอมพิวเตอร์จากผู้ป่วย 180 ราย มาสร้างเป็นแบบจำลองสามมิติ จากนั้นนำมาทำการหาตำแหน่งทางเข้าใหม่ โดยใช้ตำแหน่งที่มีความหนาของชั้นเนื้อสมองที่ต้องเจาะผ่านเพื่อเข้าสู่โพรงน้ำในสมองน้อยที่สุดในแนวระนาบแกน axial จากนั้นทำการเปรียบเทียบตำแหน่งดังกล่าวกับตำแหน่งทางเข้าที่ใช้ทั่วไปในการผ่าตัด พบว่าตำแหน่งทางเข้าใหม่ (New occipital entry point) นี้อยู่ห่างจากจุด inion ในแนวตั้งประมาณ 4 เซนติเมตร และแนวนอนประมาณ 6 เซนติเมตร มีความหนาของเนื้อสมองที่ต้องเจาะผ่านน้อยกว่าตำแหน่งFrazierอย่างมีนัยสำคัญ แต่มีความหนามากกว่าตำแหน่ง Keen อย่างมีนัยสำคัญ

สรุป: ผลจากการวิจัยคาดว่าตำแหน่งทางเข้าสู่โพรงน้ำในสมองตำแหน่งใหม่นี้มีศักยภาพที่จะใช้เป็นตำแหน่งที่ใช้ในการผ่าตัดในผู้ป่วยจริงได้ โดยยังคาดว่าอาจสามารถปรับปรุงทั้งตำแหน่งและวิธีให้ยิ่งขึ้นได้จากงานวิจัยและเทคโนโลยีที่ดีขึ้นในอนาคต และผลทางคลินิกของการผ่าตัดโดยใช้ตำแหน่งทางเข้าใหม่นี้ยังต้องการการศึกษาเพิ่มเติมในภายภาคหน้า

คำสำคัญ: โรคน้ำคั่งในโพรงสมอง, การติดเชื้อหลังการผ่าตัด, การผ่าตัดใส่สายระบายน้ำผ่านโพรงสมองลงสู่ช่องท้อง, การผ่าตัดใส่สายระบายน้ำผ่านช่องไขสันหลังส่วนเอวลงสู่ช่องท้อง

Introduction

Cerebrospinal fluid (CSF) diversion, either by external ventriculostomy drainage (EVD) or other shunting procedures, is one of the most common procedures in neurosurgery. Despite advancements in technology, these procedures are still having a high failure rate that does not decrease as time passes. Risk factors such as the etiology of hydrocephalus, age of the patient, and infections are well documented as causes of shunt failure. Catheter obstruction, which depends on surgical technique, is also one of the common causes of shunt failure[1]. Improvement in accurate catheter placement may result in improved shunt survival[2,3].

In literature, there are several access points to the ventricles, either with free hands, with the help of tools and devices, or with a neuronavigational system. There are several access sites to the lateral ventricles which could be categorized as frontal horn or anterior access, temporal horn or lateral access, and posterior horn or posterior access. The posterior parieto-occipital approach is commonly used for accessing the posterior horn of the lateral ventricles, which are occipital ventricles and trigones or atriums, and is one of the commonly used access points[4]. However, the freehand posterior approach is not well defined and there are significant variations in entry point and trajectory amongst neurosurgeons[4], some based on measurement of the pinna of the ears (which are soft tissue and can be varied) or some using the operator's fingers which increased the inaccuracies[5,6]. We believe this lack of standardization contributed to

incidences of ventricular catheter misplacement.

Two of the most common classic entry points for the posterior ventricle approach are Frazier's point and Keen's point. Frazier's point was initially described by Frazier in his series on trigeminal neuralgia management in 1928[7]. The described entry point is 6 cm superior to the inion and 3-4 cm lateral from the midline with a trajectory aimed at the opposite medial canthus and traversed the cerebral parenchyma 5-6 cm before reaching the occipital horn of the lateral ventricle[8]. Keen's point was first described by Keen in a child with hydrocephalus presumed to be due to a cerebellar tumor in 1888. The entry point has been described as a point approximately 2.5-3.0 cm behind the pinna. The brain parenchyma is traversed around 3-4 cm before reaching the trigone of the lateral ventricle[8].

Given that the entry point is a major determinant of final catheter location and the brain parenchyma traversed by the ventricular catheter may cause tissue overgrowth into the catheter leading to shunt malfunction[17], we reevaluate Frazier's point and Keen's point with 3-dimensional simulated computer tomography (3D-CT) reconstruction technology. Our study aims to measure the thickness of the brain parenchyma traversed via each posterior approach classic entry point and their relation to the point which has the thinnest brain parenchyma. We hope that our study might reveal the best entry site with the least traversed brain parenchymal tissue.

Materials and Methods

Sample size

We used the estimation of an infinite population mean formula for the calculation of the sample size. The estimated sample size calculated is 171.

$$n = \frac{z^2_{1-\frac{\alpha}{2}} \sigma^2}{d^2}$$

This study was a descriptive trial and was approved by the Ethics Council of Bhumibol Adulyadej hospital. One hundred eighty patients were collected. Sex and age were collected. Evans index was calculated for all patients. The inclusion and exclusion criteria are as below;

Inclusion criteria

- Patients who are diagnosed with hydrocephalus with records on the ICD-10 system (G91-G919) from July 2016 to July 2019

- Thai nationality, age over 18 years

- Underwent multislice CT scanning with a thin overlapping section (slice thickness 1.0) in the orbito-meatal plane with 3D facial reconstruction

Exclusion criteria

- Age below 18 years

- Patients who have asymmetrical ventricles or only one intact ventricle

- Shifting of midline structures or herniations

- Previous craniotomy or skull defect

- Intraventricular mass or intraparenchymal tumor

- Patients who previously underwent posterior ventriculostomy or shunt procedure

Evaluation of the New Occipital Ventricle Entry Point and Traversed Parenchymal Tissue

A CT craniometric study by the Syngovia® system was used with a soft tissue window in transition from caudal to rostral in axial slices. The first cut

above both sides of the thalamus was chosen as the plane for the entry site 10. On that plane, the line between the anterolateral and posteromedial walls of the atrium of the lateral ventricle was drawn. Then an imaginary line was drawn in the middle, parallel and bisecting both referenced lines and extended posteriorly, back to intercept with the outer cortex of the skull. At that point, we refer to it as our New occipital ventricle entry point (Figure 1).
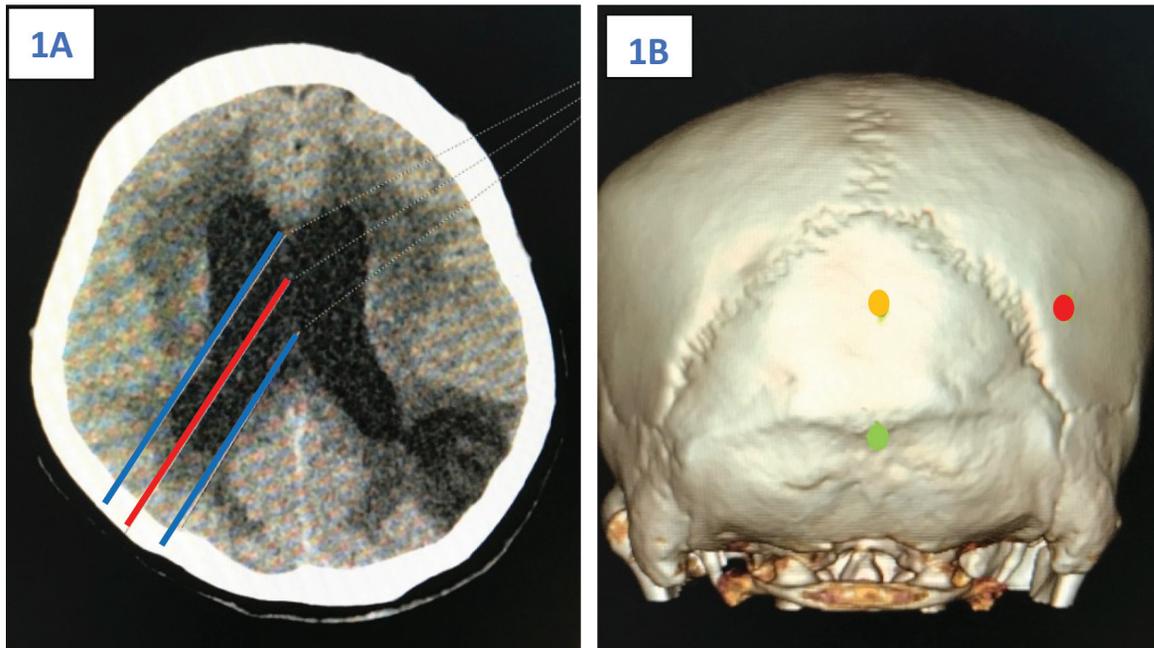
Figure 1 1A: The first axial CT cut above both sides of the thalamus. Lines were drawn on the anterolateral wall and posteromedial wall of the lateral ventricle, then an imaginary line was drawn bisecting those lines. The point at which the imaginary line intercept with the outer cortex of the skull is set as the New occipital entry point. 1B: 3D reconstruction in the bone window shows a color mark point at the inion (green dot), a midline point at the entry plane (orange dot), and the New occipital entry point (red dot).

The next step is identifying the inion landmark, which is defined as the most prominent part of the external occipital protuberance in the 3D-CT scan. We then measure the distance between the New occipital ventricle entry point and the inion landmark and then document them in horizontal & vertical distances respectively (Figure 2). Both sides of the New occipital ventricle entry point (left and right) were measured and recorded.
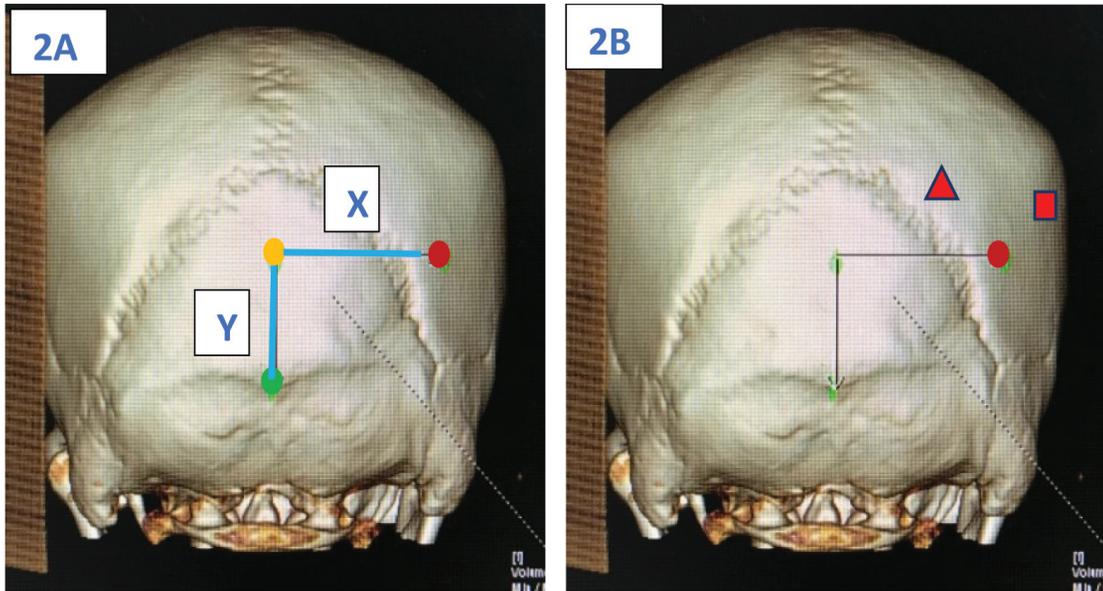
Figure 2 2A: 3D-CT bone window shows the distance between the inion landmark and the New occipital entry point. The horizontal distance (x) and the vertical distance (Y) are recorded. 2B: A Comparison of the three studied occipital ventricle entry points. Circle = the New occipital ventricle entry point, Triangle = Frazier's point, Rectangle = Keen's point.

Evaluation of the brain parenchymal thickness for the New occipital ventricle entry point, Frazier's point, and Keen's point

In the same axial CT slice in that, we identified the New occipital ventricle entry point, we measure the brain parenchymal thickness at this entry point. By using the imaginary line (the line bisecting the anterolateral and posteromedial wall of the lateral ventricle), we measured the traversed brain parenchymal tissue for this entry point (Figure 3A). For the classic entry point, we identified Frazier's and Keen's points bilaterally as well. For standardization in our study, we set the point 3 cm superior and 3 cm posterior to the helix of the ear for Keen's point
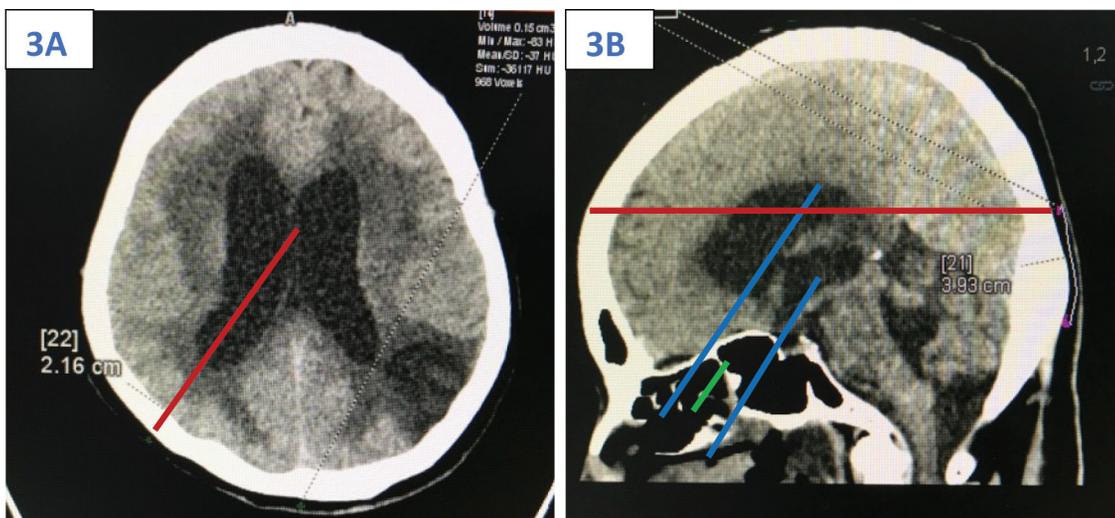
Figure 3 3A: Measurement of the brain parenchymal thickness traversed by the catheters through the New occipital ventricle entry point. 3B: The plane of the axial CT slice used for measurement of the traversed brain parenchyma.

in our study[9] and the point 6 cm superior and 4 cm lateral from the inion as Frazier's point[15]. The traversed brain parenchymal thickness for both Frazier's and Keen's points was measured in the axial CT slice perpendicularly to the outer skull cortex (Figure 4). The data recorded from these studied entry points are analyzed and calculated to find the average distance from inion and traversed brain parenchymal tissue.
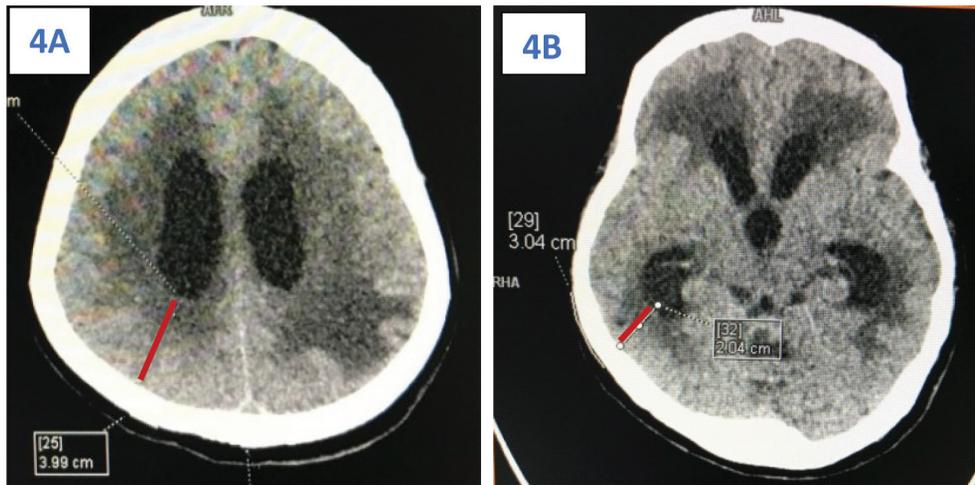
Figure 4 4A: The brain parenchymal thickness traversed by the catheter through Frazier's point. 4B: The brain parenchymal thickness traversed by the catheter through Keen's point.

Statistical Methods

The distances for all studied entry points regarding the inion and the brain parenchymal thickness were shown in Table 2. We use the average and 95% confidence interval to interpret the result. The pair-sample t-test was used to determine the brain parenchymal thickness differences between our New occipital ventricle entry point and both Frazier's and Keen's point. The Evans' index was measured and shown in average value. A *P*-value < 0.05 was considered statistical significance.

Results

Our study involved 180 patients who were diagnosed with hydrocephalus. The average age is 50.5 years old which ranged from 24 years old to 85 years old. Most of the patients are male (62.8%). All 180 patients were studied for both sides of their ventricles (total of 360 ventricles). The average Evans' index is 0.38. Demographic data for all patients are shown in Table 1.

Table 1 Demographic data

Number of patients	180		
Ventricles	Rt: 180	Lt: 180	Total: 360
Sex	Female: 67 (31.2%)	Male: 113 (62.8%)	
Age (years)	Min: 24	Max: 85	Mean: 50.5
Evans' index	Mean: 0.38		

Table 1. Demographic data of the patients included in the study. Rt = right, Lt = left, Min = minimal number, Max = maximal number

The descriptive statistics for the coordinates of the New occipital ventricle entry point with inion as the reference is shown in Table 2. The Cartesian coordinates of the New occipital ventricle entry point were significantly different from both Frazier's and Keen's points ($P < 0.005$). The mean value for the horizontal distance from the midline of the New occipital ventricle entry point using the inion landmark was 5.96 cm and 5.78 cm on the right and the left side respectively. The mean value for vertical distance superior from the inion was 4.08 cm for both the right and the left side.

The mean brain parenchymal thickness for both sides of the three approaches is presented in Table 3. The traversed brain parenchymal was the most in Frazier's point for both sides, more than our New occipital ventricle entry point and Keen's point, and the difference was significant bilaterally ($P < 0.05$ for both sides). For Keen's point, the traversed brain parenchymal was less than our New occipital ventricle entry point and the difference was statistically significant for both sides ($P < 0.001$ for the right side and $P = 0.006$ for the left side).

Table 2 The New occipital ventricle entry point with inion as the reference point.

Distances	Right Hemisphere			Left hemisphere		
	Mean (SD)	95%CI	Range	Mean (SD)	95%CI	Range
Inion reference horizontal distance (cm)	5.96 (0.5)	5.88–6.04	4.37–7.34	5.89 (0.5)	5.79–5.94	3.95–7.14
Inion reference vertical distance (cm)	4.08 (0.4)	4.0–4.15	3.05–5.45	4.08 (0.4)	4.0–4.15	3.05–5.45

Table 2. The horizontal and vertical distances from the New occipital ventricle entry point to the inion. SD = standard deviation, CI = confident interval, cm = centimeter

Table 3 Traversed brain parenchymal thickness for the three posterior ventricular approaches.

Entry point	Traversed brain parenchymal (cm)					
	Right ventricle			Left ventricle		
	Mean (SD)	95%CI	Range	Mean (SD)	95%CI	Range
The new occipital ventricle entry point	2.38 (0.3)	2.33–2.44	1.24–3.75	2.5 (0.35)	2.29–2.41	1.65–3.66
Frazier's point	3.01 (0.2)	2.97–3.05	2.64–3.89	3.12 (0.3)	3.07–3.16	2.55–3.77
Keen's point	2.23 (0.3)	2.18–2.28	1.44–3.01	2.24 (0.25)	2.2–2.29	1.75–2.98

Table 3 Brain parenchymal thickness traversed by each approach. SD = standard deviation, CI = confident interval, cm = centimeter

Discussion

Ventricular catheter placement for patients with hydrocephalus is one of the most common procedures performed by neurosurgeons and neurosurgical residents. There are several approaches for accessing the lateral ventricles; the posterior approach is one of them and perhaps, one with the most variations. Lind et al. (2008) analyzed the reconstructed MRI images in their patients and reported that the occipital approach for ventricular catheterization has the narrowest margin of error concerning trajectory compared to the frontal or lateral approach, meaning that it is the hardest approach[11]. A prior study described the use of a posterior ventricular cannulation guide aimed to reduce the inaccuracy due to the free-hand nature of the procedure[12]. Variations among neurosurgeons regarding the entry point and the trajectory is another important issue, as there is no consensus or standardization in literature or even neurosurgical textbooks. Sarkar et al. (2011) published improved accuracy of the desired entry point with the use of the Vellore localizer[10]. These emphasize the fact that the posterior approach for ventricular catheter placement is difficult and can be easily misplaced or not achieve good results.

In our study, we tried to reevaluate and calculate the mostly used posterior ventricular catheter placement entry points (Frazier's and Keen's point) in the aspect of the brain parenchymal thickness that needed to be traversed by the catheter. As in our review of the literature, proper catheter placement requires an optimal entry point and trajectory and should have a minimal amount of traversed parenchymal tissue. We also tried to find the ideal entry point which could access the ventricle via the thinnest brain parenchymal tissue.

Keen's point is found to have the thinnest traversed brain parenchyma in our study. However, its entry point has quite laterally deviated from the other two. Practically, we set the patient in a supine position with the head turned laterally when performing the CSF diversion procedure using Keen's point. It might be very difficult to perform when the patient is in a prone position. We then focus on studying the differences between Frazier's point and our New occipital ventricle entry point as both may be performed when we need to set the patient in a prone position while Keen's point is inappropriate.

Our results showed that the New occipital ventricle entry point is situated 4 centimeters above the inion and 6 centimeters lateral from the midline. By selecting this entry point we based on 2 assumptions. Firstly, the thalamus should be avoided, so we choose the first axial CT slice above the thalamus. Note that the atrium in this CT cut opens anteriorly above the thalamus into the body of the lateral ventricle[13]. Secondly, for the catheter placement through the least thickness of the brain tissue, the bisecting point of the line tangential to both the anterolateral and posteromedial imaginary line is chosen as the entry point. We then calculate the average distance of this New occipital ventricle entry point concerning the inion. We choose the inion as a reference point as it is a bony landmark, which is reliable and populated by many suggestions.

Regarding the trajectory, some variations could be problematic and confusing. As referenced, we prefer the shortest one as traversing unnecessary brain parenchyma may result in an increased risk for hemorrhage. Garell et al. (1998) described in their

technical note using the point 2 cm in the midline above the line connecting the two superior orbital rims as a frontal target[14]. Howard III et al. (1995) use the point 1 cm above the supraorbital rim instead. They also use the Ghajar posterior ventricular catheter guide to help target the desired point[12]. Ng et al. (2022) use the intersecting point of the contralateral frontal eminence in the axial plane and medial canthus in the sagittal plane as the trajectory in their technique for their parietooccipital shunt insertion in pediatric populations[4]. Lee et al. (2008) conducted a study using MRI data sets from 10 patients and reported that for satisfactory catheter placement via Frazier's point (6 cm above the inion and 4 cm lateral from midline), the best trajectory target is 4 cm above the contralateral medial canthus[15].

We chose a 3D CT scan for analysis because cadaveric studies might be inaccurate because of postmortem ventricular collapse. We believe that our results are clinically relevant, particularly for young neurosurgeons or neurosurgeon residents that are still on a learning curve and have not yet apprehended the spatial orientation of the ventricle to the skull. The use of classical landmarks may be criticized as inaccurate in real life and less relevant in an age of modern imaging technology. However, our result will nevertheless be useful in areas of practice when modern imaging or navigators are not available.

Several researchers also have the idea that the classic entry site might not be the best one for many patients. Garell et al. developed a device called "The Localizer" in Iowa, USA. The device headband with a trajectory landmark will be worn by the patient, and then a posterior projection can be made back to identify the entry site for each patient[14]. Ng et al.

reported good catheter position in their case series of 25 pediatric patients using their 3-point scale method. Their entry site varies among each patient as their technique uses the patient's cranium to create their craniometric landmark[4]. These ideas might be interesting given that each patient's cranium is unique.

Some investigators are pioneering the idea of more appropriate entry points rather than classical ones. Duong et al. (2019) used the occipital parietal point (OPP) which is the point in between Frazier's point and Keen's point in their series of 93 adult patients and reported an optimal catheter position with potentially reduced risk of shunt malfunction[16]. Their chosen entry point interestingly shares the idea of our Suggested point in that the proper entry site is more lateral than the classic Frazier's point.

The trajectory we selected for our New occipital ventricle entry point might not be very practical. By using the described imaginary line bisecting the anterolateral and posteromedial wall of the ventricle, we found that this line usually traversed the least brain parenchymal tissue and was nearly perpendicular to the outer cortex of the skull. This might give additional difficulty when performing surgery on real patients.

The major drawback of our study is that we must accept that our New occipital ventricle entry point might not truly be the point which the least traversed brain parenchymal tissue. The trajectory of our entry point is based on an axial view CT scan or in parallel to the orbitomeatal line and the traversed brain parenchymal thickness was calculated only for that plane. Regarding the 3D structure of the brain parenchymal tissue around the catheter entry point, attempts to achieve the least traversed parenchymal

thickness by concerning only the axial plane might not be appropriate. The best trajectory in the axial plane might not be the best when viewed in the coronal or the sagittal plane. Ideally, we think that a neuronavigational software that can reconstruct the brain parenchymal tissue around the interested entry point volumetrically in 3D and calculate the trajectory which traversed the least brain parenchyma in all axial, coronal, and sagittal views might be the appropriate tool for this study (which we do not have in our institute).

The other limitation of our study is that this new entry point is specific to the adult population and might not apply to pediatric patients. While using our New occipital ventricle entry point, the operator still needs to measure the appropriate ventricular catheter length, which can be varied among patients. Technically, drawing the imaginary lines manuallybythe researcher (which is then becoming the trajectory) might not be precise or be operator dependent. Additional intraoperative complicatedness when using our new entry point in a real patient is another concern and should be evaluated. Concerns are such as more difficulty in pre-operative trajectory planning, possible increase in operative time, and an additional complicatedness of the procedure, etc. Better 3D simulation software than ours in combination with a neuronavigational system might result in a more accurate entry point. Clinical trials are needed to evaluate the efficacy and outcomes of procedures using our New occipital ventricle entry point. Both short-term and long-term side effects, complications, and shunt survival need to be studied.

Conclusion

In conclusion, our result suggests that the New occipital ventricle entry point for catheter placement via posterior ventricular approach in patients with symmetrical hydrocephalus is 4 centimeters above the inion and 6 centimeters lateral from the midline. A more proper entry point and trajectory might be achieved with better neuronavigational software. Our results also need to be evaluated with clinical trials in real patients.

References

1. Sainte-Rose C, Piatt JH, Renier D, Pierre-Kahn A, Hirsch JF, Hoffman HJ, Humphreys RP, Hendrick EB. Mechanical complications in shunts. Pediatr Neurosurg. 1991-1992;17(1):2-9. doi: 10.1159/000120557. PMID: 1811706.

2. Piatt JH Jr, Carlson CV. A search for determinants of cerebrospinal fluid shunt survival: retrospective analysis of a 14-year institutional experience. Pediatr Neurosurg. 1993 Sep-Oct;19(5):233-41; discussion 242. doi: 10.1159/000120738. PMID: 8398847.

3. Tuli S, Drake J, Lawless J, Wigg M, Lamberti-Pasculli M. Risk factors for repeated cerebrospinal shunt failures in pediatric patients with hydrocephalus. J Neurosurg. 2000 Jan;92(1):31-8. doi: 10.3171/jns.2000.92.1.0031. PMID: 10616079.

4. Li Ching Ng A, Kohan S. Accurate placement of parieto-occipital shunt ventricular catheter: use of craniometrics and technical note. Childs Nerv Syst. 2021 Oct;37(10):3209-3217. doi: 10.1007/s00381-021-05332-3. Epub 2021 Sep 1. PMID: 34468838.

5. Pang D, Grabb PA. Accurate placement of coronal ventricular catheter using stereotactic coordinate-guided free-hand passage. Technical note. J Neurosurg. 1994 Apr;80(4):750-5. doi: 10.3171/jns.1994.80.4.0750. PMID: 8151359.

6. Lee CK, Tay LL, Ng WH, Ng I, Ang BT. Optimization

of ventricular catheter placement via posterior approaches: a virtual reality simulation study. Surg Neurol. 2008 Sep;70(3):274-7; discussion 277-8. doi: 10.1016/j.surneu.2007.07.020. Epub 2008 Feb 11. PMID: 18262623.

7. Frazier CH, Gardner WJ. The radical operation for the relief of trigeminal neuralgia. Surg Gynecol Obstet. 1928;47:73-7.

8. Roka, Yam. A Review of Trajectories for External Cranial Ventricular Access. Nepal Journal of Neuroscience. 2021. 18. 2-8. 10.3126/njn.v18i2.36276.

9. Agarwal, Anil; Borley, Neil; McLatchie, Greg. Oxford Handbook of Operative Surgery. Oxford University Press. 2017. p. 659. ISBN 9780191503030.

10. Sarkar H, Thakar S, Kumar SS, Moorthy RK, Rajshekhar V. A computed tomography-based localizer to determine the entry site of the ventricular end of a parietal ventriculoperitoneal shunt. Neurosurgery. 2011 Mar;68(1 Suppl Operative):162-7; discussion 167. doi: 10.1227/NEU.0b013e3182077ec1. PMID: 21304331.

11. Lind CR, Tsai AM, Law AJ, Lau H, Muthiah K. Ventricular catheter trajectories from traditional shunt approaches: a morphometric study in adults with hydrocephalus. J Neurosurg. 2008 May;108(5):930-3. doi: 10.3171/JNS/2008/108/5/0930. PMID: 18447709.

12. Howard MA 3rd, Srinivasan J, Bevering CG, Winn HR, Grady MS. A guide to placement of parietooccipital ventricular catheters. Technical note. J Neurosurg. 1995 Feb;82(2):300-4. doi: 10.3171/jns.1995.82.2.0300. PMID: 7815163.

13. Rhoton AL Jr. The lateral and third ventricles. Neurosurgery. 2002 Oct;51(4 Suppl):S207-71. PMID: 12234450.

14. Garell PC, Mirsky R, Noh MD, Loftus CM, Hitchon PW, Grady MS, Dacey RG, Howard MA 3rd. Posterior ventricular catheter burr-hole localizer. Technical note. J Neurosurg. 1998 Jul;89(1):157-60. doi: 10.3171/jns.1998.89.1.0157. PMID: 9647190.

15. Lee CK, Tay LL, Ng WH, Ng I, Ang BT. Optimization of ventricular catheter placement via posterior approaches: a virtual reality simulation study. Surg Neurol. 2008 Sep;70(3):274-7; discussion 277-8. doi: 10.1016/j.surneu.2007.07.020. Epub 2008 Feb 11. PMID: 18262623.

16. Duong J, Elia CJ, Miulli D, Dong F, Sumida A. An approach using the occipital parietal point for placement of ventriculoperitoneal catheters in adults. Surg Neurol Int. 2019 Feb 22;10:21. doi: 10.4103/sni.sni_3_18. PMID: 31123628; PMCID: PMC6416753.

17. Tayebi Meybodi K, Hoseinzadeh E, Ahmadi M, Taghvaei M, Saberi H. Reevaluation of Classic Posterior Ventricular Puncture Sites Using a 3-Dimensional Brain Simulation Model. World Neurosurg. 2017 Nov;107:22-27. doi: 10.1016/j.wneu.2017.07.134. Epub 2017 Jul 29. PMID: 28765021.