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Efficacy and Safety of Guideless Catheter Placement Technique in Revision External Ventricular Drainage and Ventricular Shunt Surgery

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ABSTRACT

AIM: To evaluate the efficacy and safety of the guideless catheter placement technique in revision surgeries for external ventricular drainage (EVD) and ventricular shunt systems to improve treatment outcomes for hydrocephalus.

MATERIAL and METHODS: We retrospectively analyzed 111 patients who underwent revision surgeries for EVD or ventricular shunt systems at the Istanbul Umraniye Training and Research Hospital from January 2020 to January 2023. Patients' demographic (age, sex), and clinical (cause of hydrocephalus, type of surgery, and postoperative complication rates, specifically for bleeding and catheter malposition) data were extracted from the patient files.

RESULTS: The use of the guideless catheter placement technique significantly reduced postoperative complications, with notably lower rates of bleeding (n=2, 1.8%) and catheter malposition (n=5, 4.5%).

CONCLUSION: The guideless catheter placement technique is a viable, cost-effective, and efficient approach for revision surgeries in EVD and shunt systems, which can potentially improve the safety and accuracy of catheter placement, reduce complication rates, and ensure favorable patient outcomes associated with revision surgeries for hydrocephalus.

KEYWORDS: Hydrocephalus, External ventricular catheter, External ventricular drainage, Shunt, Guideless

ABBREVIATIONS: CSF: Cerebrospinal fluid, **EVD:** External ventricular drainage

INTRODUCTION

The management of hydrocephalus often necessitates the implantation of ventricular catheters via external ventricular drainage (EVD) or ventricular shunt systems. These systems are critical for regulating intracranial cerebrospinal fluid (CSF) flow and pressure, thus averting potential neurological damage. However, both primary and revision surgical catheter placement procedures can be fraught with challenges, particularly due to the intricacies of ventricular anatomy and the risks associated with invasive neurosurgical procedures.

So far, a variety of techniques, such as the freehand method, using anatomical landmarks, and image-guided techniques (computed tomography [CT]-guided, ultrasound-guided, and neuronavigation-assisted procedures) have been employed for primary ventricular catheter placement, each having its advantages and limitations (2,4,5,7,8,11,17,18). Conversely, revision surgeries, which involve replacing or adjusting ex-

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isting catheter systems, present unique challenges, such as changes in ventricular anatomy due to previous surgeries, the presence of adhesions, and the need for precise catheter repositioning, warranting a meticulous and adaptable surgical approach.

To address these challenges, we introduce the guideless catheter placement technique for revision EVD and shunt surgeries. This approach leverages the existing trajectory of the previously placed catheter to reduce the risks associated with catheter malposition and streamline the surgical procedure. The present study aims to evaluate the efficacy, safety, and practical benefits of this technique to enhance patient outcomes in the management of hydrocephalus.

MATERIAL and METHODS

In this study, we screened 708 patients who received EVD or ventricular shunt surgeries at the Istanbul Umraniye Training and Research Hospital from January 2020 to January 2023. Patients undergoing their first revision surgery for EVD or ventricular shunt systems, with preoperative and postoperative imaging available for review were included in the study. Patients who had undergone previous revision surgery, those with preoperatively identified catheter malposition, and those with incomplete data in the medical records were excluded.

We utilized Hayhurst et al.'s 3-point scale to define malposition (6). Accordingly, Grade 1 is characterized by the catheter tip floating in CSF (equidistant from the ventricular walls, away from the choroid plexus, and maintaining a straight trajectory from the burr hole), Grade 2 involves the catheter tip making contact with a ventricle wall or the choroid plexus, and Grade 3 is defined by part of the catheter tip being within the parenchyma or a complete failure to cannulate the ventricle. Only patients categorized as Grade 1 were included in the study. Additionally, patients presenting with infection identified through analyses of CSF and/or blood specimens, or exhibiting clinical signs of catheter-associated infections upon physical examination, were excluded from the study; this exclusion was due to the protocol stipulating the use of catheter insertion at an alternative site for such cases. Based on the selection criteria, 111 patients were considered eligible for analysis in the revision case study. This approach allowed us to include a homogenous sample of patients, thereby enhancing the reliability of our findings regarding the effectiveness and safety of the guideless catheter placement technique in revision surgeries for EVD and shunt systems. The study was approved by the ethics committee of Istanbul Umraniye Training and Research Hospital (approval ID: B.10.1.TKH.4.34.H.GP.0.01/287). Informed consent was obtained from all individual participants included in the study.

Demographic and clinical data of the study patients, including age, sex, the pathology causing hydrocephalus, duration until revision, type of revision surgery (EVD or shunt), presence of complications (bleeding and malposition) in postoperative CT, the feasibility of removing the old catheter due to adhesions, and the success of guideless catheter placement, were retrospectively reviewed through patient charts (Table I).

Table I: General Characteristics of the Study Patients (n=111)

Characteristic (n)	Value
Gender	
Male	57
Female	54
Etiology	
Hemorrhage	56
Tumor	33
Primary Hydrocephalus	22
Previous Ventricular Entry Site	
Kocher	90
Keen	19
Frazier	2
Removed Device	
External Ventricular Drainage	82
Shunt	29
Installed Device	
External Ventricular Drainage	52
Shunt	59
Complications	
None	104
Malposition	5
Bleeding	2

Categorical variables were presented as frequency and percentage (n (%)), and continuous variables were presented as mean and standard deviation. The assumption of normality for continuous variables was tested using the Kolmogorov-Smirnov test; accordingly, the Mann-Whitney U test was used for between-group comparisons. Categorical variables between groups were compared using Fisher's exact chi-square tests. Additionally, we calculated the 95% confidence intervals. A p-value of <0.05 was considered statistically significant. All statistical analyses were performed using SPSS (version 27.0; IBM Corp., Armonk, NY, USA).

Surgical Procedure

After ensuring adequate sterile preparation and draping (Figure 1A), the team reopened the previous incision to access the skin and subcutaneous tissues (Figure 1B). The primary focus was on the careful extraction of the existing shunt or EVD system, with special attention to the catheter's exit direction and angle (Figure 1C). The length of the removed catheter was precisely measured (Figure 1D). To prevent CSF leakage, the burr hole was temporarily sealed with a finger or bone wax after removing the old catheter. Before inserting the new catheter, the guide was removed and the catheter

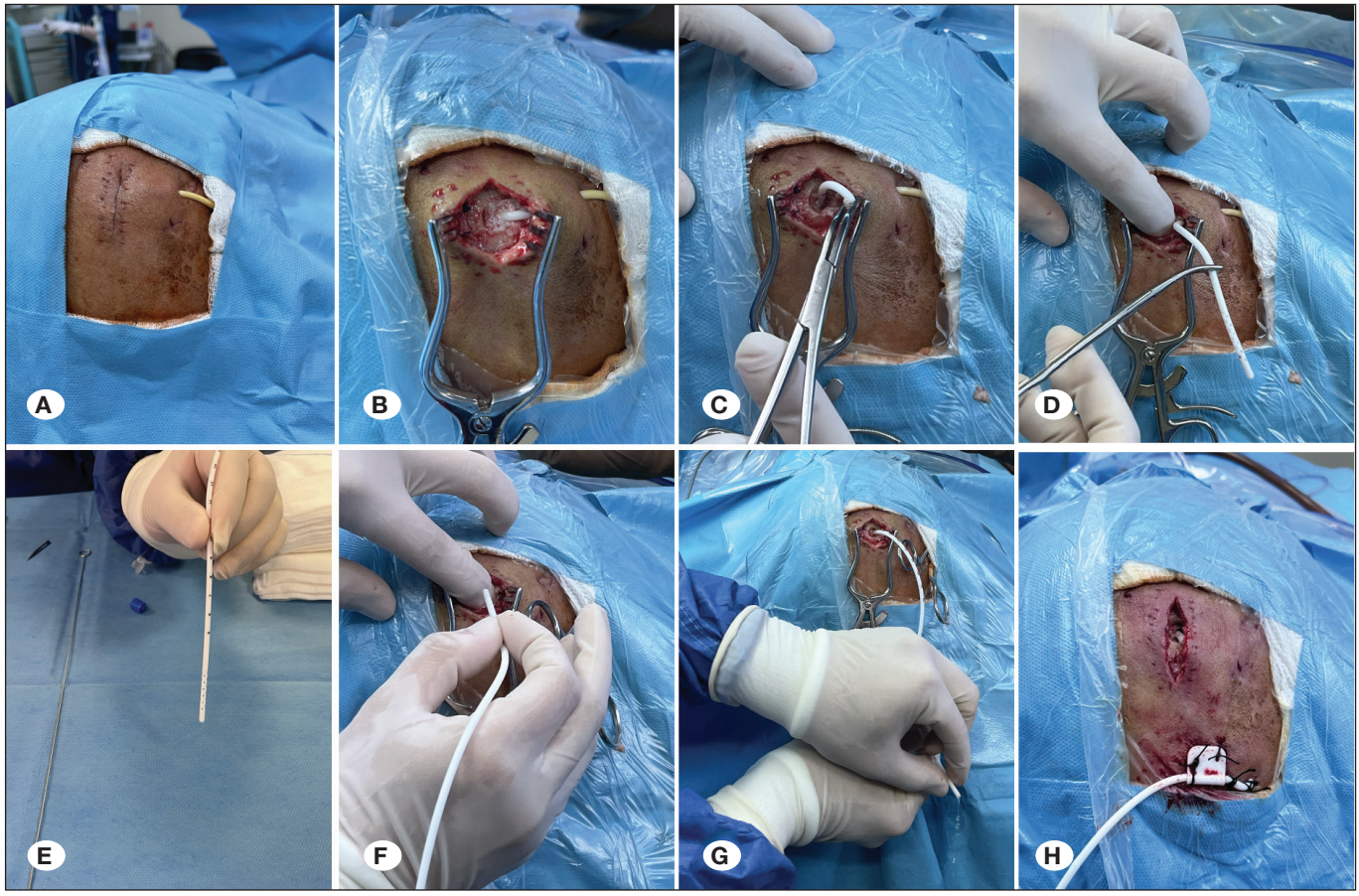

Figure 1: Overview of the revision surgical procedure. **(A)** Sterile preparation and draping. **(B)** Reopening of the previous incision. **(C)** Removal of the existing system, with special attention to the catheter's exit direction and angle. **(D)** Measuring the length of the removed catheter. **(E)** Temporary sealing of the burr hole to prevent cerebrospinal fluid leakage, followed by preparation of the new catheter to match the length of the old one. **(F)** Delivering the new catheter through the existing burr hole. **(G)** Monitoring cerebrospinal fluid flow under pressure. **(H)** Secure attachment of the catheter to the designated system.

was prepared to ensure it matched the length of the previously used one (Figure 1E). The new catheter was introduced through the pre-existing burr hole and dural opening without making additional surgical incisions. This step was executed without a guide, ensuring the new catheter aligned in the same direction and angle as the previous one (Figure 1F) while diligently monitoring the CSF flow under pressure (Figure 1G). After confirming proper CSF circulation, the catheter was securely attached to the pre-determined EVD or shunt system (Figure 1H); this step marked the completion of the revision, ensuring the restoration and effective functioning of the neurosurgical drainage system.

RESULTS

Patient Demographics and Clinical Characteristics

Among the 111 patients included in this study (mean age = 40.65 years; range = 2–86 years), 57 were male and 54 were female. Regarding the pathology underlying hydrocephalus, hemorrhage was identified as the cause in 56 patients, tumor in 33 patients, and primary hydrocephalus in 22 patients.

Among the 56 patients with hemorrhage-induced hydrocephalus, the following vascular lesions were determined–anterior communicating artery aneurysm (n=18), middle cerebral artery aneurysm (n=6), internal carotid artery aneurysm (n=5), anterior cerebral artery aneurysm (n=3), posterior cerebral artery aneurysm (n=3), basilar artery aneurysm (n=2), superior cerebellar artery aneurysm (n =1), posterior inferior cerebellar artery aneurysm (n=1), arteriovenous malformation (n=1), and trauma (n=1); 15 patients showed no vascular pathology.

In terms of tumors, lesions in the following brain areas were noted–infratentorial (n=18), lateral ventricle (n=3), temporal lobe (n=4), occipital lobe (n=2), 4th ventricle (n=2), parietal lobe (n=1), frontal lobe (n=1), 3rd ventricle (n=1), and thalamus (n=1).

Among the remaining 22 cases, 10 patients developed hydrocephalus post-meningomyelocele, three had hydrocephalus following syndromic birth, one developed hydrocephalus post-infarct, and eight were treated for hydrocephalus without a primary cause with the initial ventricular drainage system.

Revision Surgery and Outcomes

In terms of revision ventricular catheter procedures, 45 patients had their existing EVD system removed and replaced with a new EVD system, 37 had their EVD system replaced with a shunt system, seven had their shunt system replaced with an EVD system, and 22 had their shunt system replaced with a new shunt system.

Regarding the duration from primary to revision surgeries, the minimum time for revision surgery after a primary shunt surgery was 3 days while the maximum was 5475 days; in the primary EVD group, the average time to revision was 5.7 days (range = 1–7 days).

Postoperative complications included bleeding (n=2, 1.8%) and catheter malposition (n=3, 2.7%) (Table II). There was no statistically significant difference in the incidence of complications when considering age, gender, primary pathology, or the type of catheter previous or applied (p>0.05) (Table III).

In two of the 111 cases, CSF flow under pressure was not observed, which necessitated the use of a guide for successful catheter insertion. Therefore, these cases were included in the study as patients who developed complications due to catheter malposition, making the incidence of this complication 4.5%.

Table II: Patients with Observed Complication

Patient No	Age (years)	Primary Pathology	Pathology Detail	Previous Catheter	Applied Catheter	Complication
1	52	Hemorrhage	Aneurysm	EVD (Kocher)	EVD	Malposition
2	71	Hemorrhage	Aneurysm	EVD (Kocher)	EVD	Malposition
3	25	Hemorrhage	Spontanuous	EVD (Keen)	EVD	Malposition
4	19	Hydrocephalus	Myelomeningocele	Shunt (Kocher)	Shunt	Bleeding
5	55	Hydrocephalus	Myelomeningocele	Shunt (Kocher)	Shunt	Bleeding
6	32	Hemorrhage	Spontanuous	EVD (Kocher)	EVD	Malposition
7	64	Tumor	Infratentorial tumor	EVD (Kocher)	EVD	Malposition

EVD: *External ventricular drainage.*

Table III: Complication Rates of Patients Based on Demographic and Certain Clinical Characteristics

		Complication		
Variables	**Total**	**Yes**	**No**	**p-value**
Overall, n(%)	111 (100)	7 (6.3)	104 (93.7)	
Age (years), mean ± SD	40.66 ± 24.30	45.43 ± 20.12	40.34 ± 24.61	0.540[a]
Gender, n(%)				>0.999[b]
Male	55 (49.5)	3 (5.5)	52 (94.5)	
Female	56 (50.5)	4 (7.1)	52 (92.9)	
Primary diagnosis, n (%)				0.677[b]
Hemorrhage	56 (50.5)	4 (7.1)	52 (92.9)	
Hydrocephalus	22 (19.8)	2 (9.1)	20 (90.9)	
Tumor	33 (29.7)	1 (3)	32 (97)	
Applied catheter, n (%)				0.249[b]
EVD	52 (46.8)	5 (9.6)	47 (90.4)	
Shunt	59 (53.2)	2 (3.4)	57 (96.6)	
Previous catheter, n (%)				>0.999[b]
EVD	82 (73.9)	5 (6.1)	77 (93.9)	
Shunt	29 (26.1)	2 (6.9)	27 (93.1)	

p>0.05; ***a:*** *Mann-Whitney U test,* ***b:*** *Fisher's Exact test,* ***EVD:*** *External ventricular drainage,* ***SD:*** *Standard deviation.*

DISCUSSION

Ventricular catheter insertion is a crucial step in EVD and shunt surgeries for the management of hydrocephalus. Despite its critical role in neurosurgical care, the procedure is often challenging, especially when the ventricular anatomy is altered. A variety of initial catheter placement techniques have been discussed in the literature, including freehand, CT-guided, Ghajar Guide, 3D ultrasound-guided, navigation-assisted, and smartphone-supported navigation planning (1,4,5,7,8, 12,16–19, 21,22). Although the guideless catheter placement technique for revision surgeries in EVD and shunt systems has been commonly used by neurosurgical professionals, we noted a lack of comprehensive reporting on its detailed methodologies, outcomes, and potential variations in the existing neurosurgical literature. In this context, the present study provides an all-inclusive description of the technique and evaluates its efficacy and safety through a series of cases.

Optimal outcomes after EVD insertion rely heavily on accurate catheter placement, ideally targeting the frontal horn of the lateral ventricle near the foramen of Monro (7). The precise determination of the entry point (most commonly Kocher's point) and meticulous management of the catheter's angle and length are key to catheter insertion. In cases where Kocher's point is not an option, alternative sites such as Keen's point, Frazier's, and Dandy's point may be used (15).

In the context of revision surgeries, we observed an intriguing phenomenon–when a new catheter was inserted using the same trajectory as the previous one, even if the original catheter was in place for a duration as short as one day, the new catheter tended to follow the same path (Figure 2). A potential explanation for this could be the formation of a pseudo-tunnel created by the initial catheter in the brain tissue, which remains patent due to the viscoelastic nature of brain tissue and the presence of CSF along the tract. Consequently, when a new catheter is introduced through the same entry point, it naturally follows this path of least resistance, retracing the original catheter's trajectory. This hypothesis underscores the significance of ensuring anatomical correctness of the initial placement and its potential impact on subsequent revision surgeries.

The speed of the procedure is a vital consideration, particularly in the context of hydrocephalus management. While the freehand technique is faster, it poses a risk of misalignment with crucial anatomical landmarks (2,10). In contrast hand, methods like ultrasonography and neuronavigation provide enhanced accuracy (5,7,11). Neuronavigation offers increased precision but requires additional equipment and training. In this regard, the guideless catheter placement technique does not require extra equipment, thus eliminating the need for further investment and training. In revision surgeries, the presence of existing catheters and altered ventricular anatomy introduces unique challenges. Our method leverages the path of the existing catheter and presents an innovative approach to mitigate the risks of catheter malpositioning and associated complications. This technique is particularly advantageous in cases where traditional anatomical landmarks are unreliable.

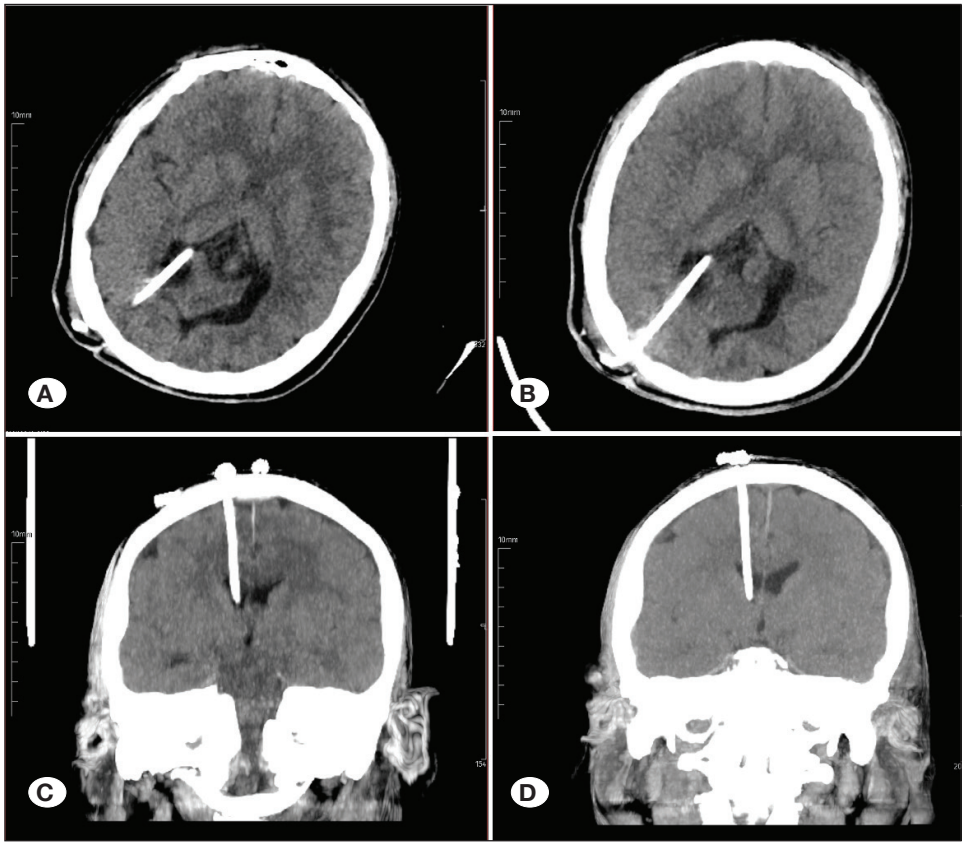

Figure 2: Computed tomography (CT) images of two different revision cases. **A)** Preoperative and **B)** postoperative axial images of Patient 1. **C)** Preoperative and **D)** postoperative coronal images of Patient 2**.**

The literature indicates that the accuracy of EVD placement ranges from 7% to 45.9% (3,8,9,20), and the incidence of hemorrhagic complications post-EVD insertion may range from 0% to 15% (2,9,13,14,23). In our study, only 1.8% of the patients who underwent revision surgery using the guideless catheter placement technique experienced hemorrhagic complications, which is consistent with the low bleeding rates reported in the literature. Likewise, the malposition rates were also quite low (4.5%), indicating a high level of accuracy.

The results of our study indicate that the guideless catheter placement technique has a significant impact on reducing postoperative complications such as bleeding and catheter malposition. Nevertheless, it is crucial to understand the underlying causes of these complications and how they relate to the surgical technique employed.

Bleeding

Bleeding (1.8%) was primarily observed in patients with shunts older than five years, where the cause of bleeding can be attributed to the presence of adhesions from the old shunt, which made the removal and replacement process more challenging. While extracting an old catheter, these adhesions can disrupt the surrounding tissues, leading to bleeding, underscoring the importance of meticulous dissection and careful handling of tissues during revision surgeries, especially in those with long-standing shunt systems.

Catheter Malposition

Catheter malposition was observed in 4.5% of cases in our series. In three patients, despite observing CSF flow during surgery, the postoperative position was suboptimal (Hayhurst's Grade 3); however, part of the catheter remained within the ventricle and did not necessitate further revision. In two patients (1.8%), the absence of CSF flow during surgery raised concerns about the catheter's placement, prompting the use of a guide to create a new tunnel and accurately reposition the catheter. These cases were classified as malposition because the catheters could not be advanced using the guideless technique.

The guideless catheter placement technique offers several advantages in revision surgeries for EVD and shunt systems. It is cost-effective and does not require specialized equipment or additional training, making it accessible in resource-limited settings. By leveraging the trajectory of the previous catheter, this technique reduces the need for multiple passes, thereby minimizing the risk of catheter malposition and decreasing operation times and intraoperative complications, such as bleeding. Yet, its efficacy relies heavily on the accuracy of the initial catheter placement, i.e., if the initial catheter was suboptimally placed, the guideless method may perpetuate this inaccuracy, reducing the effectiveness of the revision technique. The technique can also be challenging in cases with significant adhesions or anatomical changes due to previous surgeries. In primary surgeries, advanced technologies like neuronavigation and augmented reality are crucial for precise catheter placement. However, in revision cases, especially when accurate positioning of the existing catheter is required, these technologies may incur additional costs due to the need for extra devices and/or software. Additionally, the retrospective design of our study may introduce bias. Despite these limitations, our study demonstrates that careful patient selection and surgical expertise can enhance the technique's efficacy to improve patient outcomes and reduce complication rates for revision surgeries.

CONCLUSION

The guideless catheter placement technique emerges as a viable method for revision EVD and shunt surgeries. As this technique does not rely on supplementary devices or software, it is cost-efficient and can be executed rapidly with high precision, which underscores its effectiveness and practicality in clinical settings. It also offers a pragmatic solution that balances the need for accuracy with the constraints of time and resources, making it an important addition to neurosurgical practices, particularly in complex revision scenarios.

Declarations

Funding: No funding was received during the study.

Availability of data and materials: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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AUTHORSHIP CONTRIBUTION

Study conception and design: SI, MUE
Data collection: CBY, BAN, HS, LS
Analysis and interpretation of results: CKY, MUE, FA
Draft manuscript preparation: MUE, SI, AZK
Critical revision of the article: CKY
Other (study supervision, fundings, materials, etc...): AFR
All authors (MUE, SI, AZK, CBY, CKY, HS, LS, FA, BAN, AFR) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Abdoh MG, Bekaert O, Hodel J, Diarra SM, Le Guerinel C, Nseir R, Bastuji-Garin S, Decq P: Accuracy of external ventricular drainage catheter placement. Acta Neurochir 154:153-159, 2012. https://doi.org/10.1007/s00701-011-1136-9
2. Bender M, Schwarm F, Stein M, Uhl E, Reinges MHT: Placement of external ventricular drain: Comparison of two methods. J Neurol Surg A Cent Eur Neurosurg 80:116-121, 2019. https://doi.org/10.1055/s-0038-1676576
3. Bogdahn U, Lau W, Hassel W, Gunreben G, Mertens HG, Brawanski A: Continuous-pressure controlled, external ventricular drainage for treatment of acute hydrocephalus-evaluation of risk factors. Neurosurgery 31:898-904, 1992. https://doi.org/10.1097/00006123-199211000-00011
4. Eisenring C V, Burn F, Baumann M, Stieglitz LH, Kockro RA, Beck J, Raabe A, Oertel MF: sEVD-smartphone-navigated placement of external ventricular drains. Acta Neurochir 162:513-521, 2020. https://doi.org/10.1007/s00701-019-04131-9

5. Gautschi OP, Smoll NR, Kotowski M, Schatlo B, Tosic M, Stimec B, Fasel J, Schaller K, Bijlenga P: Non-assisted versus neuro-navigated and XperCT-guided external ventricular catheter placement: A comparative cadaver study. Acta Neurochir (Wien) 156:777-785, 2014. https://doi.org/10.1007/s00701-014-2026-8
6. Hayhurst C, Beems T, Jenkinson MD, Byrne P, Clark S, Kandasamy J, Goodden J, Nandoe Tewarie RDS, Mallucci CL: Effect of electromagnetic-navigated shunt placement on failure rates: A prospective multicenter study. J Neurosurg 113:1273-1278, 2010. https://doi.org/10.3171/2010.3.JNS091237
7. Hekimoglu M, Kiris T: Intraventricular shunt catheter placement of adult normal pressure hydrocephalus using an AxiEMTM electromagnetic neuronavigation system: A single-center experience. Turk Neurosurg 34:60-66, 2024
8. Huyette DR, Turnbow BJ, Kaufman C, Vaslow DF, Whiting BB, Oh MY: Accuracy of the freehand pass technique for ventriculostomy catheter placement: Retrospective assessment using computed tomography scans. J Neurosurg 108:88-91, 2008. https://doi.org/10.3171/JNS/2008/108/01/0088
9. Khanna RK, Rosenblum ML, Rock JP, Malik GM: Prolonged external ventricular drainage with percutaneous long-tunnel ventriculostomies. J Neurosurg 83:791-794, 1995. https://doi.org/10.3171/jns.1995.83.5.0791
10. Lee JH, Park CW, Lee U, Kim YB, Yoo CJ, Kim EY, Kim JM, Kim WK: Accuracy of the free hand placement of an external ventricular drain (EVD). Korean J Cerebrovascular Surg 12:82-86, 2010
11. Leu S, Kamenova M, Mariani L, Soleman J: Ultrasound-guided insertion of the ventricular catheter in ventriculoperitoneal shunt surgery: Evaluation of accuracy and feasibility in a prospective cohort. J Neurol Surg A Cent Eur Neurosurg 82:9-17, 2020. https://doi.org/10.1055/s-0040-1714388
12. Lollis SS, Roberts DW: Robotic catheter ventriculostomy: Feasibility, efficacy, and implications. J Neurosurg 108:269-274, 2008. https://doi.org/10.3171/JNS/2008/108/2/0269
13. Meyer B, Schaller K, Rohde V, Hassler W: Percutaneous needle trephination. Experience in 200 cases. Acta Neurochir 127:232-235, 1994. https://doi.org/10.1007/BF01808772
14. Miller C, Tummala RP: Risk factors for hemorrhage associated with external ventricular drain placement and removal. J Neurosurg 126:289-297, 2017. https://doi.org/10.3171/2015.12.JNS152341
15. Morone PJ, Dewan MC, Zuckerman SL, Tubbs RS, Singer RJ: Craniometrics and ventricular access: A review of Kocher's, Kaufman's, Paine's, Menovksy's, Tubbs', Keen's, Frazier's, Dandy's, and Sanchez's points. Operative Neurosurgery 18:461-469, 2020. https://doi.org/10.1093/ons/opz194
16. Ofoma H, Cheaney II B, Brown NJ, Lien B V, Himstead AS, Choi EH, Cohn S, Campos JK, Oh MY: Updates on techniques and technology to optimize external ventricular drain placement: A review of the literature. Clin Neurol Neurosurg 213:107126, 2022. https://doi.org/10.1016/j.clineuro.2022.107126
17. O'Leary ST, Kole MK, Hoover DA, Hysell SE, Thomas A, Shaffrey CI: Efficacy of the ghajar guide revisited: A prospective study. J Neurosurg 92:801-803, 2000. https://doi.org/10.3171/jns.2000.92.5.0801
18. Reinertsen I, Jakola AS, Friderichsen P, Lindseth F, Solheim O, Selbekk T, Unsgård G: A new system for 3D ultrasound-guided placement of cerebral ventricle catheters. Int J Comput Assist Radiol Surg 7:151-157, 2012. https://doi.org/10.1007/s11548-011-0622-0
19. Spadola M, Muhammad N, Ajmera S, Jabarkheel R, Tomlinson S, Miranda SP, Grady MS, Schuster J, Blue R: The device for intraventricular entry guide: A novel solution to a perpetual problem. J Neurosurg 140:1501-1506, 2023. https://doi.org/10.3171/2023.8.JNS23693
20. Stangl AP, Meyer B, Zentner J, Schramm J: Continuous external CSF drainage-a perpetual problem in neurosurgery. Surg Neurol 50:77-82, 1998. https://doi.org/10.1016/S0090-3019(97)00301-7
21. Stieglitz LH, Giordano M, Samii M, Luedemann WO: A new tool for frameless stereotactic placement of ventricular catheters. Neurosurgery 67:ons131-135, 2010. https://doi.org/10.1227/01.NEU.0000382964.72262.9A
22. Thomale UW, Knitter T, Schaumann A, Ahmadi SA, Ziegler P, Schulz M, Miethke C: Smartphone-assisted guide for the placement of ventricular catheters. Child's Nerv Syst 29:131-139, 2013. https://doi.org/10.1007/s00381-012-1943-1
23. Roitberg BZ, Khan N, Alp MS, Hersonskey T, Charbel FT, Ausman JI: Bedside external ventricular drain placement for the treatment of acute hydrocephalus. Br J Neurosurg 15:324-327, 2001. https://doi.org/10.1080/02688690120072478