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The Assessment of Geometric Reliability of Conventional Trajectory of Ventriculostomy in a Three Dimensional Virtual Model and Proposal of a New Trajectory

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Abstract

Ventriculostomy is a common neurosurgery procedure performed for many purposes. Kocher's point is most often used as the ventriculostomy entry point. But the accuracy of a cannula's trajectory into the ventricles from entry at Kocher's point is controversial. In this paper we attempt to evaluate the accuracy of the conventional sagittal trajectory, which uses Kocher's point, and evaluate a new trajectory by creating virtual ventriculostomy simulations from computed tomography images of the brain. About 66 patients without brain and skull pathology in radiography were included. Three dimensional images were constructed using thin sliced brain computed tomography images, and a virtual ventriculostomy was performed toward the previous used surface landmark. And the path of ideal ventricular catheter was simulated. The anterior surface landmarks included the ipsilateral medial canthus, the contralateral medial canthus, and the midpoint between bilateral medial canthi. The lateral surface landmark was the external auditory canal. The sagittal trajectory of the three surface landmarks located in the frontal horn of ipsilateral ventricle was 0% for the ipsilateral medial canthus, 87.88% for the midpoint between bilateral medial canthi and 26.52% for the contralateral medial canthus. The anterior surface target of ideal sagittal trajectory, which connects the Kocher's point with the central axis of ipsilateral ventricle, is contralaterally 6.7 mm away from midline. It was found that the conventional sagittal trajectory is inaccurate. The anterior target of surface landmark for the ideal sagittal trajectory is medial one third of the distance between the midline and the contralateral medial canthus.

Key words: anatomic landmarks, computer simulation, skull, ventriculostomy

Introduction

Ventriculostomy is a common neurosurgery procedure and implemented for a variety of purposes including cerebrospinal fluid diversion, delivering drugs directly into the brain, and intracranial pressure monitoring.[1] There are several cannulation sites where a ventriculostomy can be placed. Kocher's point (10 mm anterior to the coronal suture in the mid-pupillary line) is a frequently used cannulation site in adults.[2,3] Using this point and two surface landmarks, ipsilateral medial canthus (IMC) as the anterior and external auditory canal (EAC) as the lateral target, trajectory is created into the ventricle.

Recently, some neurosurgeons have started using radiologic guidance systems during ventriculostomy; however, many neurosurgeons still perform ventriculostomy without a guidance system.[4–7] While some reports show a high success rate for conventional ventriculostomy, other reports suggest that alternatives are needed due to a low success rate, multiple trials, and mispositioned catheters.[3,8–19] Stereotactic guide techniques, navigation guide techniques, and ultrasound guide techniques are being used to increase the success rate.[4–7] However, some institutions lack the equipment or the funding necessary to increase the success rate, and some cases are too emergent to utilize the guidance techniques. In these cases, there is no choice but to perform ventriculostomy at the bedside without any

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assist from the image guiding tools. The purpose of this study is to evaluate the geometric reliability of the conventional ventriculostomy drainage trajectory and propose a new trajectory using three dimensional virtual models.

Materials and Methods

This study was approved by the Institutional Review Board and regional ethics committee of the Chungnam National University Hospital (Approval code: 2019-05-085). All adult patients who underwent brain computed tomography (CT) angiography between January 2018 and August 2018 were included. Whereas if there were abnormal findings such as previous brain surgery, skull lesions or abnormalities, brain space occupying lesions (brain tumors, hemorrhage, cerebral infarction etc.), arachnoid cyst and encephalomalacia, they were excluded from this study.

A virtual trajectory for ventriculostomy was created by reconstructing a source image from 1-mm sliced CT image taken with a SOMATOM Definition Flash CT scanner (Siemens Healthcare, Forchheim, Germany) at Chungnam National University Hospital (Daejeon, Korea). This images were uploaded onto the Leksell SurgiPlan Version 10.1 (Elekta Instrument AB, Stockholm, Sweden) for reconstruction. Using the "anterior commissure–posterior commissure" line tool three points were selected, both Kocher's points and one EAC, to create a plane. This plane was defined as the "key plane" (Fig. 1A) and became the coronal trajectory when performing the actual ventriculostomy. Kocher's point was defined as the intersecting point of 30 mm lateral from the sagittal suture and 10 mm anterior from the coronal suture and EAC as the lateral surface landmark. The shortest line from the fornix to the head of the caudate nucleus in the lateral ventricle observed in the key plane was defined as the "ventricle width" (Fig. 1B). The bicaudate indices were the ratio of the width of both lateral ventricles at the level of the heads of the caudate nuclei to the distance between the inner tables of the skull at the same level. The cephalic indices were the ratio of the maximum width of biparietal diameter to maximum length of occipitofrontal diameter. The IMC, the contralateral medial canthus (CMC) and midpoint between bilateral medial canthi (MP) were used as anterior targets. The trajectory that connected the Kocher's point with each anterior target became the sagittal trajectory when placing a ventricular catheter. The three anterior targets were projected onto the key plane (Fig. 1B), and the image of the key plane and image of the facial surface with the three anterior targets were collaged (Fig. 1C). When the coronal trajectory was constant, virtual ventriculostomies were performed for each anterior targets. For the three anterior targets, three sagittal trajectories were displayed on the key plane. Each trajectory showed a path through which the catheter would actually pass (Fig. 1D). Whether each path passes the ventricle or not was analyzed. If it did not pass into the ventricle, its location in the brain was further evaluated. If it passed into the ipsilateral ventricle, its location was evaluated to determine if it was located in the lateral or medial side of long axis of the lateral ventricle. To find the ideal sagittal trajectory, we constructed a line connecting Kocher's point with the midpoint of the ventricle width in the key plane (Fig. 2A). The point of intersection between the ideal sagittal trajectory and the line connecting the IMC and the CMC was defined as the ideal anterior target (Fig. 2B). Whether the ideal point was located on the ipsilateral side or the contralateral side with respect to the midline was determined and this distance was measured. In 132 cases, virtual ventriculostomies were performed using an average ideal anterior target to create the sagittal trajectory in order to determine whether the ipsilateral ventricle would be entered in the key plane.

Statistical analysis was performed using SPSS Version 24.0 (IBM, Armonk, NY, USA). The correlation between catheter location and other variables was analyzed using a *t*-test for the continuous variables and Chi-square test for the categorical variables. *P*-values of <0.05 were considered significant.

Results

Two-hundred and forty-two adult patients who underwent brain CT angiography between January 2018 and August 2018 were selected and a 1-mm thin sliced CT was obtained from each. Of those, 176 patients were excluded due to a history of brain surgery, skull lesions, brain occupying lesions such as brain tumors or hemorrhages, cerebral infarction, arachnoid cyst or encephalomalacia. A total of 66 patients with no brain lesion with normal size ventricles were analyzed.

Data summary

A total of 66 patients were virtually simulated bilaterally makings a total of 132. The patient population's male to female ratio was 27:39 and the mean age was 53.77 (21–78) years. The average ± SD width of the ventricles was 8.81 ± 3.42 mm, the average distance from the midline to the medial canthus was 16.03 ± 1.78 mm, the average bicaudate

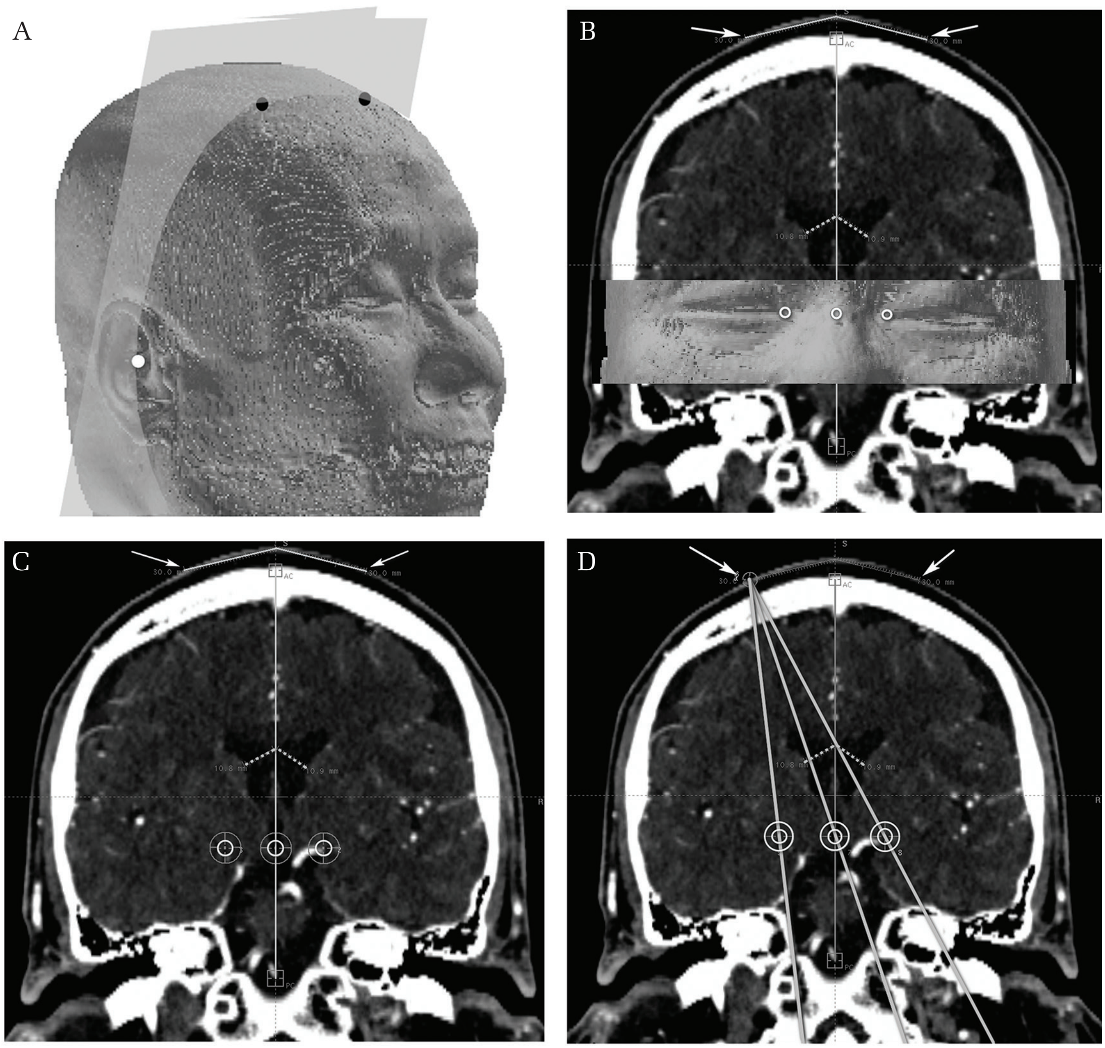

Fig. 1 **The reconstructed image from 1-mm thin slice computed tomography (CT) images which were uploaded onto Leksell SurgiPlan®. (A) The reconstructed three-dimensional surface image. The gray plane was reconstructed to form the "key plane" consisting of three points, including the bilateral Kocher's points (*black spots*) and one external auditory canal (*white spot*). (B) The collage image of the reconstructed facial surface and "key plane" image. The *white circles* represent the facial surface landmarks, which were the bilateral medial canthi and the midpoint between bilateral the medial canthi. The *gray dash line* in the lateral ventricle represents the "ventricle width." It is the shortest line connecting the fornix and the head of the caudate nucleus in the lateral ventricle observed in the key plane. The *white arrows* represent the Kocher's point. (C) The reconstructed image of the key plane. The *white circles* show the facial surface landmarks on the key plane and the *white arrows* indicate Kocher's point. (D) The virtual EVD simulation trajectories toward the three separate facial surface landmarks from the right Kocher's point (The *gray line* represents the path through which the actual ventricular catheter passes).**

index was 13.69 ± 0.34 mm and the average cephalic index was 86.52 ± 6.29% (Table 1).

Virtual ventriculostomy for each anterior target

Keeping the coronal trajectory constant, virtual ventriculostomy was performed using the three sagittal trajectories, each with an anterior target, and the results are shown in Table 2. When the IMC was set as the anterior target, the success rate of the catheter passing into the ipsilateral ventricle was not 100%. Thirty cases (22.73%) went into the internal capsule and 102 cases (77.27%) into the putamen. The ventricle width and bicaudate index indicate the size of ventricle. The larger the ventricle width and bicaudate index, the more the catheter tended to pass into the internal capsule. This was statistically significant (*P*-value = 0.033). When the anterior target was set as MP, 116 cases (87.88%) had succeeded in passing the catheter into the ipsilateral frontal horn of the ventricle; however,

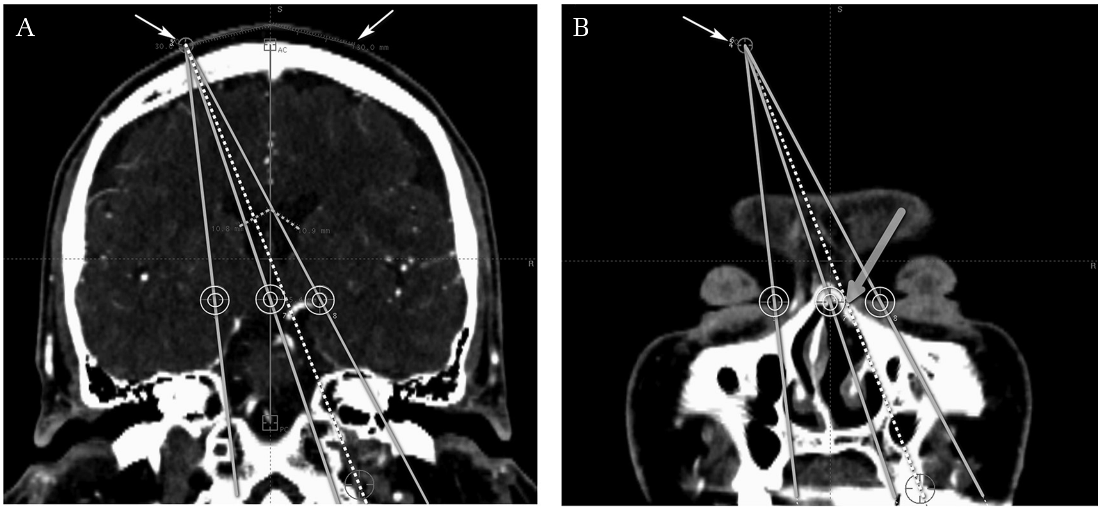

Fig. 2 **(A) The ideal sagittal trajectory in the key plane. (B) The reconstructed image showing the sagittal trajectories using the three facial surface landmarks and an ideal sagittal trajectory on the face, moving parallel to the key plane. The *white dash line* represents the line connecting Kocher's point with the midpoint of the width of the ventricle in the key plane. The *white dash line* presents the ideal sagittal trajectory. The *gray lines* represent sagittal trajectories using three surface landmarks (*white circles*: ipsilateral medial canthus, contralateral medial canthus, and midpoint between bilateral medial canthi). The *gray arrow* is surface landmark of ideal anterior target.**

Table 1 **Summary of the patient's data**

	Average value
Age	53.77 (21–78)
Sex (Male:Female)	39:27 (40.91%:59.09%)
Ventricle width	8.81 mm (±3.42)
Bicaudate index (%)	13.69 (±0.34)
Cephalic index (%)	86.52 (±6.29)
Distance between medial canthus and midline	16.03 mm (±1.78)
Distance between ideal anterior target point and midline	6.31 mm (±1.79)

Table 2 **Location of ventricular catheter for each anterior target and correlation between catheter location and ventricle width and catheter location according to each anterior target**

Anterior target	Catheter location	Number (%)	Average value of each ventricle width according to catheter location (mm)	Average value of each bicaudate index according to catheter location (mm)	P-value*
Ipsilateral medial canthus	Putamen	102 (77.27)	7.94 (±2.84)	12.75 ± 2.55	0.033
	Internal capsule	30 (22.73)	11.79 (±3.61)	16.53 ± 2.95	
	Ipsilateral ventricle	0 (0)	–		
Surface midpoint	Caudate nucleus	16 (12.12)	5.24 (±1.30)	10.32 ± 1.00	0.002
	Ipsilateral ventricle	116 (87.88)	9.31 (±3.33)	14.15 ± 0.34	
Contralateral medial canthus	Ipsilateral ventricle	35 (26.52)	12.26 (±3.21)	17.21 ± 1.71	0.028
	Contralateral ventricle	97 (73.48)	7.57 (±2.54)	12.41 ± 0.84	

*P-value represents comparisons between ventricle width and location of catheter using t-test.

16 cases had (12.12%) failed. The ventricular catheter tended to deviate laterally at the midpoint of the ventricle width. When the cannulation failed to reach the ventricles, the ventricular catheters passed through the head of the caudate nucleus. The larger the ventricle width and bicaudate index, the more the catheter deviated toward the medial side of the midpoint of the ventricle width. This was statistically significant (*P*-value = 0.002).

When the CMC was set as the anterior target, all the ventricular catheter successfully passed into the ventricle. However, only 35 cases (26.52%) passed through the main target, the ipsilateral ventricle, whereas 97 cases (73.48%) passed into the contralateral ventricle. As the ventricular width and bicaudate index increased, the ventricular catheter was located in the ipsilateral ventricle. This was statistically significant (*P*-value = 0.022).

The ideal sagittal trajectory was the extension line between the ipsilateral Kocher's point and the midpoint of the ventricle width. The ideal anterior target was where the ideal sagittal trajectory and the intercanthal line met. The average distance of the ideal anterior target was contralateral side 6.31 ± 1.79 mm from the midline (Table 1). When using the ideal sagittal trajectory with the ideal anterior target, all cases (100%) successfully passed into the ipsilateral ventricle. Figure 3 showed the ventriculostomy success rate according to each anterior target.

Discussion

In 1908, H. Tillmaans published the modern concept of the ventriculostomy technique, which has remained largely unchanged to date.[20] Additionally, Kocher's point, which is widely used in the current procedures of ventriculostomy, was presented by Theodor Kocher and has been used for 100 years.[21] There have been many reports on the accuracy of ventriculostomy using this point; however, a high failure rate of freehand ventriculostomy has been reported to be 6.5–28.5%.[3,8–13,16,18] There are conflicting reports some stating that ventriculostomy using the existing targets creates an accurate trajectory while others stating and that an alternative target is needed because the existing targets create inaccurate trajectories.[3,8–13,16,18] In previous reports, if CSF could not be diverted through the ventricular catheter it was considered a failure.[16,18] In some surveys, neurosurgeons have overestimated the success rate of their ventriculostomies and have reported several attempts for successful drain CSF.[2,22] Kakarla et al.[12] classified the placement of a ventricular catheter into three grades in the brain CT after a total of 332 ventriculostomies. Grade I was where the catheter was placed in the ipsilateral frontal horn of lateral ventricle or third ventricle and was most optimally placed. Assuming failure if the ventricular catheter placement is not grade I increases the failure rate by 18.9–60.1%.[3,8–13,16] In a virtual simulation study, the failure rate of the conventional trajectory was reported to be 90%, which is similar to ours.[3]

There are reports that the success rate of ventriculostomy increased when the sagittal trajectory is directed toward the medial or contralateral side and the coronal trajectory is constant.[3,8,19,23,24] Abdoh et al.[8] reported the failure rate of ventriculostomy was

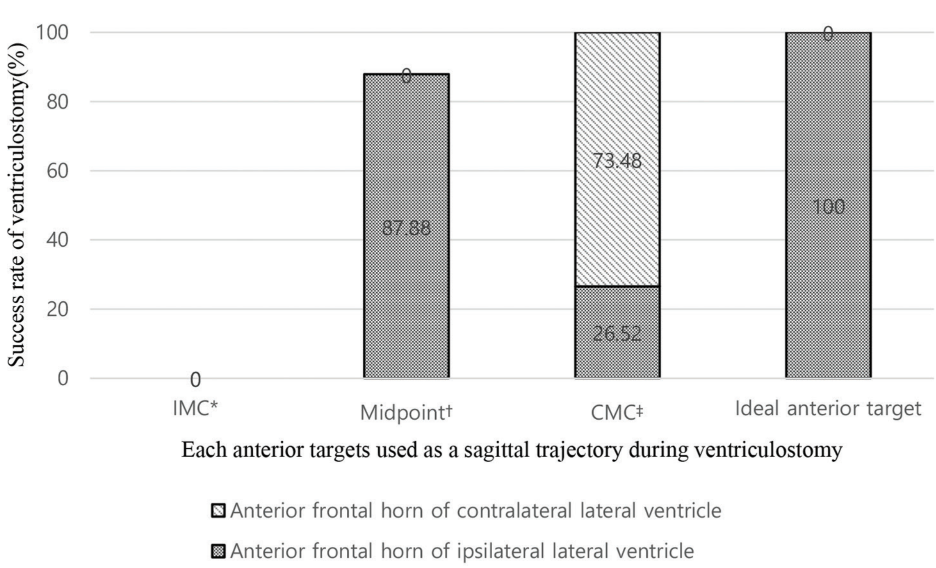

Fig. 3 The ventriculostomy success rate according to each anterior target. *: Ipsilateral medial canthus, †: Midpoint between bilateral medial canthi, ‡: Contralateral medial canthus.

4.5% when the sagittal trajectory headed toward the nasion. Raabe et al.[19] analyzed the sagittal trajectory for various entry points around Kocher's point and reported that the closer the entry point was to the midline, the more the sagittal trajectory was directed toward the IMC, and as the entry point moved to the lateral side the more the sagittal trajectory was directed toward the CMC. The results of our study showed that the IMC used as a conventional sagittal trajectory is very inadequate for ventriculostomy. And sagittal trajectory for two different surface landmarks (MP and CMC) could increase the success rate, but it is an inappropriate landmark for optimal location of ventricular catheter. Also our results showed that the most accurate anterior target for the ideal sagittal trajectory was 6.3 mm from the midline to the contralateral side in the intercanthal line. However, the ideal anterior target did not have a surface landmark, so there are limitations when actually performing a ventriculostomy. Thus, we determine that the ideal anterior target for the ideal sagittal trajectory is the medial one third point of the distance between the midline and the CMC.

There could be several reasons why the use of previous sagittal trajectory is inappropriate for implementing ventriculostomy. First, most reports of successful ventriculostomy with conventional trajectory were accompanied by ventriculomegaly. When IMC was selected as the anterior target for the ventriculomegaly, it is presumed that normal ventricle size was not considered. A large ventricle is more likely to succeed. Our results also showed that as the ventricle size increased, the ventricular catheter tended to converge toward the midline. The more the catheter heads the midline, the higher is the success rate. Second, it is known that Asians tend to have a longer intercanthal distance than Caucasians, which means that the position of the medial canthus is more medial in Caucasians than in Asians. In past studies, the intercanthal distance of Caucasians averaged 25–30 mm, and the intercanthal distance of Asians averaged 37.51 mm for men and 35.55 mm for women.[25,26] In our study, the average intercanthal distance was 32.06 mm, which is 2–7 mm longer than the average Caucasian intercanthal distance (Table 1). This indicates that the sagittal trajectory is more laterally directed in Asians than in Caucasians, which may be the reason for the increased ventriculostomy failure rate using the conventional trajectory. Third, we estimated that sagittal trajectory may vary depending on the shape of the skull in each race. Although ethnicities are not clearly identified in studies of ventriculostomy trajectories, conventional trajectories are considered to be based on studies conducted in Europe and North America on Caucasians.[25,26] Most Caucasians have a dolichocephalic skull.[27] Most of our subjects had brachycephalic skull (Table 1). Several reports have suggested that the perpendicular trajectory from Kocher's entry point could be a successful ventriculostomy.[3,17,28] The perpendicular trajectory in the dolichocephalic skull can be estimated relatively easily because the coronal angulation of the dolichocephalic skull contour is greater than that of the brachycephalic skull. Therefore, there is a limitation in presenting the perpendicular trajectory as an alternative to the conventional trajectory on the surface of the skull when ventriculostomy is performed by free hand in the brachycephalic skull. So reconsidering accurate anterior surface landmark is necessary for a more successful ventriculostomy.

Because this study is a hypothetical study using a CT image, the results of prospective studies applied in actual clinical practice are required. Therefore, the results must be compared with the experimental results of actual ventriculostomy. In addition, our study was based on a normal brain. Further research is needed to determine what will happen when the ventricle size is increased or when the midline is shifted by a brain lesion. In addition, it is necessary to further analyze the ethnic differences.

Conclusion

The results of our study show that the existing sagittal trajectory is inaccurate, especially due to the nature of brachycephalic skull measurements. The anterior target surface landmark of the ideal sagittal trajectory is the medial one-third distance between the midline and the CMC.

Conflicts of Interest Disclosure

There is no financial interest or benefit from this study, and there is no conflicts of interest.

References

1) Bratton SL, Chestnut RM, Ghajar J, et al.: Guidelines for the management of severe traumatic brain injury. VII. Intracranial pressure monitoring technology. *J Neurotrauma* 24: S45–S54, 2007
2) Lind CR, Correia JA, Law AJ, Kejriwal R: A survey of surgical techniques for catheterising the cerebral lateral ventricles. *J Clin Neurosci* 15: 886–890, 2008
3) Muirhead WR, Basu S: Trajectories for frontal external ventricular drain placement: virtual cannulation of adults with acute hydrocephalus. *Br J Neurosurg* 26: 710–716, 2012

4) Hayhurst C, Beems T, Jenkinson MD, et al.: Effect of electromagnetic-navigated shunt placement on failure rates: a prospective multicenter study. *J Neurosurg* 113: 1273–1278, 2010

5) Greenfield JP, Schwartz TH: Catheter placement for Ommaya reservoirs with frameless surgical navigation: technical note. *Stereotact Funct Neurosurg* 86: 101–105, 2008

6) Krötz M, Linsenmaier U, Kanz KG, Pfeifer KJ, Mutschler W, Reiser M: Evaluation of minimally invasive percutaneous CT-controlled ventriculostomy in patients with severe head trauma. *Eur Radiol* 14: 227–233, 2004

7) Crowley RW, Dumont AS, Asthagiri AR, et al.: Intraoperative ultrasound guidance for the placement of permanent ventricular cerebrospinal fluid shunt catheters: a single-center historical cohort study. *World Neurosurg* 81: 397–403, 2014

8) Abdoh MG, Bekaert O, Hodel J, et al.: Accuracy of external ventricular drainage catheter placement. *Acta Neurochir* (*Wien*) 154: 153–159, 2012

9) Foreman PM, Hendrix P, Griessenauer CJ, Schmalz PG, Harrigan MR: External ventricular drain placement in the intensive care unit versus operating room: evaluation of complications and accuracy. *Clin Neurol Neurosurg* 128: 94–100, 2015

10) Hsieh CT, Chen GJ, Ma HI, et al.: The misplacement of external ventricular drain by freehand method in emergent neurosurgery. *Acta Neurol Belg* 111: 22–28, 2011

11) 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

12) Kakarla UK, Kim LJ, Chang SW, Theodore N, Spetzler RF: Safety and accuracy of bedside external ventricular drain placement. *Neurosurgery* 63: ONS162–ONS166; discussion ONS166–ONS167, 2008

13) Park YG, Woo HJ, Kim E, Park J: Accuracy and safety of bedside external ventricular drain placement at two different cranial sites: Kocher's point versus forehead. *J Korean Neurosurg Soc* 50: 317–321, 2011

14) Patil V, Lacson R, Vosburgh KG, et al.: Factors associated with external ventricular drain placement accuracy: data from an electronic health record repository. *Acta Neurochir* (*Wien*) 155: 1773–1779, 2013

15) Saladino A, White JB, Wijdicks EF, Lanzino G: Malplacement of ventricular catheters by neurosurgeons: a single institution experience. *Neurocrit Care* 10: 248–252, 2009

16) Toma AK, Camp S, Watkins LD, Grieve J, Kitchen ND: External ventricular drain insertion accuracy: is there a need for change in practice? *Neurosurgery* 65: 1197–1200; discussion 1200–1201, 2009

17) Rehman T, Rehman Au, Ali R, et al.: A radiographic analysis of ventricular trajectories. *World Neurosurg* 80: 173–178, 2013

18) Lee JH, Park CW, Lee U, et al.: Accuracy of the free hand placement of an external ventricular drain (EVD). *Kor J Cerebrovascular Surgery* 12: 82–86, 2010

19) Raabe C, Fichtner J, Beck J, Gralla J, Raabe A: Revisiting the rules for freehand ventriculostomy: a virtual reality analysis. *J Neurosurg* 128: 1250–1257, 2018

20) Srinivasan VM, O'Neill BR, Jho D, Whiting DM, Oh MY: The history of external ventricular drainage. *J Neurosurg* 120: 228–236, 2014

21) Schültke E: Theodor Kocher's craniometer. *Neurosurgery* 64: 1001–1004; discussion 1004–1005, 2009

22) O'Neill BR, Velez DA, Braxton EE, Whiting D, Oh MY: A survey of ventriculostomy and intracranial pressure monitor placement practices. *Surg Neurol* 70: 268–273; discussion 273, 2008

23) Nowacki A, Wagner F, Söll N, et al.: Preliminary results of emergency computed tomography-guided ventricular drain placement-precision for the most difficult cases. *World Neurosurg* 114: e1290–e1296, 2018

24) Krombach G, Ganser A, Fricke C, et al.: Virtual placement of frontal ventricular catheters using frameless neuronavigation: an "unbloody training" for young neurosurgeons. *Minim Invasive Neurosurg* 43: 171–175, 2000

25) Wu XS, Jian XC, He ZJ, Gao X, Li Y, Zhong X: Investigation of anthropometric measurements of anatomic structures of orbital soft tissue in 102 young Han chinese adults. *Ophthalmic Plast Reconstr Surg* 26: 339–343, 2010

26) Lee JJ, Ramirez SG, Will MJ: Gender and racial variations in cephalometric analysis. *Otolaryngol Head Neck Surg* 117: 326–329, 1997

27) Franco FC, de Araujo TM, Vogel CJ, Quintão CC: Brachycephalic, dolichocephalic and mesocephalic: Is it appropriate to describe the face using skull patterns? *Dental Press J Orthod* 18: 159–163, 2013

28) Ghajar JB: A guide for ventricular catheter placement. Technical note. *J Neurosurg* 63: 985–986, 1985

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