Calvarial slope affecting accuracy of Ghajar Guide technique for ventricular catheter placement

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OBJECTIVE The Ghajar Guide technique is used to direct a ventricular catheter at a 90° angle to the skull surface at Kocher's point. However, the human calvaria is not completely spherical. Lateral to the sagittal midline, the calvaria slopes downward with individual variation and thereby affects the accuracy of ventricular catheter placement. Accordingly, the authors investigated the accuracy of the orthogonal catheter trajectory using radiographic simulation and examined the effect of the calvarial slope on this accuracy.

METHODS A catheter trajectory orthogonal to the skull surface at Kocher's point and the ideal catheter trajectory to the foramen of Monro were drawn bilaterally on coronal head images of 52 patients with hydrocephalus. The correction angle, the difference between the 2 catheter trajectories, was then measured. Meanwhile, the calvarial slope was measured around Kocher's point by using a coronal head image. The correlation between the correction angle and factors such as the calvarial slope and bicaudate index was then assessed using a Pearson correlation analysis.

RESULTS The ventricular catheter trajectory orthogonal to the skull at Kocher's point in the patients with hydrocephalus led to a catheter trajectory into the ipsilateral (70.2%) or contralateral (29.8%) lateral ventricles. The correction angles ranged from −3.3° to 16.4° (mean ± SD 5.7° ± 3.7°). In 87 (83.7%) head sides, lateral deviation from the orthogonal trajectory was required to approximate the ideal trajectory, and the correction angle ranged from 2.0° to 16.4° (mean 6.7° ± 2.9°). The calvarial slope in the 104 head sides ranged from 15.6° to 32.5° (mean 24.2° ± 3.1°). Pearson correlation analysis revealed a strong positive correlation ($r = 0.733$) between the calvarial slope and the correction angle.

CONCLUSIONS The accuracy of ventricular catheter placement using the Ghajar Guide technique is affected primarily by the calvarial slope around Kocher's point. A radiographic analysis of a preoperative coronal head image can be used to estimate the accuracy of ventricular catheter placement and enable adjustment to approximate the ideal catheter trajectory.

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KEY WORDS catheterization; cerebral ventricles; hydrocephalus; skull; ventriculoperitoneal shunt; surgical technique

ACCURATE placement of a ventricular catheter is crucial for ventriculoperitoneal shunt placement and external ventricular drainage. Although frameless stereotaxis can be used in patients with smaller ventricles,^{1,2,7,14,15} the ventricular catheter is still commonly placed based on the surface anatomy of the head or just orthogonal to the skull for ventriculoperitoneal shunt placement in patients with larger ventricles or for external ventricular drainage.^{3,4,6–8,10,16}

The Ghajar Guide technique, using a catheter guide with a rigid tripod, was introduced for ventricular catheter

placement in 1985.⁵ This guide was designed to direct the ventricular catheter at a 90° angle to the skull surface at Kocher's point based on the facts that the body of the lateral ventricle is located in the midpupillary line and the curve of the superior aspect of the frontal horn roughly parallels the curve of the overlying skull.

However, the human skull is not exactly spherical. Lateral to the sagittal midline, the calvaria slopes downward and exhibits individual variations. Thus, catheter placement orthogonal to the skull at Kocher's point does not guarantee ideal catheter placement in the ipsilateral

frontal horn of the lateral ventricle near the foramen of Monro.^{9,11,17}

Accordingly, we investigated the accuracy of ventricular catheter placement orthogonal to the skull using radiographic simulation and examined the effect of the calvarial slope on this accuracy.

Methods

Patient Population

Between January 2013 and December 2014, a total of 89 patients underwent ventriculoperitoneal shunt placement for hydrocephalus at our institution. The inclusion criteria for this study included the following: 1) age > 20 years, 2) a diagnosis of hydrocephalus, 3) treatment with a ventriculoperitoneal shunt, and 4) available preoperative coronal CT or MR images. The exclusion criteria included the following: 1) midline brain shift and 2) compressed, distorted, or enlarged frontal horn of the lateral ventricle caused by an adjacent parenchymal lesion. As a result, 52 of the 89 patients were finally included in this study. The study was reviewed and approved by the Kyungpook National University institutional ethics committee. Informed consent was obtained from each patient.

Radiographic Simulation of Catheter Trajectories

Various CT scanners (LightSpeed, General Electric; Aquilion 64, Toshiba Medical Systems) were used to perform axial head imaging based on a collimated slice width of 2.5 mm from the skull base to the vertex (120 kVp [kilovolt potential], 180 mA, 0.8 seconds). The coronal images were then reconstructed by using a slice thickness of 0.625 mm and 0.5-mm increments based on a soft-tissue algorithm. Meanwhile, the coronal T2-weighted MR images were obtained at 3.0 T for the whole brain using the following parameters: TR 3400 msec, TE 102 msec, slice thickness 6 mm, gap 2 mm, matrix 384 × 288, and FOV 200 mm.

The technique of catheter placement orthogonal to the skull surface was simulated on the preoperative coronal images by using PiViewSTAR (INFINITT Co., Ltd.), an electronic picture-archiving and communication system that integrates simple measurement tools (e.g., distance and angle measurements).

On a coronal image at or around the foramen of Monro, a bur-hole site was marked at a point 3 cm lateral to the midline on the skull. On the circular line outlining the skull surface, a 3-cm-long chord was drawn with both ends equidistant from the bur-hole site. A perpendicular line starting at the middle of the chord was then drawn to the ventricular system, corresponding to a catheter trajectory orthogonal to the skull surface. Thereafter, the ideal catheter trajectory toward the foramen of Monro was drawn from the middle of the chord (Fig. 1).

The correction angle, the difference between the ideal trajectory and the orthogonal trajectory, was then measured, which resulted in a positive or negative number according to whether the orthogonal catheter trajectory lay medial or lateral, respectively, to the ideal trajectory. This procedure was performed bilaterally with each coronal head image.

FIG. 1. Coronal CT image showing radiographic analysis of the catheter trajectories. The correction angle is the difference between the catheter trajectory (90°) orthogonal to the skull surface and the ideal catheter trajectory (100°) to the foramen of Monro. Here, the correction angle is 10°.

Associated Factors That Affect Accuracy of the Ghajar Guide Technique

The calvarial slope and bicaudate index of each patient were measured by using a picture-archiving and communication system. To measure the calvarial slope using the coronal head image, a 3-cm-long chord was drawn with both ends equidistant from the bur hole site (Kocher's point, 3 cm lateral to the midline) on the circular line outlining the skull surface. The angle between the chord below Kocher's point and the horizontal line (i.e., the calvarial slope) was then measured (Fig. 2). In addition, the bicaudate index, 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, was measured by using the preoperative axial CT or MR images.

Intraobserver and Interobserver Variabilities

Two experienced neurosurgeons (W.S. and K.S.P.) independently evaluated the preoperative coronal CT and MR images to determine the correction angle and calvarial slope. The 2 observers evaluated each image twice at an interval of > 1 week. The mean value of the measurements recorded by both observers was then used as the measurement result. Also, the interobserver variability was calculated by comparing the results from both observers, and the intraobserver variability was assessed by comparing the results recorded by each observer.

Statistical Analysis

The statistical analyses were performed by using SPSS version 18.0 for Windows (SPSS, Inc.) to calculate the Pearson correlation coefficient for evaluating the intraobserver and interobserver variabilities of the correction an-

FIG. 2. Coronal CT image showing measurement of the calvarial slope. The calvarial slope is defined as the angle between a 3-cm-long chord with both ends equidistant from Kocher's point and the horizontal line. An angle of 25° means a high calvarial slope.

gle and calvarial slope measurements. The intraobserver and interobserver agreement was considered good if the Pearson coefficient was between 0.6 and 0.8 and excellent if the coefficient was greater than 0.8.

The correlation between the correction angle and the associated factors, such as the calvarial slope and bicaudate index, was assessed by using Pearson correlation analysis. The results were considered significant for probability values less than 0.05. Mean values are presented $\pm$ SD.

Results

Patients

The patient population ($n = 52$) consisted of 31 men and 21 women with a mean age of 63.6 ± 12.1 years (range 34–83 years). Preoperative coronal CT images that were reconstructed by using preoperative axial CT scans were available for 44 patients, whereas preoperative coronal MR images were available for 8 patients. The ventricles in each patient were dilated and located in the midline. The bicaudate index values ranged from 0.15 to 0.49 (mean 0.28 ± 0.06).

Radiographic Simulation of Catheter Trajectories

In 22 of the 52 patients, radiographic simulation of catheter placement orthogonal to the skull showed a catheter trajectory into the contralateral lateral ventricle unilaterally ($n = 13$) or bilaterally ($n = 9$). Notwithstanding, there was no failure of ventricular catheterization.

Of the 104 head sides of the 52 patients, radiographic simulation in 31 (29.8%) sides revealed a catheter trajectory into the contralateral lateral ventricle; simulation in 12 (11.5%) of these sides revealed a contralateral trajectory without traversing the ipsilateral lateral ventricle and

in the other 19 sides (18.3%) revealed a catheter trajectory into the contralateral lateral ventricle after traversing the superomedial corner of the ipsilateral lateral ventricle and upper half of the septum pellucidum. Radiographic simulation in the remaining 73 (70.2%) head sides revealed a satisfactory catheter trajectory into the ipsilateral frontal horn of the lateral ventricle.

The Pearson coefficient that indicates interobserver agreement on the correction angle was 0.96, whereas the coefficients that indicate intraobserver agreement on the correction angle were 0.99 and 0.95 for the 2 observers.

The correction angles ranged from -3.3° to 16.4° (mean $5.7^\circ \pm 3.7^\circ$). The orthogonal catheter trajectory approximated the ideal trajectory (correction angle less than $\pm 2^\circ$) in 15 sides (14.4%). However, in 87 sides (83.7%), lateral tilting of the orthogonal trajectory was required to approximate the ideal trajectory (correction angle range 2.0° – 16.4° [mean $6.7^\circ \pm 2.9^\circ$]), whereas medial tilting was required in only 2 sides (correction angles -2.3° and -3.3°).

Associated Factors That Affect Accuracy of the Ghajar Guide Technique

The Pearson coefficient that indicates interobserver agreement on the calvarial slope was 0.86, whereas the coefficients that indicate intraobserver agreement on the calvarial slope were 0.99 and 0.85 for the 2 observers.

The calvarial slopes of the 104 head sides ranged from 15.6° to 32.3° (mean $24.2^\circ \pm 3.1^\circ$). Pearson correlation analysis revealed a strong positive correlation between the calvarial slope and the correction angle ($p < 0.001$; $r = 0.733$), as shown in Fig. 3. A simple linear regression analysis was used to develop an equation for predicting the dependent variable (y , correction angle) given a value (x , calvarial slope) for the independent variable. This equation was $y = 0.8768x - 15.531$. The value of R^2 was 0.54.

Meanwhile, Pearson correlation analysis of the bicaudate index and the correction angle revealed a significant ($p < 0.01$) yet weak positive correlation ($r = 0.310$), as shown in Fig. 4.

Discussion

The Ghajar Guide technique using a catheter guide with a rigid tripod is often applied for external ventricular drainage and ventriculoperitoneal shunt placement,^{5,9,17} and it has been reported to provide better accuracy than freehand catheter placement. However, application of the technique is not always accurate,^{9,11} and the difference from the ideal catheter trajectory had not been reported previously for patients with hydrocephalus.

A radiographic analysis of the ventricular catheter trajectory orthogonal to the skull was performed by Rehman et al.¹¹ However, their study focused only on patients with a normal ventricular size and revealed a catheter trajectory in a nonventricular space in 10% of the patients. In our radiographic study, we analyzed patients with hydrocephalus with a bicaudate index of ≥ 0.15 , and although the catheter trajectory passed through a ventricular space in every case, it passed into the contralateral lateral ventricle in 30% of the head sides.

FIG. 3. Graph of Pearson correlation analysis results for the calvarial slope and correction angle, showing a strong positive correlation ($r = 0.733$).

To our knowledge, our study of how the calvarial slope affects the accuracy of catheter placement orthogonal to the skull is novel, and the results are crucial for understanding and successfully applying the Ghajar Guide technique. As such, a patient with a high-slope calvaria can suffer catheterization into the contralateral lateral ventricle when the neurosurgeon uses the Ghajar Guide technique, whereas a patient with a low-slope calvaria and smaller ventricle can suffer nonventricular catheterization lateral to the ipsilateral lateral ventricle.

The correction angle varied predictably as a function of the calvarial slope according to the following equation: $\text{correction angle} = (0.8768 \times \text{calvarial slope}) - 15.531$. When the calvarial slope is $> 18^\circ$, the catheter trajectory directs medially toward the contralateral lateral ventricle. Thus, if the calvarial slope is 30° , the catheter trajectory directs medial to the ipsilateral foramen of Monro with a correction angle of 10.8° . Meanwhile, when the slope is below 18° , the catheter trajectory directs lateral to the foramen of Monro and then to the brain parenchyma lateral to the ventricular wall. Also, if the slope is $< 12^\circ$, the lateral deviation of the orthogonal catheter trajectory from the trajectory toward the foramen of Monro is greater than 5° , which thereby increases the risk of catheterization into the brain parenchyma and necessitates the use of a more accurate stereotactic technique.

Among our cases with large ventricular size and a high bicaudate index, the success rate of ventricular catheterization including the ipsilateral and contralateral lateral ventricles was high. However, the incidence of a catheter trajectory close to the ideal trajectory was low and the correction angle was high, showing a weak positive correlation between the bicaudate index and the correction angle.

Thus, to overcome the limitations of the Ghajar Guide technique, an adjustable catheter guide is needed to realign the orthogonal trajectory according to a preoperative radiographic assessment using a coronal head image.¹³ If a more accurate catheter placement is needed, a frameless or frame-based stereotactic technique can be used.^{1,2,7,14,15}

FIG. 4. Graph of Pearson correlation analysis results for the bicaudate index and correction angle, showing a weak positive correlation ($r = 0.310$).

In a recent US survey of the surgical techniques used for ventriculostomy placement in patients with slit ventricles, the Ghajar Guide technique was used by only 6.7% of the respondents, whereas the remaining respondents used image guidance or a freehand technique.¹² When the survey asked about improvements that would increase usage of the Ghajar Guide, 22.1% of the respondents suggested an adjustable guide for a midline shift or abnormal ventricular anatomy, and 19.0% suggested the availability of more data on the use of the Ghajar Guide technique. Thus, the results of our study may encourage greater use of a Ghajar Guide–based technique with coronal adjustment.

Our study has several important limitations. First, it was based on only a small series of patients from a single institution. Second, the series included only Asian patients, which raises the possibility of racial differences in calvarial morphology. Third, the sagittal calvarial slope was not evaluated; it was considered less important because the ventricular system is oriented sagittally. Notwithstanding, the results of our study shed light on the coronal calvarial slope and accuracy of the Ghajar Guide technique and warrant future studies to improve the Ghajar Guide technique.

Conclusions

A radiographic analysis of the ventricular catheter trajectory orthogonal to the skull surface at Kocher's point in patients with hydrocephalus showed a catheter trajectory into the ipsilateral (70%) or contralateral (30%) lateral ventricles. The accuracy of the ventricular catheterization using the Ghajar Guide technique was affected primarily by the calvarial slope. Radiographic analysis of a preoperative coronal head image can be used to estimate the accuracy of ventricular catheter placement and enable adjustment to achieve the ideal catheter trajectory.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: J Park. Acquisition of data: Son, KS Park. Analysis and interpretation of data: J Park, KS Park, Lee. Drafting the article: J Park. Approved the final version of the manuscript on behalf of all authors: J Park. Statistical analysis: Lee. Administrative/technical/material support: Kim. Study supervision: J Park.

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