A Morphometric Analysis of Commonly Used Craniometric Approaches for Freehand Ventriculoperitoneal Shunting

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BACKGROUND: Ventricular catheter tip position is a predictor for ventriculoperitoneal shunt survival. Cannulation is often performed freehand, but there is limited consensus on the best craniometric approach.

OBJECTIVE: To determine the accuracy of localizing craniometric entry sites and to identify which is associated with optimal catheter placement.

METHODS: This is a retrospective analysis of adult patients who underwent ventriculoperitoneal shunting. The approaches were categorized as Kocher's, Keen's, Frazier's and Dandy's points as well as the parieto-occipital point. An accurately sited burr hole was within 10 mm from standard descriptions. Optimal catheter tip position was defined as within the ipsilateral frontal horn.

RESULTS: A total of 110 patients were reviewed, and 58% (65/110) of burr holes were accurately sited. Keen's point was the most correctly identified (65%, 11/17), followed by Kocher's point (65%, 37/57) and Frazier's point (60%, 3/5). Predictors for accurate localization were Keen's point (odds ratio 0.3; 95% CI: 01-0.9) and right-sided access (odds ratio 0.4; 95% CI: 0.1-0.9). Sixty-three percent (69/110) of catheters were optimally placed with Keen's point (adjusted odds ratio 0.04; 95% CI: 0.01-0.67), being the only independent factor. Thirteen patients (12%) required shunt revision at a mean duration of 10 ± 25 mo. Suboptimal catheter tip position was the only independent determinant for revision (adjusted odds ratio 0.11; 95% CI: 0.01-0.98).

CONCLUSION: This is the first study to compare the accuracy of freehand ventricular cannulation of standard craniometric entry sites for adult patients. Keen's point was the most accurately sited and was a predictor for optimal catheter position. Catheter tip location, not the entry site, predicted shunt survival.

KEY WORDS: Ventriculoperitoneal shunting, Craniometric entry site, Morphometric analysis

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Ventriculoperitoneal (VP) shunting is one of the commonest procedures performed in neurosurgical practice, but there is no consensus on the best approach for ventricular cannulation. Optimal catheter placement is vital for long-term shunt survival. Studies have demonstrated tip location to be associated with catheter occlusion, the commonest cause for shunt failure in 30% to 50% of patients.[1-7] Conventional approaches dictated by surface anatomic landmarks, craniometric points, have largely been adopted for historical reasons, and there is considerable variation in practice regarding entry site selection.[8-10] They include the frontal (Kocher's point), parietal (Keen's point), and occipital (Frazier's or Dandy's point) approaches.[11]

ABBREVIATIONS: **aOR,** adjusted OR; **IQR,** interquartile range; **POP,** parieto-occipital point; **VP,** ventriculoperitoneal.

Few studies have attempted to conduct a morphometric analysis to identify which commonly used VP shunt approach is superior. Previous studies relied on cadaveric or image-derived models with normal ventricular volumes and limited sample sizes of fewer than 50 patients.[10,12,13] This study not only quantitatively assessed the accuracy of localizing standard craniometric entry points in the real-world setting but also evaluated catheter trajectory variability. We determined predictors for accurate entry site identification, optimal catheter placement, and shunt survival.

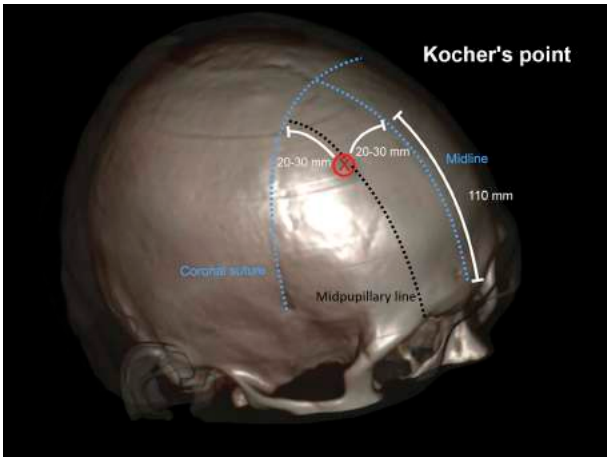

FIGURE 1. *Craniometric entry sites assessed according to conventional surface landmark descriptions.*[11] *Kocher's point was the standard frontal approach.*

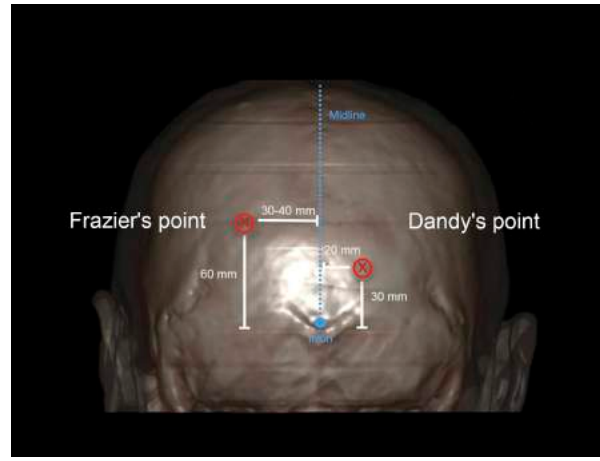

FIGURE 3. *Frazier's point and Dandy's point: standard occipital entry sites.*

METHODS

This was a retrospective single-center study of adult patients who underwent VP shunting from January 1, 2014, to March 30, 2020. Institutional review board approval (KW/EX-15-176 (92-03)) and informed consent were obtained. Patients who underwent shunting with another neurosurgical procedure in the same setting or had previous shunting were excluded. All burr holes were 14 mm in diameter. All procedures used antibiotic-impregnated ventricular catheters (Bactiseal, Codman, Johnson & Johnson) with a programmable differential pressure valve (Strata II, Medtronic). Ventricular cannulations were performed freehand without image guidance.

Two independent neurosurgeons with at least 2 yr of VP shunt operative experience reviewed the preoperative and first postoperative computed tomography (CT) scans. All scans were performed by using a 64-detector CT scanner (GE LightSpeed VCT; General Electric Healthcare). For the preoperative scan, the biventricular width, the Evans[14] index, and ventricular volume were measured using a digital imaging and communication in medicine viewer (Horos, http://www.horosproject.org). Postoperative scans were performed within 24 h, within 1 wk before discharge, and every 3 to 6 mo for up to at least 2 yr. Craniometric burr hole identification and catheter tip position were recorded from the first postoperative scan. The entry points assessed were Kocher's, Keen's, Frazier's and Dandy's points as well as the parieto-occipital point, with the latter 4 collectively known as posterior approaches (Figures 1-4).[11] An accurately sited burr hole was defined as its center within 10 mm from its standard craniometric points. This cutoff was selected to allow for potential drill slippage during burr hole creation. Burr holes located beyond 20 mm, unless specified in the operative records, were considered intentionally sited by the neurosurgeon for tailored ventricular access and were excluded from review. It was reasoned

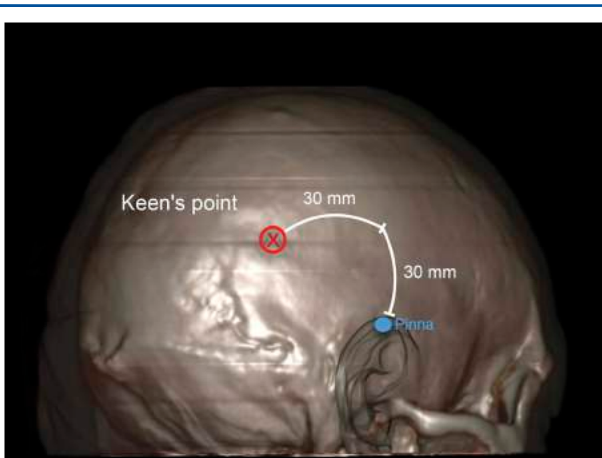

FIGURE 2. *Keen's point: standard parietal entry site.*

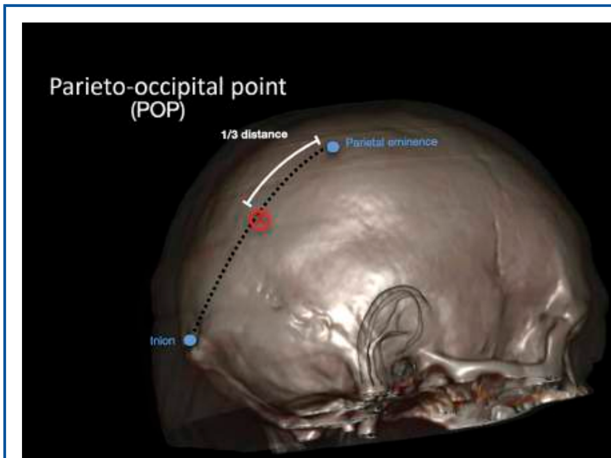

FIGURE 4. *POP: standard parietal entry site. POP, parieto-occipital point.*

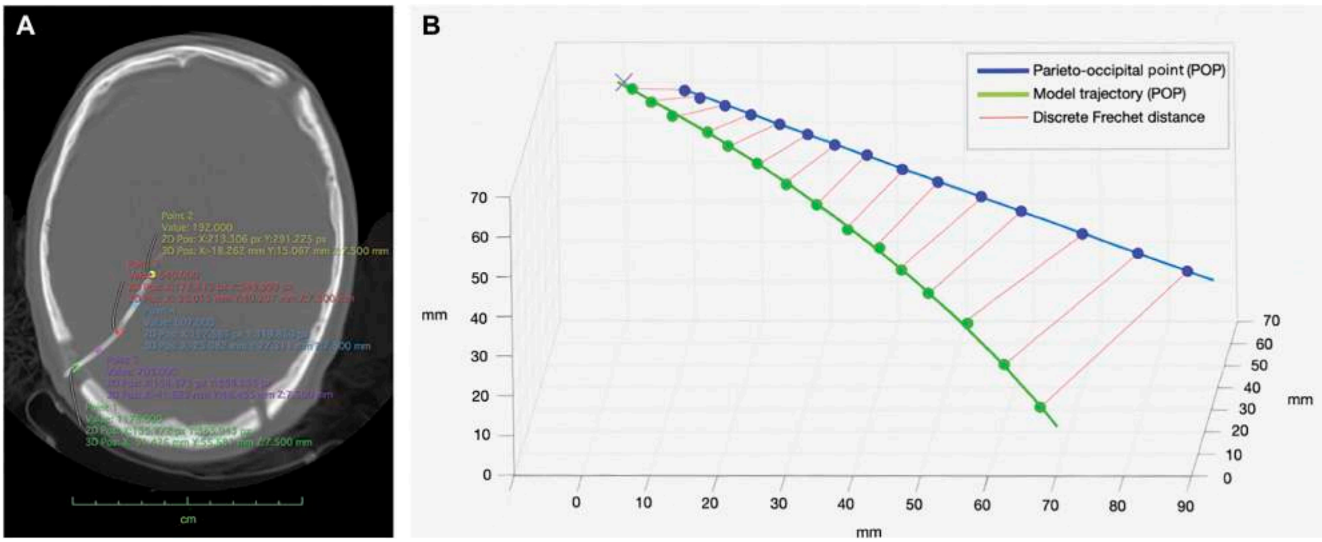

FIGURE 5. *Quantifying ventricular catheter trajectory variability.* **A**, *Annotation of the burr hole entry site and the catheter on source CT DICOM images using equidistant points was first performed.* **B**, *These points were then plotted on a 3D graph, and a second-degree polynomial curve was calculated to delineate their path. The discrete Frechet distance (red line) was measured for each pair of points between the ideal model catheter trajectory (green) and the eventual trajectory (blue). The mean Frechet distance was determined and used to compare trajectory variability of each standard craniometric approach. 3D, three-dimensional; CT, computed tomography; DICOM, digital imaging and communication in medicine; POP, parieto-occipital point.*

that to have the drill slip by more than 20 mm was considered highly unlikely given the limited room permitted by a typical shunt scalp wound. Optimal catheter placement was defined as its tip within the ipsilateral frontal horn of the lateral ventricle.[15] Shunt revision due to occlusion or malposition, defined as its tip being either within an eloquent region or at a nonventricular cerebrospinal fluid (CSF) space, was documented. Patients were followed up every 3 to 6 mo for at least 2 yr. A shunt was considered occluded if there was radiological evidence of recurrent hydrocephalus or if the patient experienced raised intracranial pressure symptoms.

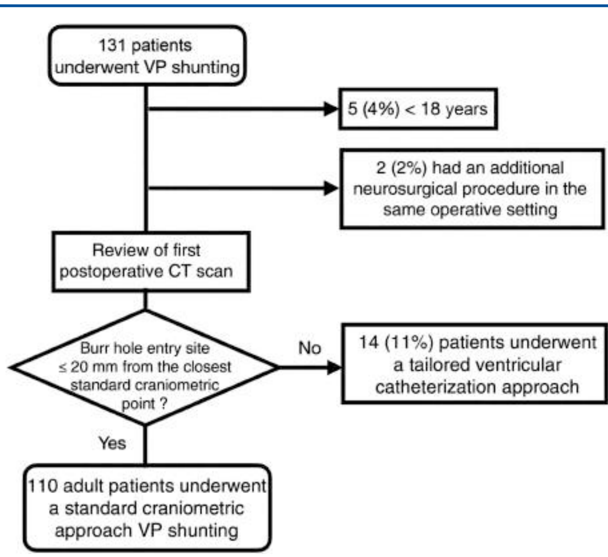

FIGURE 6. *Patient flowchart. CT, computed tomography; VP, ventriculoperitoneal.*

Ideal Catheter Trajectory Selection and Frechet Distance Determination for Trajectory Deviation

CT images were centered to a selected template scan to allow their coregistration in the same stereotactic space for interindividual comparisons. They were then exported to the Horos viewer where the burr hole entry site and catheter trajectory were mapped using a series of equidistant points (Figure 5A). These data points were then processed by using MATLAB (Mathworks Inc), and the catheter trajectory delineated. For each approach, a model patient with the most accurate burr hole site and best catheter trajectory was selected by agreement among the 2 independent scan assessors. The ideal trajectory was selected by 2 criteria: (1) The catheter tip and its side holes were within the ipsilateral frontal horn without contacting the ventricular wall or septum pellucidum and (2) the intracranial catheter length was shortest.[2] Catheter trajectory data were then reset to each entry point to adjust for interindividual factors such as cranium size and shape. The discrete Frechet distance, that is, the shortest distance between 2 points of the ideal catheter trajectory and its eventual path, was calculated, and the mean distance was derived (Figure 5B).[16]

Data Analysis

Interobserver agreement was determined for burr hole accuracy and catheter position by using the Fleiss Kappa test for categorical data. Because a cutoff distance of 20 mm was used to presume a tailored catheterization approach, post hoc outliers were identified to detect

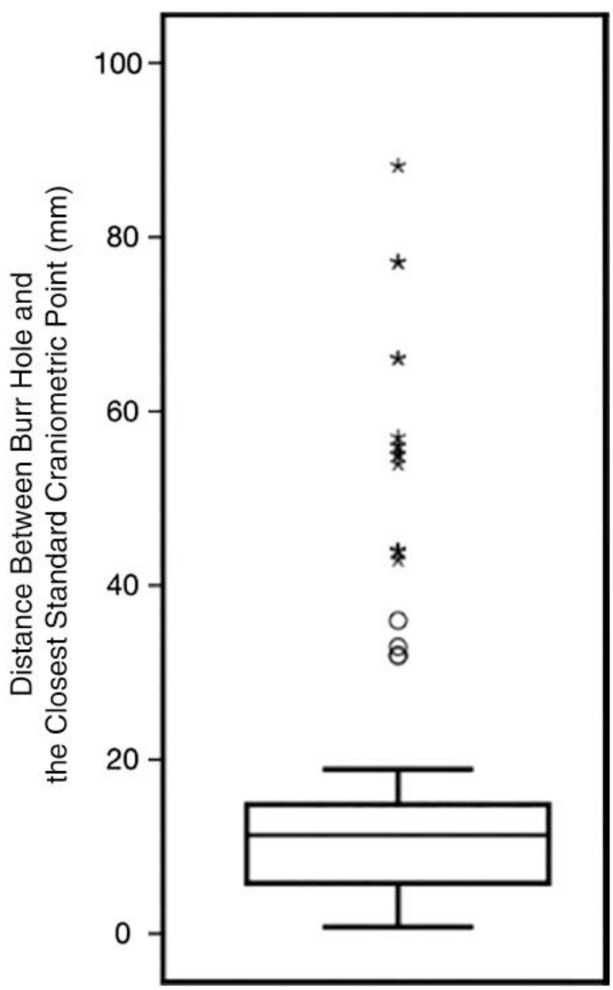

FIGURE 7. *Outlier identification. Box plot of the distance from the center of each burr hole at the calvarial surface from its closest standard craniometric point. Median: 12 mm and IQR: 9 mm. All outlier burr hole sites (11%, 14/131) were beyond 20 mm, and most were extreme outliers, that is, more than 3 times the IQR above the upper quartile. Outlier burr holes were considered intentionally created by the neurosurgeon for a nonstandard tailored ventricular catheterization approach. IQR, interquartile range.*

selection bias. If only burr holes more than 20 mm away were identified as outliers, they were excluded from the analysis.

Chi-square testing and multivariable binary logistic regression were performed to investigate the relationship between burr hole accuracy and catheter tip position. The variables included in the regression analyses were classified into surgery-related and disease-related, that is, ventricular size. Surgery-related variables were operator experience, emergency shunting, burr hole laterality, burr hole accuracy, and the craniometric approach adopted. Only significant variables identified in univariable analysis (*P*-value < .05) were included in multivariable stepwise regression to adjust for possible confounding factors. Statistical analyses were performed by using statistics software (SPSS version 20.0, SPSS Inc).

TABLE 1. **Interobserver Agreement for Preoperative Ventricular Size Assessment, VP Shunt Approaches, and Catheter Positions**

CT Scan Assessment Factors	n = 110 (%)	K-statistic[b] (95% CI)
Preoperative CT scan		
Biventricular width, mm, mean ± SD	47 ± 12	0.69 (0.61-0.75)
Evans ratio, mm, mean ± SD	0.4 ± 0.1	0.68 (0.61-0.75)
Ventricular volume, cc, mean ± SD	93 ± 84	0.62 (0.56-0.66)
Postoperative CT Scan		
Craniometric burr hole categorization (%)		
Kocher	57 (52)	0.92 (0.89-0.95)
POP	31 (28)	0.57 (0.51-0.60)
Keen	17 (16)	0.63 (0.59-0.67)
Frazier	5 (5)	0.62 (0.58-0.67)
Dandy	0	0.95 (0.91-0.98)
Accurately sited burr hole (%)[a]	65 (58)	0.77 (0.71-0.85)
Ventricular catheter position		
Optimal placement	69 (63)	0.96 (0.90-0.99)

CT, computed tomography; POP, parieto-occipital point; SD, standard deviation; VP, ventriculoperitoneal.
[a]An accurate burr hole was one-sided within 10 mm of standard craniometric descriptions.
[b]Fair agreement: 0.21-0.40; moderate agreement: 0.41-0.60; good agreement: 0.61-0.80; excellent agreement: 0.81-1.00.

RESULTS

A total of 131 patients underwent VP shunting with 21 patients excluded from the analysis (Figure 6). Five were <18 yr, and 2 adult patients had another neurosurgical procedure performed in the same operative setting. Fourteen patients (11%) had burr holes located more than 20 mm away from their closest standard craniometric point and were outliers with a mean distance of 53 mm ± 15 (Figure 7). These patients were the only outliers identified and were excluded. One hundred ten patients (84%) were reviewed with a mean age of 56 ± 17 yr, and none were lost to follow-up. The median follow-up duration was 28 mo (interquartile range [IQR]: 10-55). The main cause for shunting was aneurysmal subarachnoid hemorrhage in 37% of patients (41/110), followed by brain tumors (31%, 34). For scan interobserver agreement, the k-statistic results were mostly good to excellent apart from parieto-occipital point (POP) localization where only moderate agreement was achieved (Table 1).

Most shunts were performed by neurosurgical trainees (79%, 87/110) having undergone a mean training duration of 15 ± 15 mo. Forty-eight percent of patients (53/110) were shunted under emergency conditions. The preferred burr hole entry site was the Kocher point (52%, 57/110) and POP (28%, 31/110). All patients had the abdominal catheter implanted through a mini laparotomy.

Craniometric Burr Hole Localization

Fifty-eight percent (65/110) of burr holes were accurately located (Figures 8 and 9). The approach with the highest accuracy

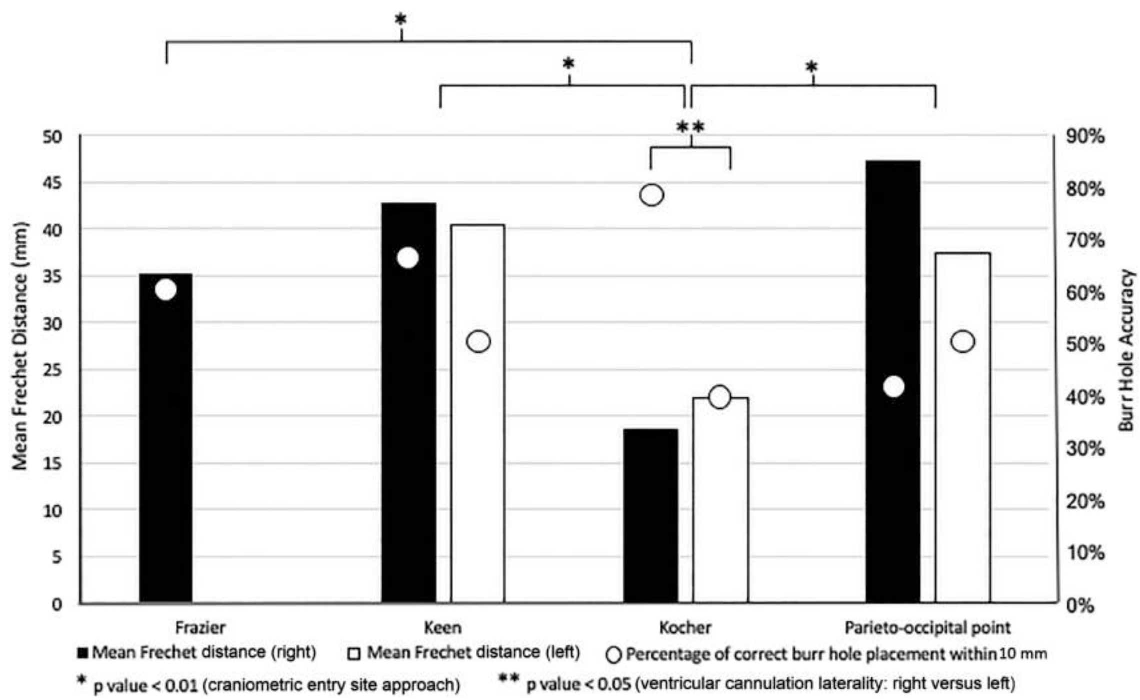

FIGURE 8. *Chart demonstrating the mean Frechet distance (left y-axis) from the model catheter trajectory for each craniometric entry site subcategorized according to laterality. Kocher's point yielded significantly lower catheter trajectory deviations from the model course than the other entry points (*P-value < .01). The proportion of accurately localized burr holes for each site is shown (right y-axis, white circles). Right-sided Kocher's point burr holes were also more accurately identified than left-sided ones (**P-value < .05).*

was Keen's point (65%, 11/17), followed by Kocher's point (65%, 37/57), Frazier's point (60%, 3/5), and the POP (42%, 13/31).

The only predictors for accurate localization were laterality and approach: namely, right-sided ventricular access (odds ratio [OR] 0.4; 95% CI: 0.1-0.9) and Keen's point (OR 0.3; 95% CI: 0.1-0.9). Multivariable regression revealed that a right-sided approach was the only independent factor (adjusted OR [aOR]: 0.2; 95% CI: 0.1-0.6). Surgical experience either by duration of training (*P*-value: .17) or whether the surgeon was a board-certified specialist (*P*-value: .26) did not influence burr hole identification accuracy.

Ventricular Catheter Trajectory Deviation

The entry point with the least deviation from the ideal trajectory was Kocher's point with a mean Frechet distance of 19 ± 10mm, followed by Frazier's point (28 ± 16mm), the POP (31 ± 17 mm), and Keen's point (38 ± 21 mm) (Figures 8 and 10). Adopting Kocher's point (*P*-value: <.001) and having an accurately positioned burr hole (*P*-value: .01) were the only factors associated with a significantly lower Frechet distance. There was no difference with cannulation laterality (*P*-value: .15), surgical experience (*P*-value: .98), and training duration (*P*-value: .44).

Factors Predicting Optimal Ventricular Catheter Position

Sixty-three percent (69/110) of catheters were at an optimal location. Eighty-eight percent (15/17) of patients shunted through Keen's point had optimal catheter placement, followed by the POP (77%, 24/31). Only 53% (30/57) of patients with Kocher's point catheterization had an optimal tip location. Multivariable analysis revealed that Keen's point (aOR 0.04; 95% CI: 001-0.67) and neurosurgical trainees (aOR 0.24; 95% CI: 0.06-0.90) were the only independent significant predictors (Table 2).

Surgical Factors Associated With Shunt Revision due to Occlusion or Malposition

Thirteen patients (12%) required shunt revision at a median duration of 1 mo (IQR: 0.5-17). The causes were occlusion (31%, 4/13), ventricular catheter malposition (31%, 4), infection (24%, 3), and overshunting (15%, 2). All 4 occlusions were within the ventricular catheter, and patients underwent shunt replacement at a median duration of 8 mo (IQR: 1-71). For the 4 patients with malpositioned ventricular catheters, all were located at nonventricular CSF spaces and were revised within 3 d. One-way analysis of variance was performed to detect whether the duration of patient follow-up and the choice of catheterization approach introduced selection bias for early shunt revision. The F-statistic was 0.38 (*P*-value: .76),

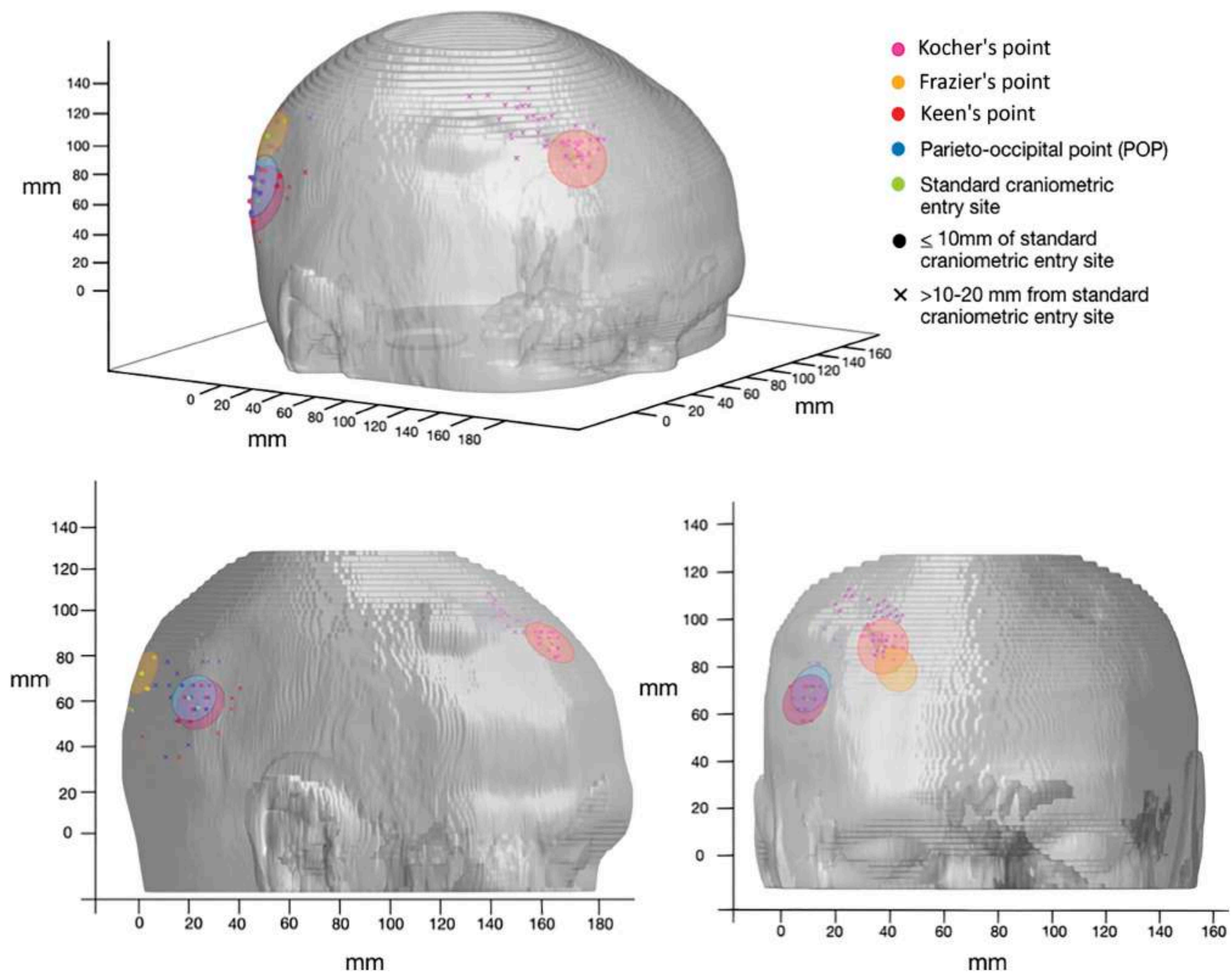

FIGURE 9. *Variability of standard craniometric entry site localization. Colored areas encircle regions 10 mm from the standard entry site (green circle for each craniometric point). The center of actual burr holes sites within this region is defined as accurately placed. Burr holes >10 to 20 mm away from the standard entry site are presented by "x." Note that a substantial number of Kocher's point burr holes were placed posterior to the intended site. The patient consented to publication of this image. POP, parieto-occipital point.*

indicating no significant difference in the follow-up durations between each craniometric point group.

A significantly higher proportion of patients who required revision had suboptimal catheter positions (18%, 7/40) (OR: 14.6; 95% CI: 1.7-12.3). Multivariable regression revealed that suboptimal catheter position was the only independent significant predictor for shunt revision (aOR 0.11; 95% CI: 0.01-0.98) (Table 3).

DISCUSSION

It is well-established that optimal ventricular catheter placement is important in preventing CSF shunt malfunction.[1-4,6] Improving catheter accuracy is, therefore, a subject of intense clinical research. Such efforts can be categorized as either image-guided (intraoperative ultrasound, fluoroscopy, or stereotactic neuronavigation) or endoscopic-assisted. For image-guided cannulations, retrospective studies have documented their superiority in placing better-positioned catheters.[17-24] However, 2 meta-analyses that reviewed the use of intraoperative ultrasound or stereotaxy observed no clear benefit for shunt survival.[25,26] As for endoscopic-assisted catheterization, a randomized controlled trial also showed that both accuracy and shunt survival were not improved compared with freehand techniques.[27]

Apart from the lack of robust evidence supporting their routine use, other reasons for the limited adoption of these tools include

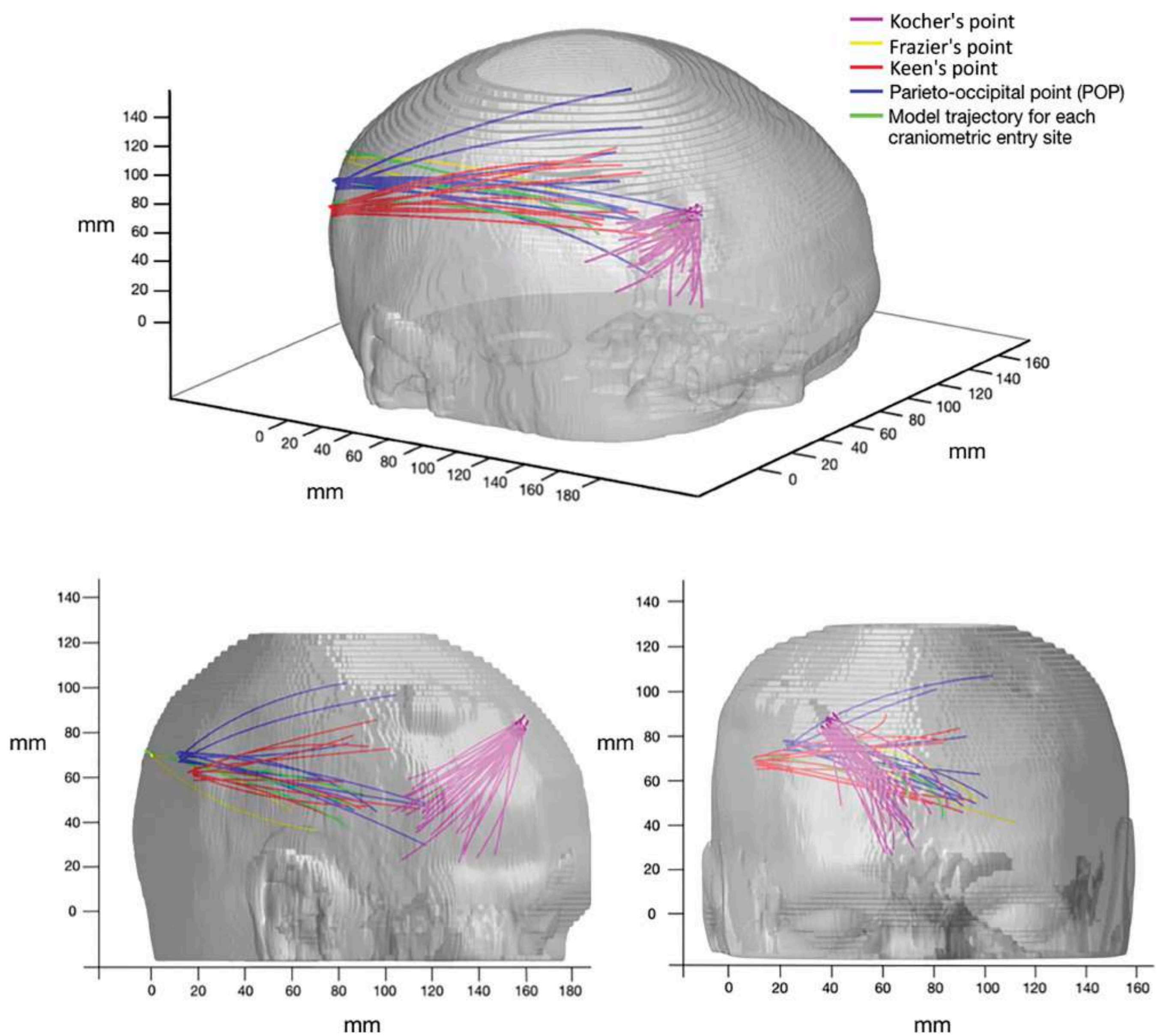

Figure 10. *Variability of ventricular catheter trajectories from standard craniometric entry sites. The green trajectory corresponds to the ideal model catheter trajectory for each entry site. The Frechet distance quantifies the degree of course deviation from this ideal trajectory. The patient consented to publication of this image. POP, parieto-occipital point.*

their relative inaccessibility, especially during emergency settings, and the additional experience required for their utilization.[28] A survey on ventriculostomy practices revealed that 94% of neurosurgeons were reluctant to use any technological aids if they extended procedure durations by 10 min.[29] Because an operative time beyond 40 min has been associated with an elevated risk of infection, this general reluctance is pertinent.[30,31] Therefore, we expect that in most countries, most VP shunts will continue to be performed freehand. It is incumbent on the neurosurgeon to be aware of the limitations of this technique when using conventional craniometric approaches.[13]

An interesting finding was that only 58% of burr holes were accurately located. Even for the most frequently used Kocher's point, only 65% of neurosurgeons were able to identify it. Because most VP shunts were performed by neurosurgical trainees, we investigated whether experience could have influenced burr hole localization accuracy, catheter trajectory variability, and shunt revision. We observed that neurosurgical experience was not an independent

TABLE 2. Predictors for Optimal Ventricular Catheter Position by Univariable and Multivariable Binary Logistic Regression[a]

Factors	Optimal n = 70 (%)	Nonoptimal n = 40 (%)	OR (95% CI)	Adjusted OR (95% CI)
Surgical factors				
Neurosurgical experience: trainee vs board-certified specialist	64 (91)	26 (65)	0.17 (0.06-0.50) Sig.	0.24 (0.06-0.90) Sig.
Duration of training, mean ± SD, mo	15.8 ± 16.3	14.1 ± 13.4		
Emergency procedure	30 (43)	23 (58)		
Accurately sited burr hole	40 (57)	24 (60)		
Right-sided burr hole	56 (80)	31 (78)		
Burr hole entry site				
Kocher	30 (43)	27 (68)		
Keen	15 (21)	2 (5)	0.13 (0.03-0.63) Sig.	0.04 (0.01-0.67) Sig.
Frazier	1 (1)	4 (10)		
POP	24 (34)	7 (18)		
Ventricular size				
Evans ratio, mean ± SD	0.37 ± 0.08	0.35 ± 0.08		
Biventricular width, mean ± SD, mm	48.0 ± 12.5	45.3 ± 9.5		
Ventricular volume, mean ± SD, cc	95.9 ± 96.7	87.7 ± 52.2		

OR, odds ratio; POP, parieto-occipital point; SD, standard deviation; Sig., statistically significant.
[a]Optimal catheter placement was defined as its tip within the ipsilateral frontal horn of the lateral ventricle.

predictor. This may be due to the sufficient level of training the operator had at the time of shunting. The mean duration of neurosurgical trainee operative exposure was 15 mo. In addition, board certification requires the successful completion of a VP shunting procedure-based assessment in which trainees are required to operate independently under the direct observation of a specialist trainer.

TABLE 3. Factors Associated With VP Shunt Occlusion or Malposition Requiring Revision by Univariable and Multivariable Binary Logistic Regression[a]

Factors	No need for revision n = 96 (%)	Shunt revision n = 8 (%)	OR (95% CI)	Adjusted OR (95% CI)
Surgical factors				
Neurosurgical experience: resident vs board-certified specialist	83 (86)	3 (38)	0.10 (0.02-0.48) Sig.	
Duration of training, mean ± SD, mo	15 ± 15	7 ± 2		
Emergency procedure	46 (47)	5 (63)		
Tract hematoma	22 (23)	1 (13)		
Accurately sited burr hole	57 (59)	3 (38)		
Right-sided burr hole	70 (81)	4 (50)	0.23 (0.05-0.99) Sig.	
Burr hole entry site				
Kocher	49 (51)	5 (63)		
Keen	15 (16)	1 (13)		
Frazier	4 (4)	1 (13)		
POP	29 (30)	1 (13)		
Optimal ventricular catheter position	69 (72)	1 (13)	0.07 (0.01-0.59) Sig.	0.11 (0.01-0.98) Sig.
Ventricular catheter trajectory variability Frechet distance, mean ± SD, (mm)	26 ± 16	21 ± 13		
Ventricular size				
Evans ratio, mean ± SD	0.4 ± 0.1	0.3 ± 0.1		
Biventricular width, mean ± SD, mm	48 ± 12	42 ± 6		
Ventricular volume, mean ± SD, cc	90 ± 86	139 ± 59		

CSF, cerebrospinal fluid; OR, odds ratio; POP, parieto-occipital point; SD, standard deviation; Sig., statistically significant; VP, ventriculoperitoneal.
[a]Catheter malposition was defined by its tip being either within an eloquent region or at a nonventricular CSF space.

Our study demonstrates the difficulties of identifying standard craniometric points by surface anatomy alone. For Kocher's point, palpating for the coronal suture can be difficult when the scalp is thick. Alternatively, one could measure from the nasion and midline, but this anthropometric method can be subject to considerable variability. A review comparing craniometric caliper measurements of skull specimens with CT-based determinations revealed a significant underestimation in several cranial indices, especially along the anterior–posterior plane.[32] This could explain why frontal burr holes were more posteriorly located (Figure 9). Similarly, for the POP, the parietal eminence is frequently described as a region, but to identify a distinct point can be challenging. Using more conspicuous surface landmarks such as the pinna of the ear (Keen's point) or the inion (Frazier's point) could have accounted for their better localization.

Regardless of its inaccurate identification, Kocher's point the most reliable catheter trajectory course. We postulate that the lack of consensus regarding a surface landmark target for posteriorly inserted catheters could have accounted for this. Numerous target landmarks have been proposed. For the POP, catheters were targeted toward a midline point 4 cm above the nasion.[33] For Frazier's point, catheters have variably been aimed at a target 4 cm above the contralateral medial canthus or above the nasion or the glabella.[10,11,33-35] The target for Keen's point was described as 4 cm above the nasion and for Dandy's point 2 cm above the glabella.[10,11,35] Others proposed directing catheters orthogonal to the skull.[11,36,37] Our results reflect the remarkable variability of trajectory targets and corroborate previous studies that failed to identify a single landmark for these posterior approaches (Figure 10).[9,35,38]

The only independent predictor for shunt revision was catheter tip location, and our observations concur with preceding studies.[1-4,6,19] We also noted that a contributing factor for achieving optimal placement was adopting Keen's point (88%, 15/17). This is in agreement with the results of Lind et al[9] in which this parietal entry point offered a significantly greater range of possible angles for successful cannulation than the occipital approaches. This is in contrast to Kocher's point where only 43% (30/70) were optimally placed and is comparable with a recent systematic review that observed an ideal position rate of 69%.[39] From our study, Keen's point was more accurately located than the other posterior approaches. Other advantages of using a posterior approach include not requiring an additional relay scalp wound and a lower risk of epilepsy compared with frontal shunts.[40]

Limitations

This was a single-center retrospective study, and despite being the largest of its kind reviewing morphometric data in the literature, it was insufficient to conduct subgroup analysis. For example, only 5 patients (5%) had catheters placed through Frazier's point and 17 (15%) through Keen's point. Another limitation was we could not ascertain preoperatively which ventricular cannulation approach the neurosurgeon intended to adopt and we resorted to a 20-mm cutoff. Similarly, we did not attempt to analyze the target trajectory surface landmark. It was assumed that all participating neurosurgeons would use similar operative techniques, but a lack of standardization was apparent. We used a relatively strict definition where the target region for optimal catheter placement was the ipsilateral frontal horn, but others proposed including the third ventricle or the contralateral frontal horn.[2,15,41] We did not investigate whether using less stringent criteria would have produced different results.

CONCLUSION

Relying on surface anatomy alone to localize standard craniometric points for freehand VP shunting is an imprecise technique. Keen's point was the most accurately identified entry point and was an independent predictor for optimal catheter position, which in turn was a determinant of shunt survival. Until prospective trials are performed, one should be cognizant of the limits of adopting these approaches.

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COMMENT

In this study, the authors compared the accuracy of freehand ventricular cannulation of commonly utilized craniometric entry sites. Using 3D reconstructed scans of 110 shunted hydrocephalic adult patients, the authors determined that Keen's point was the most accurately determined entry site and was an independent predictor for optimal catheter position and that optimal catheter tip position was an independent predictor for shunt survival. The authors are to be commended for performing an innovative and unique, hypothesis-driven study with interesting results to boot. Two features make this an outstanding manuscript: first, the study offers a direct comparison of the freehand ventricular cannulation accuracy for craniometric entry sites by using a comprehensive morphometric analysis; and second, the study coincidentally demonstrates a high proportion of burr holes that are placed inaccurately, which raises potential quality improvement opportunities within our specialty. This study represents an excellent scientific approach to an interesting question with results that are meaningful to neurosurgeons and our patients.

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