The relative efficacy of 3 different freehand frontal ventriculostomy trajectories: a prospective neuronavigation-assisted simulation study

Matthew A. Kirkman, MRCS, MEd,^{1,2} William Muirhead, MRCS,¹ and Nick Sevdalis, PhD³

¹Victor Horsley Department of Neurosurgery, The National Hospital for Neurology and Neurosurgery, University College London Hospitals NHS Foundation Trust, Queen Square, London; ²Department of Surgery and Cancer, Imperial College London, St Mary's Campus, London; and ³Health Service and Population Research Department, Institute of Psychiatry, Psychology and Neuroscience, King's College London, United Kingdom

OBJECTIVE Ventriculostomy is a relatively common neurosurgical procedure, often performed in the setting of acute hydrocephalus. Accurate positioning of the catheter is vital to minimize morbidity and mortality, and several anatomical landmarks are currently used. The aim of this study was to prospectively evaluate the relative performance of 3 recognized trajectories for frontal ventriculostomy using imaging-derived metrics: perpendicular to skull (PTS), contralateral medial canthus/external auditory meatus (CMC/EAM), and ipsilateral medial canthus/external auditory meatus (IMC/EAM).

METHODS Participants completed 9 simulated ventriculostomy attempts (3 of each trajectory) on a model head with Medtronic StealthStation coregistered imaging. Performance measures were distance of the ventricular catheter tip to the foramen of Monro (FoM) and presence of the catheter tip in a lateral ventricle.

RESULTS Thirty-one individuals of varying seniority and prior ventriculostomy experience performed a total of 279 simulated freehand frontal ventriculostomies. The PTS and CMC/EAM trajectories were found to be significantly more likely to result in both the catheter tip being closer to the FoM and in a lateral ventricle compared with the IMC/EAM trajectory. These findings were not influenced by the prior ventriculostomy experience of the participant, corroborating the significance of these results.

CONCLUSIONS The PTS and CMC/EAM trajectories were superior to the IMC/EAM trajectories during freehand frontal ventriculostomy in this study, and further data from studies incorporating varying ventricular sizes and bur hole locations are required to facilitate a change in clinical practice. In addition, neuronavigation and other guidance techniques for ventriculostomy are becoming increasingly popular and may be superior to freehand techniques, necessitating further prospective data evaluating their safety, efficacy, and feasibility for routine clinical use.

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KEY WORDS external ventricular drain; hydrocephalus; neurosurgical simulation; trajectory; ventriculostomy; surgical technique

VENTRICULOSTOMY for insertion of an external ventricular drain (EVD) is a relatively common neurosurgical procedure, often performed in the setting of acute hydrocephalus. Accurate positioning of the catheter is crucial, not least because malpositioning of a catheter tip can result in complications and the need for revision surgery, potentially increasing hospital length of stay and morbidity as well as mortality risk.¹³ Ventriculostomy is commonly performed freehand with the aid of anatomical landmarks, and although in some centers the

use of neuronavigation to facilitate insertion has increased in recent years, resource limitations as well as time constraints in the acutely deteriorating patient suggest that for the foreseeable future, freehand ventriculostomy is likely to remain commonplace.

Nevertheless, limitations of the freehand technique are well recognized. It has been shown to be inaccurate,^{1,5,17} with an average of 2 passes required for successful catheter placement.⁵ Furthermore, data suggest that freehand ventriculostomy results in the catheter lying somewhere in

ABBREVIATIONS CMC = contralateral medial canthus; EAM = external auditory meatus; EVD = external ventricular drain; FoM = foramen of Monro; IMC = ipsilateral medial canthus; PTS = perpendicular to skull.

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the ipsilateral lateral ventricle less than 60% of the time,^{5,17} with an even lower proportion of catheters (less than 40%) resting in the frontal horn of the lateral ventricle, which is usually the intended target.¹⁷ This degree of error is most likely to result from erroneous trajectories and interindividual differences in patient anatomy. To target the frontal horn of the lateral ventricle, different trajectories are often used, including insertion of the catheter perpendicular to the skull, and aiming the catheter at the intersection of the ipsilateral or contralateral medial canthus and the external auditory meatus (Fig. 1).^{3,9}

Previous studies assessing the relative merits of different trajectories for ventriculostomy have largely focused on the retrospective analysis of imaging data alone.^{11,14} The advent of neuronavigation has facilitated the ability to observe ventriculostomy trajectory objectively in real time. To this end, the aim of the present study was to prospectively evaluate the relative performance of 3 recognized trajectories for frontal ventriculostomy in real time using metrics derived from imaging using the StealthStation S7 Surgical Navigation System (Medtronic). To our knowledge, this is the first prospective study of real-time simulated frontal ventriculostomy addressing this topic.

Methods

Participants

Ethics approval to perform this study was granted by the Imperial College Research Ethics Committee. Participants were recruited through a mailing list for neurosurgery residents in London, United Kingdom, with additional participants recruited locally from the Department of Neurosurgery at the National Hospital for Neurology and Neurosurgery, Queen Square, London. For practical reasons, only individuals who spoke fluent English were eligible to take part. There were no other inclusion or exclusion criteria, and no financial incentives were offered for participation in this study. Data collection took place within the operating rooms of the National Hospital for Neurology and Neurosurgery.

Equipment

The Medtronic StealthStation S7 Surgical Navigation System was loaded into AxiEM (electromagnetic mode).

A hollow resin model head (Sawbones, Pacific Research Laboratories Inc.) was used for the simulated ventriculostomy (Fig. 1). The external contours of the model head were formed from the fusion of a CT and MRI scan of an individual with normal ventricles (Fig. 2), and the scans were used with the StealthStation for registration purposes. A bur hole was fashioned into the model head at Kocher's point on the right side, defined as 11 cm posterior to the nasion and 2.5 cm lateral to the midline. The AxiEM Cranial Non-Invasive Shunt Kit (Medtronic) was used in combination with a Codman Bactiseal External Ventricular Drain Catheter (Codman and Shurtleff Inc.) during the simulation (Fig. 3). The model head was placed on a head ring, stabilized with tape, and draped to maximize the realism of the simulation.

Study Protocol

Each participant underwent the same study protocol (Fig. 4), in which they were asked to insert the ventricular catheter into the model head through a bur hole placed at Kocher's point using 3 different trajectories (Fig. 1) and to aim for the ipsilateral FoM. Participants were asked to pass the catheter to a fixed depth of 7.2 cm as marked on the catheter itself (Fig. 3), determined a priori as the optimal length required to reach the ipsilateral FoM from the surface of the model head. The 3 trajectories chosen were ipsilateral medial canthus/external auditory meatus (IMC/EAM), contralateral medial canthus/external auditory meatus (CMC/EAM), and perpendicular to skull (PTS), in that order. Participants were only allowed 1 attempt at each trajectory during each trial, and there were a total of 3 trials. Each individual participant performed all 3 trials consecutively on the same day. Different participants took part on different days, however. Thus, participants had 3 attempts at each of the 3 trajectories—a total of 9 attempts completed by each participant—and all participants were asked to perform the trials in the same order. The study was intentionally designed so that ventriculostomies were performed in this specific sequence and not in a randomized manner, so that at no point were participants asked to use the same trajectory in succession. If the study were randomized, with only 3 trajectories to choose from, the risk of a participant being asked to use the same trajectory in 2 or more successive attempts in a study of 279 ventricu-

FIG. 1. The resin model head used in the study, along with the 3 proposed trajectories represented by arrows passing through the bur hole at Kocher's point. Figure is available in color online only.

FIG. 2. A screenshot from the Medtronic StealthStation display monitor during the ventriculostomy task, with 4 views of the cranium. The *red crosshairs* represent the location of the catheter tip, and the *orange dotted line* in the top 2 panels and the bottom left screen indicates the optimal trajectory to reach the FoMs from the bur hole. The *orange crosshair* in the bottom right screen indicates the FoM, and the *green text* on this same screen indicates the distance of the catheter tip to the FoM (in mm). Figure is available in color online only.

lostomy attempts would be high, and more likely to result in a learning effect than the methodology adopted here.

Participants did not receive any visual or other feedback regarding how close they were to the FoM during or after the trials, and only the assessor was able to see the StealthStation monitor during the trials. Study participants were fully debriefed upon completion of their final trial.

Outcome Measures

We used the StealthStation to record 2 objective measures of technical performance: 1) distance of the ventricular catheter tip from the FoM (in mm; Fig. 2), a consistent and fixed target that has been used in similar studies,^{5,12} and 2) whether the catheter tip had successfully entered and remained in a lateral ventricle, which may be considered a more practical and relevant outcome measure (binary measure, yes/no).

Data Analysis

All data were entered into SPSS Statistics software (version 20, IBM) for analysis; a p value < 0.05 was considered statistically significant. Paired-samples t -tests and repeated measures ANOVA and mixed-design ANOVA were performed to analyze participants' performance. The performance measure of the proportion of catheter tips resting in a lateral ventricle was converted into a percentage score (%) for reporting purposes. Data on the anatomical location of the catheter tip were recorded at the time of the simulation and re-verified by 1 of the authors (M.A.K.) at a later point. To assess for a learning affect, we reviewed performance from the first to the third trial of each of the 3

trajectories, and from the first to the ninth ventriculostomy attempt of the overall protocol.

Results

Thirty-one participants (16 men, 15 women) were recruited into the study. Two of these were medical students; the remainder included doctors with experience in neurosurgery, ranging in seniority from 1st-year trainee to senior resident. The mean length of neurosurgical experience in our cohort was 49.4 ± 39.51 months (range 1–144 months), and the mean number of ventriculostomies previously performed was 43 ± 47.12 (range 0–202). For the purposes of analysis, we used the number of ventriculostomies performed previously as a measure of participant experience, and created “low,” “medium,” and “high” ventriculostomy

FIG. 3. The ventricular catheter and Medtronic AxiEM probe used in this study. **Upper:** The AxiEM probe next to the ventricular catheter. A marking at 7.2 cm on the catheter (*arrow*) indicates to participants how deep the catheter should pass from the surface of the model head (representing the scalp). **Lower:** Demonstration of how the 2 were combined for use in our study. Figure is available in color online only.

FIG. 4. A schematic of the study protocol.

experience groups using the 33.33rd and 66.67th percentiles as cutoff values. Thus, those who had performed up to 10 ventriculostomies previously were classed as having “low ventriculostomy experience” ($n = 10$), those who had performed between 11 and 47 ventriculostomies as “medium ventriculostomy experience” ($n = 11$), and those who had performed 48 or more ventriculostomies as “high ventriculostomy experience” ($n = 10$). The results are presented according to the 2 performance measures used.

Distance of Catheter Tip to the Foramen of Monro

There were significant associations between the mean distance to the FoM across the 3 trials between all 3 trajectories, with the IMC/EAM and CMC/EAM values being most strongly associated (Table 1).

A significant influence of trajectory choice on distance to FoM was identified (mixed-design ANOVA, $F = 4.490$, $p = 0.016$). Further exploration of this relationship revealed that the shortest distance of the catheter tip to the FoM was observed when the PTS trajectory was used (mean distance 12.58 mm across the 3 ventriculostomy attempts), followed by the CMC/EAM (mean 13.88 mm) and IMC/EAM (mean 15.15 mm) trajectories (Table 2, Fig. 5). Both the PTS and CMC/EAM trajectories resulted in a lower mean distance of the catheter tip to the FoM compared with the IMC/EAM trajectory (paired-samples t-test, PTS vs IMC/EAM: $t = 2.616$, $p = 0.014$; CMC/EAM vs IMC/EAM: $t = 2.173$, $p = 0.038$). There was no difference in mean distance of the catheter tip to the FoM when comparing the PTS and CMC/EAM trajectories ($t = 1.407$, $p = 0.17$), suggesting that these 2 trajectories result in equally superior performance over the IMC/EAM trajectory (Fig. 5).

In investigating the effects of previous ventriculostomy experience on performance between the different trajectories used, dividing participants into low, medium, and high ventriculostomy experience groups using the criteria described in the *Methods* found no statistically significant effect of experience on catheter distance to the FoM in the 3 trajectories (mixed-design ANOVA, $F = 0.437$, $p = 0.65$). Furthermore, no interaction was observed between previous experience and trajectory (mixed-design ANOVA, $F = 1.314$, $p = 0.276$). Taken together, these data indicate that the observed differences in results between the 3 trajectories were not due to differences in competency and were due only to the trajectory chosen.

To assess for a learning effect, we compared individual performance at each trajectory over time, and we observed significant reductions in distance to FoM from the first to the third trial when using PTS (repeated measures ANOVA, $F = 5.195$, $p = 0.012$) and CMC/EAM ($F = 6.229$, $p = 0.006$) but not IMC/EAM trajectories ($F = 2.614$, $p = 0.09$). However, for the IMC/EAM trajectory, a significant decrease in distance to FoM was observed between the first and second attempt ($F = 4.888$, $p = 0.035$), and indeed it was observed that in all the trajectories the greatest improvement in performance was noted between the first and second ventriculostomy attempts. To confirm the presence of a learning effect, we analyzed overall performance across all 9 ventriculostomy attempts, which all participants completed in the same order, and found a significant

TABLE 1. Comparison of the Pearson correlation values for distance to the FoM of the different trajectories used in this study

Trajectory	IMC/EAM	CMC/EAM	PTS
IMC/EAM	—	—	—
CMC/EAM	0.74†	—	—
PTS	0.386*	0.469†	—

* $p < 0.05$.† $p < 0.01$.‡ $p < 0.0001$.

improvement in the distance to FoM when going from the first to the ninth ventriculostomy trial (repeated measures ANOVA, $F = 4.080$, $p = 0.004$).

Proportion of Ventricular Catheter Tips in a Lateral Ventricle

Trajectory choice had a significant influence on the proportion of catheter tips in a lateral ventricle (mixed-design ANOVA, $F = 21.526$, $p < 0.0001$). Further exploration of this relationship revealed that the trajectory associated with the highest proportion of catheter tips in a lateral ventricle averaged over the 3 trials was the PTS trajectory (69%, Table 2), followed by the CMC/EAM (68%) and IMC/EAM (30%) trajectories. Both the PTS and CMC/EAM trajectories resulted in a higher proportion of catheter tips resting in a lateral ventricle compared with the IMC/EAM trajectory (paired-samples t-test, PTS vs IMC/EAM: $t = -6.920$, $p < 0.001$; CMC/EAM vs IMC/EAM: $t = -5.624$, $p < 0.001$). There was no difference in the proportion of catheter tips resting in a lateral ventricle between the PTS and CMC/EAM trajectories ($t = -1.50$, $p = 0.882$), suggesting again that these 2 trajectories result in equally superior performance compared with the IMC/EAM trajectory.

No statistically significant effect of participants' previous experience on the proportion of catheter tips resting in a lateral ventricle was identified (mixed-design ANOVA, $F = 0.225$, $p = 0.80$), and no interaction between previous experience and trajectory occurred (mixed-design ANOVA, $F = 0.131$, $p = 0.97$). These data further corroborate the notion that the observed differences in results between the 3 trajectories were due solely to the trajectory chosen.

To evaluate for the presence of a learning effect using this performance measure, it was not present when the 3 trajectories were investigated separately, with no significant change in the proportion of catheter tips that remained in a lateral ventricle across the 3 trials in any of

FIG. 5. Graphs illustrating performance at ventriculostomy during this study, using the 2 performance measures specified in our protocol, according to the different trajectories used. Error bars represent 95% confidence intervals. **Upper:** Graph showing the distance of the tip of the ventricular catheter from the FoM over the 3 trials, in mm. Lower values indicate better performance. **Lower:** Graph showing the percentage of ventriculostomy attempts that resulted in the EVD catheter being correctly sited in a lateral ventricle (LV) over the 3 trials. In this performance measure, higher values indicate better performance. *Comparisons significant at $p < 0.05$ (paired samples t-test). Figure is available in color online only.

TABLE 2. Mean distance of the ventricular catheter tip from the FoM, and mean success at inserting the catheter tip in a lateral ventricle over the 3 ventriculostomy attempts, separated by trajectory used*

Trajectory	Distance to FoM in mm (SD)				Mean % Success at Entering Lateral Ventricle (SD)			
	Attempt 1	Attempt 2	Attempt 3	Mean	Attempt 1	Attempt 2	Attempt 3	Mean
IMC/EAM	16.39 (0.67)	15.00 (0.92)	14.06 (1.40)	15.15 (4.41)	29 (46.1)	39 (49.5)	23 (42.5)	30 (29.0)
CMC/EAM	16.12 (4.68)	12.98 (5.59)	12.55 (6.48)	13.88 (4.59)	65 (48.6)	68 (47.5)	71 (46.1)	68 (29.2)
PTS	14.60 (6.45)	11.74 (5.48)	11.38 (5.85)	12.58 (5.37)	61 (49.5)	68 (47.5)	77 (42.5)	69 (32.1)

* Values rounded to 2 decimal places where appropriate.

the 3 trajectory groups (repeated measures ANOVA, PTS: $F = 1.666$, $p = 0.207$; CMC/EAM: $F = 0.136$, $p = 0.873$; IMC/EAM: $F = 1.107$, $p = 0.344$). However, when performance was analyzed in individuals across all 9 ventriculostomy attempts, a significant improvement was found in the proportion of catheter tips resting in a lateral ventricle when moving from the first to the ninth attempt (repeated measures ANOVA, $F = 8.000$, $p < 0.0001$).

Table 3 demonstrates the anatomical locations of the catheter tips according to trajectory. It can be observed that, relative to the IMC/EAM trajectory, ventriculostomy attempts with the PTS and CMC/EAM trajectories were more likely to result in the catheter tip resting in a ventricle, particularly the targeted ipsilateral ventricle.

Discussion

The results of this prospective study of 279 simulated ventriculostomies suggest that, during freehand frontal ventriculostomy, aiming the catheter either perpendicular to the skull or at the intersection of the contralateral medial canthus and external auditory meatus is significantly more likely to result in both the catheter tip being closer to the FoM and in a lateral ventricle, compared with a trajectory relying on the intersection between the IMC and the EAM. This finding is consistent with a previous retrospective analysis of imaging in which superiority of the PTS and CMC/EAM trajectories over the IMC/EAM trajectory was also demonstrated.¹¹ Performance did not vary significantly according to the number of ventriculostomies performed previously by our participants, supporting the notion that the differences in performance observed were solely due to the trajectories used and not the expertise of the person performing the ventriculostomy. To elaborate, one would not expect experience or expertise to influence performance in ventriculostomy with a prefashioned bur hole and prespecified trajectory, although one would if the participant would be allowed to perform the ventriculostomy without prior instructions.

Without knowing the results of this study, 13 (42%) of the 31 participants in our study had a preference to insert the catheter using the PTS trajectory and a similarly high proportion had a preference for the IMC/EAM trajectory ($n = 12$, 39%). Four participants (13%) had a preference for a trajectory at the intersection of the glabella and the EAM, and 2 participants (7%) had no preference for a specific trajectory. Interestingly, no participants expressed a preference for the CMC/EAM trajectory, and the reasons for this are unclear. There is little prior evidence to support the use of one freehand trajectory over another, and although our study suggests relative inferiority of the IMC/EAM trajectory, further data are required to support a change in practice. Regardless, there are likely to be several barriers to influencing ventriculostomy practice in the clinical setting, and further work will be required to fully elucidate and address these. Although our data, owing to the nature of this preliminary study, cannot be directly translated into clinical practice, they do suggest that in principle the CMC/EAM trajectory, which was not favored by any of our participants prior to taking part in our study, may be an alternative option to the PTS trajectory during freehand ventriculostomy.

TABLE 3. Anatomical location of the catheter tip across all participants ($n = 31$) and all ventriculostomy attempts ($n = 279$), according to trajectory used

Trajectory	Catheter Tip Location (%)		
	Ipsilateral Lateral Ventricle	Contralateral Lateral Ventricle	Elsewhere*
IMC/EAM	12 (13)	16 (17)	65 (70)
CMC/EAM	52 (56)	11 (12)	30 (32)
PTS	55 (59)	9 (10)	29 (31)

* Such as the third ventricle, subarachnoid space, brain tissue, etc.

Although the PTS and CMC/EAM trajectories were superior to IMC/EAM in our study, they were not perfect. Over two-thirds of ventriculostomy attempts using the PTS and CMC/EAM trajectories resulted in the catheter tip resting in a lateral ventricle which, although more than double the percentage of those inserted using the IMC/EAM trajectory (Table 3), still means that almost one-third of attempts using the PTS and CMC/EAM trajectories resulted in the catheter tip being sited in other structures, such as the third ventricle, subarachnoid space, and brain tissue. These values are similar to rates of malpositioned ventricular catheters reported elsewhere.^{5,17}

Several studies have compared the accuracy of image-guided compared with freehand ventriculostomy in clinical settings, finding the latter to be superior in terms of accuracy^{4,6,18} and shunt revision rates.^{2,4,6,18} The highest quality evidence to date comes from a prospective cohort study of 75 patients undergoing de novo ventriculoperitoneal shunt insertion at 3 European centers, which found that electromagnetic navigation significantly reduced poor shunt placement and early shunt revision rates.⁴ Interestingly, patients with slit ventricles, a group that may be assumed to benefit most from neuronavigation, were excluded. These findings have been corroborated in a recent 10-year retrospective analysis of 236 patients undergoing 426 ventricular shunt insertion or revision procedures at the University of Minnesota,⁶ a 5-year retrospective study of 249 patients undergoing ventriculostomy at the University of Michigan,¹⁸ and a 2-year retrospective study of 211 patients undergoing 242 shunt placements at the University of Virginia, which looked solely at rates of shunt revision as an outcome measure.²

Despite these apparent advantages, neuronavigation systems are not universally available, and there are concerns about the time required for setup in emergency situations. One prospective study of 35 patients undergoing ventriculostomy in the intensive care unit found that the addition of electromagnetic image guidance technology significantly improved the accuracy of catheter placement compared with historical data based on freehand ventriculostomy, but the use of image guidance added 36 minutes to the overall time until catheter insertion.¹⁰ Nevertheless, this must be balanced against the fact that the use of neuronavigation systems may reduce the number of attempts required to successfully enter the ventricle and the morbidity and brain damage associated with multiple catheter insertions. Thus, prospective trial data are required to better establish the role of neuronavigation in ventriculostomy, with reported safety, efficacy, and feasibility outcomes,

and this is the subject of 2 ongoing randomized trials incorporating smartphone-assisted technology.^{15,16}

In addition to its burgeoning use in the clinical setting, particularly in patients with small or dysmorphic ventricles, image guidance is being increasingly used as a training tool for ventriculostomy in residents^{7,8} although evidence that the training translates into improved patient outcomes is currently lacking. However, training with the use of image-guidance technology may increase familiarity with the technology reducing setup times, thus influencing clinical outcomes in this manner.

Strengths of this study include its prospective nature, the large number of simulated ventriculostomies analyzed, the lack of missing or incomplete data, and the realism afforded by data collection taking place in a real operating room. Previous studies have largely relied on the retrospective analysis of imaging data alone. Another strength is the wide range of experience of the participants of this study, ranging from 1 month to 12 years of prior neurosurgical experience and prior performance of 0–202 ventriculostomies. This is a sufficiently wide range to confirm that the lack of effect of experience on performance observed in our study was genuine.

The main limitation of our study was the potential for recruitment bias. Although there was a lack of haptic feedback during the simulated ventriculostomy task, this may have served to improve the reliability and validity of our results, because participants did not have tactile information to influence trajectories. The use of a fixed bur hole location and depth to pass the ventricular catheter may be perceived as a limitation, but this was an attempt to minimize the variables that could affect task performance and the time and expense associated with allowing individual participants to fashion bur holes “on demand.” Kocher’s point was chosen because it is regularly used as the preferred location for siting a bur hole for frontal ventriculostomy, and although different definitions of Kocher’s point exist, we chose one that is widely used in our locality (11 cm posterior to nasion and 2.5 cm lateral to the midline). Future studies may wish to use varying bur hole locations to provide the participant with increased flexibility, although such studies are likely to require a much greater number of participants to account for the additional “noise” created by the introduction of another variable into the analysis. The ventricles in the imaging used in the study were of normal size, which, rather than being a limitation, was intended to increase the difficulty of the task and bring out differences in performance between the trajectories. It was believed that assessing efficacy differences in trajectory performance in the setting of gross hydrocephalus would be more difficult, due to the presence of a much larger margin for error, particularly in relation to our performance measure of whether the catheter tip rests in a ventricle. However, this point does highlight the fact that our imaging data are based on a single patient, which belies the individual patient complexity and anatomical variance facing clinicians on a daily basis. As such, it would be important in future studies to ensure translational relevance by utilizing imaging demonstrating a range of ventricular sizes and configurations.

A final discussion point on limitations relates to the observed improvement in overall performance when go-

ing from the first to the final ventriculostomy attempt. All participants completed the tasks in the same order, and the protocol was designed so that the trajectories were performed in a rotatory manner (IMC/EAM, CMC/EAM, PTS, IMC/EAM, CMC/EAM, PTS, and so on; Fig. 4) and not allocated through randomization. This avoided the risk of participants performing the same trajectory 2 or more times in succession, an issue that is likely to result from randomizing 279 attempted ventriculostomies in the presence of only 3 possible trajectories. Thus, learning effects and order effects are unlikely to have influenced the superiority of one trajectory over another.

Conclusions

In our study, the PTS and CMC/EAM trajectories were superior to the IMC/EAM trajectory during simulated freehand frontal ventriculostomy. Further data from studies incorporating varying ventricular sizes and bur hole locations are required to corroborate our preliminary findings and facilitate a change in clinical practice. At the same time, high-quality prospective data are required to evaluate the safety, efficacy, and feasibility of routine neuronavigation and other guidance techniques for ventriculostomy in the clinical setting, as their use may be superior to the freehand technique.

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Disclosures

Dr. Sevdalis is the owner and director of London Safety & Training Solutions Ltd., which provides team skills training and advice on a consultancy basis in hospitals and training programs in the UK and internationally.

Author Contributions

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Correspondence

Matthew A. Kirkman, Victor Horsley Department of Neurosurgery, The National Hospital for Neurology and Neurosurgery, Queen Square, London WC1N 3BG, United Kingdom. email: matthew.kirkman@gmail.com.