Comparison of the accuracy of ventricular catheter placement using freehand placement, ultrasonic guidance, and stereotactic neuronavigation

Clinical article

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Object. The objective of this study was to compare the accuracy of 3 methods of ventricular catheter placement during CSF shunt operations: the freehand technique using surface anatomy, ultrasonic guidance, and stereotactic neuronavigation.

Methods. This retrospective cohort study included all patients from a single institution who underwent a ventricular CSF shunting procedure in which a new ventricular catheter was placed between January 2005 and March 2010. Data abstracted for each patient included age, sex, diagnosis, method of ventricular catheter placement, site and side of ventricular catheter placement, Evans ratio, and bifrontal ventricular span. Postoperative radiographic studies were reviewed for accuracy of ventricular catheter placement. Medical records were also reviewed for evidence of shunt failure requiring revision through December 2011. Statistical analysis was then performed comparing the 3 methods of ventricular catheter placement and to determine risk factors for inaccurate placement.

Results. There were 249 patients included in the study; 170 ventricular catheters were freehand passed, 51 were placed using stereotactic neuronavigation, and 28 were placed under intraoperative ultrasonic guidance. There was a statistically significant difference between freehand catheters and stereotactic-guided catheters (p < 0.001), as well as between freehand catheters and ultrasound-guided catheters (p < 0.001). The only risk factor for inaccurate placement identified in this study was use of the freehand technique. The use of stereotactic neuronavigation and ultrasonic guidance reduced proximal shunt failure rates (p < 0.05) in comparison with a freehand technique.

Conclusions. Stereotactic- and ultrasound-guided ventricular catheter placements are significantly more accurate than freehand placement, and the use of these intraoperative guidance techniques reduced proximal shunt failure in this study.

(http://thejns.org/doi/abs/10.3171/2012.11.JNS111384)

Key Words • cerebrospinal fluid • ventricular catheter • ultrasonography • ventriculoperitoneal shunt • stereotactic neuronavigation • functional neurosurgery

Ventriculoperitoneal shunt placement is one of the most commonly performed neurosurgical procedures. Despite advances in shunt catheter materials and the valves used, there remains a high rate of shunt failure. In fact, 1 recent study reported shunt failure in 32% of adult patients undergoing VP shunt placement. Mechanical dysfunction remains the most common cause of this failure. The most common reason for proximal catheter failure is believed to be obstruction of the catheter by the choroid plexus; theoretically, optimal catheter placement should help reduce this risk. In pediatric patients, this factor has been examined by comparing endoscopically versus nonendoscopically placed ventricular catheters. Data has shown that endoscopic ventricular catheter placement reduces the odds of proximal obstruction, although it did not decrease the overall failure rate. Given the high rate of failure, it intuitively makes sense that everything should be done to optimize catheter placement. Most ventricular catheters are placed using anatomical landmarks in a freehand fashion, although adjuncts are available, including stereotactic neuronavigation and intraoperative ultrasonography, yet no data exist comparing these methods. In this study, we sought to compare the accuracy of ventricular catheter placement between anatomical landmark–guided freehand placement, stereotactic neuronavigation–guided placement, and ultrasonic-guided placement.

Abbreviations used in this paper: EVD = external ventricular drain; VP = ventriculoperitoneal.
Comparison of ventricular catheter placement accuracy

Methods

Study Design

This cohort study was approved by the University of Michigan Institutional Review Board, and data were obtained by retrospective review of medical records, including radiographic images. Information technology personnel designed and implemented a search paradigm to query the University of Michigan information systems and electronic medical records to identify all adult patients (18 years of age or older) who underwent placement of a VP, ventriculopleural, or ventriculoatrial shunt between January 2005 and May 2010. All patients underwent preliminary chart review to ensure a shunt had been placed. A “new” shunt was considered any shunt in which a ventricular catheter was passed into the ventricular system in a new location and not through an existing tract. All patients not meeting this criterion were excluded. The collection of radiographic studies was then reviewed for each patient, and patients were included if they had a CT scan of the head both within 48 hours prior to the operation and within 48 hours following the operation. All patients who did not meet this criterion were excluded.

Data Collection

From this population of patients, a detailed chart review was performed and the following data were abstracted: age, sex, reason for shunting, site of shunt (frontal or occipital), side of shunt (right or left), bifrontal ventricular span (based on preoperative CT scan), Evans ratio (based on preoperative CT scan), and accuracy of ventricular catheter placement (based on postoperative CT scan). The bifrontal ventricular span was measured as the width of the lateral margin of the right frontal horn to the lateral margin of the left frontal horn at its widest point on an axial image. The Evans ratio was calculated by dividing the bifrontal ventricular span by the widest width of the inner table of the cranium. An “accurate” ventricular catheter placement was credited when the tip of the ventricular catheter resided within the intended ventricle. All catheter placements in this study were intended for the ipsilateral ventricle, although under certain circumstances, this was not always the case. For example, a right-frontal ventricular catheter was considered accurate when the tip of the ventricular catheter resided within the intended ventricle. All catheter placements in this study were intended for the ipsilateral ventricle, although under certain circumstances, this was not always the case. For example, a right-frontal ventricular catheter was considered accurate when the tip of the ventricular catheter resided within the right lateral ventricle or passed through the foramen of Monro into the third ventricle. Placement was considered inaccurate if the ventricular catheter tip resided in the left frontal horn, outside of the ventricular system, and other locations. The accuracy of each ventricular catheter placement was determined by comparing the operative approach to the documented tip position in each of the radiology reports from the postoperative CT scans. Each postoperative CT scan was then reviewed by a member of the study team to confirm that our assessment of the catheter tip agreed with the assessment documented in the radiology report. In all patients, the assessment of the study team was in accordance with the radiology report.

Each medical record was also reviewed and episodes of shunt failure through December 2011 were documented. Operative reports at the time of shunt revision were reviewed and the failed portion of the shunt was noted: proximal failure was considered failure of the ventricular catheter, while distal failure was considered failure of the valve or distal catheter (peritoneal, atrial, or pleural).

Statistical Analysis

Statistical analysis was performed using commercially available software (SPSS version 18, IBM Corporation). All categorical data were assessed using the chi-square test. Multivariate logistic regression was used to assess an independent association of our variables of interest with catheter placement accuracy. For purposes of multivariate logistic regression, the following were considered to be dichotomous variables: accuracy of placement (accurate/inaccurate), anatomical site (frontal/occipital), side (left/right), method of placement (guided placement including ultrasound and stereotactic neuronavigation, or freehand). Evans ratio and bifrontal ventricular span were considered continuous variables. Statistical significance was considered to be p < 0.05.

Results

Baseline Characteristics

During the study period, 253 new shunt operations were performed. Four patients were excluded because they did not have either a preoperative or postoperative CT scan. Of the 249 remaining cases, 170 ventricular catheters were freehand passed based on standard surface anatomy, 51 were placed using stereotactic neuronavigation, and 28 were placed under intraoperative ultrasonic guidance. Baseline characteristics of the study population are provided in Table 1.

Comparison of Placement Methods

During the study period, 94 (55%) of 170 freehand passed catheters were placed accurately (Table 2), compared with 45 (88%) of 51 stereotactic-guided catheters and 25 (89%) of 28 ultrasound-guided catheters. There was a statistically significant difference in placement accuracy between freehand catheters and stereotactic-guided catheters (p < 0.001), as well as between freehand catheters and ultrasound-guided catheters (p < 0.001). There was no observed difference between stereotactic-guided and ultrasound-guided placement (p = 0.89).

Risk Factors for Inaccurate Catheter Placement

In the multivariate logistic regression analysis, the only risk factor for inaccurate placement was freehand methodology in comparison with ultrasound/stereotactic guidance (p < 0.001). Side (p = 0.72), location (p = 0.12), bifrontal ventricular span (p = 0.68), and Evans ratio (p = 0.42) were not found to be significantly associated with inaccurate catheter placement. In comparison with stereotactic-guided placement, freehand placement had an odds ratio of 6.06 for inaccurate placement (95% CI 2.46–14.97), while the odds ratio was 6.74 for inaccurate placement in comparison with ultrasound-guided placement (95% CI 1.96–23.17). If stereotactic- and ultrasound-guided placement was considered as 1 group,
the odds ratio of inaccurate placement by the freehand method was 6.29 (95% CI 2.95–13.41).

The subpopulation of patients undergoing freehand catheter placement was examined separately for risk factors of inaccurate freehand catheter placement. Bivariate statistics for this group are shown in Table 2. In multivariate logistic regression analysis, neither the side (p = 0.87) nor the location (p = 0.38) was a significant risk factor for inaccurate placement. Interestingly, ventricular size, whether measured by bifrontal ventricular span (p = 0.63) or by Evans ratio (p = 0.35), was not correlated with risk of inaccurate placement.

Notably, there was no significant difference in ventricular size between those patients undergoing freehand placement and those who underwent stereotactic- or ultrasound-guided placement. The range of ventricular sizes and the minimum ventricular size accurately targeted by each method are provided in Table 3. Of note, catheter placement using an occipital approach with ultrasonic guidance was attempted in only 1 patient, and the placement of this catheter was inaccurate.

**Comparison of Failure Rates**

During the study period, 27 (16%) of 170 shunts placed using the freehand technique failed and required revision. Of the 27 shunts requiring revision, 20 were due to proximal failure and 7 were due to distal failure. Overall, 12% of shunts placed using the freehand technique experienced proximal failure. Of the 79 shunts placed using stereotactic neuronavigation or ultrasonic guidance, 8 (10%) failed and required revision. Of the 8 shunts requiring revision, 3 were due to proximal failure and 5 were due to distal failure. Overall, 4% of shunts placed using stereotactic neuronavigation or ultrasonic guidance experienced proximal failure. There was no difference in overall failure rate between the freehand technique and stereotactic neuronavigation/ultrasonic guidance (p = 0.22). There was, however, a statistically significant difference in proximal failure rates, with stereotactic neuronavigation/ultrasonic guidance showing significantly less proximal failure (p < 0.05).

**Discussion**

Cerebrospinal fluid diversion using VP shunt place-
Comparison of ventricular catheter placement accuracy

<table>
<thead>
<tr>
<th>Placement Method</th>
<th>Bifrontal Span (mm)</th>
<th>Evans Ratio</th>
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<tr>
<td></td>
<td>Range of Ventrapted</td>
<td>Minimum Accurately</td>
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<tr>
<td></td>
<td>Minimum Accurately</td>
<td>Targeted</td>
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<tr>
<td>freehand</td>
<td>22.0–97.7</td>
<td>24.6</td>
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<tr>
<td>stereotactic-guided</td>
<td>22.5–55.3</td>
<td>22.5</td>
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<tr>
<td>ultrasound-guided</td>
<td>25.8–62.5</td>
<td>27.3</td>
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Ultrasound-guided catheter placement was significantly more accurate than freehand placement and was equivalent to stereotactic-guided placement. In our study, 89% of catheters placed using ultrasound guidance were accurately placed. Of note, only 1 catheter placement was attempted using the occipital approach with ultrasonic guidance, and it was inaccurately placed. Thus, we cannot recommend ultrasonic guidance as a useful option for placement of catheters by the occipital approach. More data are needed to determine the usefulness of ultrasonography with this approach. The minimal bifrontal ventricular span accurately targeted by ultrasonography was 27.3 mm. As a result, we believe that ultrasonic guidance is a useful method for frontal-approach ventricular catheters targeting ventricles with a bifrontal ventricular span of at least this size.

The only factor identified in this study to be a risk factor for inaccurate placement was use of the freehand technique using standard anatomical landmarks. Among the freehand catheter placements, none of the factors identified in this study increased the risk of inaccurate placement. It is not surprising that the side of placement was not significant, but notably neither the location nor ventricular size (whether measured by Evans ratio or bifrontal ventricular span) was significant. A commonly employed method used by neurosurgeons is to use adjunctive measures such as stereotactic guidance when the ventricles are believed to be subjectively small. We found that placement is equally as likely to be inaccurate throughout the full range of ventricular size. This may not generalize to EVD placement, although previous data suggest that placement of EVDs using the freehand technique is accurate in only 65% of cases according to the standards used in this study. We hypothesize that one of the factors contributing to increased inaccurate freehand placement during CSF shunting procedures is the difficulty in identifying surface landmarks caused by the draping used in the operating room. The same amount of draping is not present at the bedside when EVDs are placed, making identification of key surface landmarks easier. Furthermore, the standard head position for VP shunt placement is turned to the side. This makes assessment of the midline and confirming a trajectory orthogonal to the skull more challenging than in “nose-up” procedures such as externalized ventriculostomy. In our anecdotal experience, the rate of accurate placement of EVDs appears to be higher than that of ventricular catheters as part of CSF diversion operations. While a 45% rate of inaccurate placement with the freehand technique appears to be exceptionally high, it is consistent with other published data. In their study, Theodosopoulos et al. found that only 38% of catheters were optimally placed and 53% would have been considered accurate according to the definition used in our study. Similarly, Lind et al. found that 56% of catheters were placed accurately in their study. Our data, together with theirs, suggest that we likely underestimate the rate of catheter misplacement using the freehand technique.

Ultimately, more accurate placement only matters if it leads to reduced failure rates. Previous data from the
pediatric literature suggest that utilizing an endoscope to ensure accurate placement of the ventricular catheter leads to reduced proximal failure but does not decrease the overall rate of shunt failure. Based on that data, we hypothesized that increased utilization of stereotactic and ultrasonic guidance with resultant increases in accuracy of placement would lead to reduced proximal catheter failure. Our data support this hypothesis. Increased accuracy using stereotactic and ultrasonic guidance led to a reduction in proximal catheter failure. Similar to data for utilization of an endoscope, we did not observe a reduction in the overall rate of shunt failure. Others, however, have demonstrated a reduction in distal catheter failure rate when the distal peritoneal catheter was placed laparoscopically as opposed to via minilaparotomy. Furthermore, there is some data to suggest that the use of programmable valves reduces shunt failure/revision. Thus, while we did not find a difference in overall shunt failure rate in our study, it may be that a combination of the use of stereotactic/ultrasonic guidance for placement of the ventricular catheter, laparoscopic placement of the peritoneal catheter, and the use of a programmable valve has the potential to reduce shunt failure by optimizing each component of the system.

Conclusions

Based on this study, both stereotactic- and ultrasound-guided ventricular catheter placements are significantly more accurate than freehand placement based on surface anatomy. The only risk factor identified in this study for inaccurate placement was the use of the freehand technique. Notably, ventricular size did not correlate with risk of inaccuracy. The increased accuracy of stereotactic-ultrasound guidance led to a reduction in proximal shunt failure, although there was no observed difference in overall failure. Stereotactic and ultrasonic guidance are useful adjuncts in the placement of ventricular catheters and have the potential to reduce proximal failure rates of CSF shunts.

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 to the study and manuscript preparation include the following. Conception and design: Sullivan. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Sullivan. Statistical analysis: Wilson, Stetler, Al-Holou. Study supervision: Sullivan.

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