Prediction of ventriculoperitoneal shunt dependency in patients with aneurysmal subarachnoid hemorrhage

Clinical article

MICHAEL CHAN, M.D.,1 ALI ALARAJ, M.D.,1 MATEO CALDERON, M.D.,1 SEBASTIAN RAMON HERRERA, M.D.,1 WEIHUA GAO, M.S.,2 SEAN RULAND, D.O.,3 AND BEN ZION ROITBERG, M.D.1

Departments of 1Neurosurgery and 3Neurology, School of Medicine; and 2Department of Biostatistics, School of Public Health, University of Illinois at Chicago, Illinois

Object. Patients with subarachnoid hemorrhage treated using external ventricular drainage due to obstructive hydrocephalus commonly remain shunt-dependent. Based on identified risk factors for external ventricular drain (EVD) challenge failure, the authors sought to determine the likelihood that a patient will require a permanent shunt.

Methods. The authors reviewed 89 consecutive cases of aneurysmal subarachnoid hemorrhage with obstructive hydrocephalus for parameters associated with EVD challenge failure and permanent shunt requirement. Significant parameters were combined in a discriminant function analysis to create a failure risk index (FRI). Linear regression analysis was performed correlating the FRI with the actual rate of shunt dependency.

Results. Patients requiring a permanent shunt had: a larger third ventricular diameter (7.0 vs 5.4 mm; p = 0.02) and a higher Hunt and Hess grade (3 vs 2; p = 0.02) at the time of admission; and a larger third ventricular diameter (6.6 vs 5.2 mm; p = 0.04), a larger bicaudate diameter (31.9 vs 30.2 mm; p = 0.03), and higher CSF protein levels (76.5 vs 40.3 mg/dl; p < 0.0001) at the onset of EVD challenge. These patients were also more likely to be female (p = 0.01) and have a posterior circulation location of their aneurysm (p = 0.01). The FRI score was calculated based on a weighted combination of the above parameters. Linear regression analysis between FRI values and the percentage of patients who required a permanent shunt had a correlation coefficient of 91%; the risk of a permanent shunt requirement increased linearly with a rising FRI score.

Conclusions. An FRI score created by discriminant function analysis can predict whether or not a permanent shunt is required, even if separate factors are not in agreement with each other or show a weak correlation when considered separately. An increased FRI score was strongly and linearly correlated with the risk of EVD challenge failure. A prospective study is necessary to validate the FRI. (DOI: 10.3171/2008.5.17560)

KEY WORDS • aneurysmal subarachnoid hemorrhage • discriminant function analysis • external ventricular drain • ventriculoperitoneal shunt

Abbreviations used in this paper: CSF = cerebrospinal fluid; EVD = external ventricular drain; FRI = failure risk index; NICU = neurosurgical intensive care unit; RBC = red blood cell; SAH = subarachnoid hemorrhage; VPS = ventriculoperitoneal shunt; WBC = white blood cell.
Prediction of ventriculoperitoneal shunt dependency

**Data Collection**

Patient demographic data, Fisher grade, Hunt and Hess grade at presentation, aneurysm location, and treatment modalities (including coil embolization and clip placement) were recorded. Computed tomography scans obtained from the GE Lightspeed Ultra CT scanner in 5-mm axial slices were reviewed at admission, and at the onset and at the end of the EVD challenge period. The WBC, RBC, and protein levels in the CSF, as well as serum sodium levels, third ventricular diameter, and bicaudate diameter were recorded at the time of admission and at the start and conclusion of EVD challenge. We also reviewed the number of days spent in the NICU, the total number of days spent in the hospital, and the presence or absence of a craniectomy, CSF infections, and administration of hypertonic saline.

**External Ventricular Drain Challenge Protocol**

At our institution, all patients with SAH undergo a head CT scan upon arrival. Patients with evidence of obstructive hydrocephalus receive immediate insertion of an EVD. The EVD is kept open at 10 cm above the external auditory canal, unless the patient fails to improve clinically with persistent dilation of the ventricular system, in which case the CSF is drained at a lower pressure level. The EVD challenge is initiated when there is a CSF RBC count < 10,000 cells/ml and no evidence of hydrocephalus, CSF leak, or a large bulging subcutaneous CSF collection (particularly in patients with a decompressive craniectomy). After a prechallenge baseline CT scan, the EVD is clamped, the intracranial pressure is monitored, and the patient is examined hourly for clinical neurological change for 48 hours, after which a CT scan is performed. Patients were considered to have an unsuccessful EVD challenge test if they had notably increased headaches that were relieved by unclamping the EVD, CSF leakage from the incision site, decreased level of consciousness, sustained intracranial pressure > 20 cm H2O for at least 30 minutes, or radiographic evidence of increased ventricular size compared with the baseline head CT. Patients who failed the EVD challenge received a VPS. Those who passed the challenge had the EVD removed and were discharged from the NICU if other medical conditions permitted.

**Statistical Analysis**

The parameters reviewed as potential risk factors for EVD challenge failure were statistically analyzed. Parametric variables such as patient age, third ventricular diameter on challenge, hospital days, and CSF protein levels at challenge baseline were reviewed with a 2-sample t-test. Nonparametric variables, including third ventricular diameter on admission, bicaudate diameter on admission, bicaudate diameter on challenge, serum sodium levels on admission, serum sodium levels at the time of challenge, number of days of CSF drainage, CSF RBC and WBC levels, number of days of EVD clamping, number of days in the NICU, Fisher grade, and Hunt and Hess grade were analyzed using the Wilcoxon rank-sum test. Nominal parameters such as sex, presence of CSF infections, location of aneurysm, and treatment modality were analyzed using the chi-square test. A probability value ≤ 0.05 was considered statistically significant. The Hosmer and Lemeshow goodness-of-fit test was used to check the fit of the model.

The patients were divided into the EVD challenge-pass group and the EVD challenge-fail group. Based on the parameters that demonstrated statistical significance, discriminant function analysis was used to create an index of risk of EVD challenge failure (the FRI). The FRI was stratified at 0.5 points segments. A plot of the stratified FRI level versus the percentage of patients who failed their challenge at each particular FRI segment was used to create a linear regression plot. Statistical analysis was performed using SAS statistical software version 9 and SPSS statistical software version 14.

**Results**

**Population Characteristics**

Of 157 patients reviewed, 64% were female and 36% were male. Excluded from the study were 34 patients who did not require EVD placement, 24 patients with EVDs who had no vascular pathologies, and 10 patients who died. Eighty-nine patients had both aneurysmal SAH and required EVD placement. Of these 89 patients, 73% had anterior circulation aneurysms and 27% had posterior circulation aneurysms; 64% of the aneurysms underwent clip placement and 36% underwent coil embolization. Thirty-eight of the 89 patients passed their EVD challenge (the pass group) and 43 patients failed (the fail group), requiring VPS placement. A VPS was placed in 8 patients without a challenge due to poor neurological grade and bulging subcutaneous CSF collections overlying a craniectomy site.

**Prediction of Challenge Failure**

The following variables demonstrated statistically significant differences between the fail and pass groups: mean third ventricular diameter at time of admission (7.0 vs 5.4 mm; p = 0.02); mean third ventricular diameter at time of challenge (6.6 vs 5.2 mm; p = 0.04); mean bicaudate diameter at the time of challenge (31.9 vs 30.2 mm; p = 0.03); mean CSF protein levels at the time of challenge (76.5 vs 40.3 mg/dl; p < 0.0001); mean Hunt and Hess grade at the time of admission (3 vs 2; p = 0.02); sex (63.5% female vs 34.5% male; p = 0.01); and location of the aneurysm (77.3% posterior vs 44.1% anterior circulation location; p = 0.01; Table 1). Additionally, increasing values of each risk factor was associated with greater risk of EVD challenge failure (Fig. 1).

To predict the risk of EVD challenge failure, we combined the data for these parameters and used a discriminant function analysis to calculate a combined FRI value for each patient. The FRI value was calculated as follows:

\[
FRI = -3.589 + 0.074 (TA) - 0.02 (TC) + 0.151 (HH) + 0.011 (CSFP) + 0.042 (BC) + 1.398 (sex) + 0.750 (circulation).
\]

In this formula, TA represents the third ventricular diameter in mm at admission, TC is the third ventricular diam-
TABLE 1: Summary of the statistically significant parameters between the EVD challenge groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>EVD Challenge Group</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean 3rd ventricular diameter on admission (mm)</td>
<td>Failed: 7.0, Passed: 5.4</td>
<td>0.02</td>
</tr>
<tr>
<td>mean 3rd ventricular diameter on challenge (mm)</td>
<td>Failed: 6.6, Passed: 5.2</td>
<td>0.04</td>
</tr>
<tr>
<td>mean bicaudate diameter on challenge (mm)</td>
<td>Failed: 31.9, Passed: 30.2</td>
<td>0.03</td>
</tr>
<tr>
<td>mean CSF protein (mg/dl)</td>
<td>Failed: 76.5, Passed: 40.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>mean Hunt &amp; Hess grade</td>
<td>Failed: 3, Passed: 2</td>
<td>0.02</td>
</tr>
<tr>
<td>sex (%)</td>
<td>Failed: 0.01, Passed: 0.635</td>
<td>0.01</td>
</tr>
<tr>
<td>F</td>
<td>Failed: 63.5, Passed: 36.5</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Failed: 34.5, Passed: 65.5</td>
<td></td>
</tr>
<tr>
<td>circulation (%)</td>
<td>Failed: 0.01, Passed: 0.01</td>
<td></td>
</tr>
<tr>
<td>anterior</td>
<td>Failed: 44.1, Passed: 55.9</td>
<td></td>
</tr>
<tr>
<td>posterior</td>
<td>Failed: 77.3, Passed: 22.7</td>
<td></td>
</tr>
</tbody>
</table>

In mm at the time of challenge, HH is Hunt and Hess grade, CSFP is the CSF protein level at time of challenge in mg/dl, and BC is the bicaudate diameter at the time of challenge in mm. Female sex receives a score of 1 and male sex receives a score of 0. Posterior circulation location of the aneurysm receives a score of 1 and an anterior circulation aneurysm receives a score of 0.

A linear regression analysis between FRI values and the percentage of patients with each FRI value who failed EVD challenge had a correlation coefficient of 91% (Fig. 2); that is, the risk of challenge failure increased linearly with an increasing FRI value.

Discussion

We identified parameters associated with EVD challenge failure. CSF protein level at the time of challenge was the single most predictive factor. Using a discriminant function analysis that combined a number of separate risk factors improved our predictive ability for EVD challenge failure.

In other studies, factors such as advanced age, higher Fisher grade, higher Hunt and Hess grade, presence of acute hydrocephalus, increased CSF drainage time, continuous CSF drainage, and female sex were risk factors for a need for a VPS. Some authors have found endovascular treatment of aneurysms was also strongly associated with VPS requirement, while others have not. Cisternal hemorrhage has been strongly associated with the need for a VPS. The presence of ruptured posterior fossa aneurysms has been associated with the development of hydrocephalus requiring shunts in 28–53% of these patients. Rupture of anterior communicating artery aneurysms has also been associated with an increased permanent shunt requirement.

Our study, like others, demonstrates no effect of CSF RBC levels on EVD challenge failure rates. However, we used a CSF RBC level of 10,000 cells/ml or less as an empirical criterion above which EVD challenge was not attempted. Thus the importance of a very high CSF RBC count cannot be evaluated as we assumed it to be important a priori. Our 56% permanent shunt rate is higher than the results commonly reported in the scientific literature of 8–50%. Because we do not routinely start the EVD challenge in patients who are in the peak vasospasm period or with elevated transcranial Doppler values, our patients may undergo CSF drainage for a longer duration, which may predispose them to chronic hydrocephalus. We also continuously drain CSF, which predisposes patients to shunt-dependent hydrocephalus. Finally, our patients with poorer grades are more likely to require permanent shunts, which is consistent with the findings of other authors.

We did not find an association between CSF infection or CSF WBC counts and risk of shunt dependency. Among patients who failed the EVD challenge, the average CSF WBC count was 113 cells/µl, and among those who were successfully weaned from their EVD the average CSF WBC count was 71 cells/µl (p = 0.59). The number of CSF infections was low, with 3 infections occurring in the challenge-fail group and 2 infections in the challenge-pass group, and therefore we cannot draw strong conclusions in this regard. At least we can say that CSF infection did not uniformly result in shunt dependency. We found a number of new parameters that are associated with an increased risk of EVD challenge failure: 1) third ventricular diameter at the time of admission, 2) third ventricular diameter at the time of EVD challenge, 3) bicaudate ventricular diameter at the time of challenge, 4) CSF protein level at the time of challenge, 5) sex, and 6) aneurysm location. We have no good explanation as to why female sex predisposes one to an increased need for a VPS in our patient population with aneurysmal SAH. We speculate that some anatomical factors, such as a thinner scalp or smaller size of the skull, may change some factors related to the EVD or its tunneling under the scalp. Some of the risk factors may depend on each other; more severe hemorrhage may cause increased Fisher grade, Hunt and Hess grade, and hydrocephalus, whereas hydrocephalus by itself may cause coma and thus increase the Hunt and Hess grade. Analyzing the parameters individually does not account for the complexity of the situation. Our use of the discriminant function analysis allowed us to arrive at a single combined individual risk index, despite contradictory results from individual predictors.

We sought to improve the ability to identify patients who will become shunt dependent. Successful prospective identification may help to avoid the risky EVD challenge procedure in patients with a high risk of failure, shorten the duration of the challenge period in patients with a higher likelihood of passing, reduce the number of days in the NICU and the total cost of hospitalization, and decrease the incidence of CSF infections.

The FRI demonstrated a strong linear correlation with failure of EVD challenge. However, our results should be interpreted with caution. We applied the FRI to the same population from which it was derived. This is an essential step of “postdiction,” meaning that we have found a com-
bined calculated risk index that correlates well with the actual failure rate in our patients. Nonetheless, our study is a positive step toward the development of an objective system of tailored prediction of EVD challenge failure. In the future, it may be possible to calculate an FRI for a prospective patient, plot it on the graph, and determine what his or her individual risk of EVD challenge failure is. The FRI will need prospective validation at multiple institutions.

Conclusions

Discriminant function analysis of multiple clinical
factors allows calculation of a novel FRI that strongly and linearly correlated with the risk of EVD challenge failure. Prospective validation of this method is warranted.

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

References
Prediction of ventriculoperitoneal shunt dependency


Accepted May 8, 2008.

Please include this information when citing this paper: published online October 24, 2008; DOI: 10.3171/2008.5.17560.

Address correspondence to: Ben Z. Roitberg, M.D., University of Illinois at Chicago School of Medicine, Neuropsychiatric Institute (MC799), Department of Neurosurgery, 912 South Wood Street, Chicago, Illinois 60612-7329. email: Roitberg@uic.edu.