Preterm infants are at risk for an extensive array of neurological complications, of which the most commonly observed and severe is intraventricular hemorrhage (IVH). Currently, IVH is seen in approximately 15%–20% of infants with birth weights below 1500 g and in 50% of infants with birth weights less than 750 g. In 25%–50% of cases, progressive posthemorrhagic ventricular dilation and posthemorrhagic hydrocephalus (PHH) develop as a result of IVH. Symptomatic PHH has been associated with poor outcomes, including elevated rates of cognitive deficits, disability, and mortality. Although the incidence rates of IVH have recently begun to decline, there still lacks consensus on the optimal paradigm for treating PHH.

While some cases of PHH can be managed by serial lumbar punctures, many require surgical intervention. Due to the susceptibility of preterm infants to infection and other risks associated with insertion of a permanent ventriculoperitoneal (VP) shunt, a temporary device is of-
The ventricular reservoir requires physicians to remove CSF by reservoir taps to manage PHH; in contrast, the VSGS allows fluid to be continuously redistributed into a subgaleal scalp pocket for resorption and does not require CSF to be repeatedly and manually removed.9,10,16,18,25 The severe neurological complications associated with IVH and PHH and the increasing survival rates of infants with extremely low birth weights necessitate a better understanding of the benefits and disadvantages associated with the reservoir and VSGS. In this study, a retrospective review of preterm infants treated for IVH and PHH at a single institution over a 14-year period was performed. The birth weights, weights at surgery, infection rates, VP shunt rates, and rates of VP shunt infection in infants receiving the reservoir and those treated with VSGS were compared.

Methods

Data Collection and Outcome Measures

A retrospective review of 90 patients who were diagnosed with IVH and PHH at the Johns Hopkins Children’s Center between 1998 and 2011 was conducted. All research protocols were approved by the Johns Hopkins University Institutional Review Board for Human Research. The diagnosis of IVH and PHH was established by cranial ultrasonography. Forty-four patients were treated with a ventricular reservoir and were compared with a cohort of 46 patients treated with a VSGS. The medical records of these patients were reviewed for information on demographics, birth history, IVH Papile grade,19,30 treatment course, rates of positive CSF Gram stain or cultures, rates of hardware infection requiring device removal, rates of device CSF leakage, VP shunt rates, and rates of short-term VP shunt infection (defined as VP shunt infection within 3 months of insertion). Prematurity was defined as an estimated gestational age (EGA) at birth of less than 37 weeks. To verify the presence of hydrocephalus, Evans ratios (maximum ventricular width divided by the maximum biparietal distance) were determined from preoperative ultrasound images. To examine short-term outcomes after temporary device insertion, postoperative images were also evaluated. Due to the lack of electronic records, imaging was unavailable for patients treated with the reservoir.

Treatment Techniques

In the 44 patients who underwent reservoir placement, a Medtronic CSF-Neonate reservoir, 10 mm, with integrated 3- to 4-cm right angle ventricular catheter was inserted in the right frontal region, adjacent to the anterior fontanelle, through a curvilinear incision. Patients who subsequently presented with signs of increased intracranial pressure (ICP), such as vital sign instability, rapid increase in head circumference, or increase in ventricular size by ultrasound, underwent reservoir tapping for a goal volume of 10 ml/kg. For the 46 patients who underwent VSGS insertion, a large subgaleal pocket was created adjacent to the neonatal reservoir. The dome of the reservoir had cross-hair slits cut into it to allow for CSF egress. In 35 VSGS patients, in an attempt to reduce the risk of scarring in the pocket, a 4- to 5-cm diameter sterile plastic sheath was placed within the pocket and secured to the reservoir and pericranium with sutures. The material for the sheath was either from Gore PRECLUDE Dura Substitute (W.L. Gore & Associates, Inc.) or cut away from a sterile intravenous saline bag. CSF was analyzed for cell count, protein, glucose, and bacterial culture after each reservoir tap. In cases of CSF culture positivity, infants were treated with intravenous antibiotics initially, and the device was removed based on bacterial clearance and/or surgeon preference. Minimal criteria for insertion of a VP shunt were progressive ventricular dilation, rapid increase in head circumference, and weight greater than 2 kg. The reservoirs were removed at the time of shunt insertion.

Data Analysis

Comparisons of patient demographics and outcomes data between the reservoir and VSGS groups were performed using Pearson’s chi-square test or Fisher’s exact test and the Student t-test for parametric data. Kaplan-Meier survival analysis was used to determine the cumulative probability of VP shunt insertion after initial device insertion and the probability of VP shunt revision after shunt placement. Cox proportional hazards regression analysis was used to identify factors influencing time to VP shunt insertion and factors predicting VP shunt revision. Hazard ratios were calculated with 95% CIs. Statistical significance was defined as p < 0.05. All statistical analyses were performed using Stata/IC 12 (StataCorp LP).

Results

Patient Population

Ninety pediatric patients were diagnosed with PHH and were initially treated with a temporizing device (Table 1). The mean EGA at birth was 26.5 ± 2.1 weeks (± SD; range 23–31 weeks), and the mean birth weight was 925 ± 291 g (range 390–1798 g). All 90 patients were premature, and most presented with several comorbidities, including congenital heart disease (patent ductus arteriosus, ventral septal defects, and atrial septal defects), respiratory distress syndrome, anemia, chronic lung disease, tracheo-esophageal fistulas, hyperbilirubinemia, and sepsis. There was a high representation of African American infants, at 53.3%. There was equal representation of both sexes; 42 patients were male (46.7%), and 48 were female (53.3%). Forty-six patients (51.7%) had Grade III IVHs, and 43 (48.3%) had Grade IV IVHs; the IVH grade was unavailable in 1 patient.
Ventricular reservoir versus VSG shunt for PHH

The mean follow-up time was 40.8 ± 30.8 months (range 2.7–136.7 months). Preoperative Evans ratios were calculated for those patients with adequate imaging for review; the mean ratio for the VSGS patients (n = 44; data for 2 patients were unavailable) was 0.58 ± 0.08 (range 0.43–0.80), confirming the presence of pronounced ventriculomegaly in all patients treated with the VSGS.

The ventricular reservoir was the predominant device inserted early during the study period (1998–2007), while the VSGS was predominant later (2007–2011). In 2007, there was a uniform agreement among the neurosurgeons to switch to the VSGS due to its theorized benefits. In comparing the 2 patient populations, the 46 patients who underwent VSGS placement had a significantly lower mean EGA at birth compared with the 44 patients in the reservoir cohort, at the time of device insertion, VSGS patients had a significantly higher mean birth weight compared with reservoir patients (reservoir, 0.99 ± 0.27 kg; VSGS, 1.12 ± 0.37 kg; p = 0.004) (Table 2). There were no significant differences in the distribution of IVH grades among the reservoir and VSGS patients. Four (9.1%) of the reservoir patients and 2 (4.5%) VSGS patients died during their initial hospital stay. No patients in either group died during the course of follow-up after discharge. Of the reservoir patients, 2 patients died of respiratory failure and 1 patient died of liver failure; the cause of death for 1 patient was multifactorial. The 2 VSGS patients died due to respiratory failure.

### TABLE 1: Patient demographics and characteristics*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>male sex</td>
<td>42 (46.7)</td>
</tr>
<tr>
<td>mean gestational age at birth in wks</td>
<td>26.5 ± 2.1</td>
</tr>
<tr>
<td>mean birth weight in kg</td>
<td>0.93 ± 0.29</td>
</tr>
<tr>
<td>ethnicity</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>38 (42.2)</td>
</tr>
<tr>
<td>African American</td>
<td>48 (53.3)</td>
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<tr>
<td>other</td>
<td>4 (4.4)</td>
</tr>
<tr>
<td>IVH grade†</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>46 (51.7)</td>
</tr>
<tr>
<td>IV</td>
<td>43 (48.3)</td>
</tr>
<tr>
<td>Evans ratio‡</td>
<td>0.58 ± 0.08</td>
</tr>
</tbody>
</table>

* Values represent the number of patients (%); mean values are presented with SD.
† Papile grades are presented. The grade was unavailable for 1 patient.
‡ Evans ratios are calculated for VSGS patients (n = 44; data for 2 patients were unavailable).

### TABLE 2: Patient clinical characteristics by device type*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reservoir (n = 44)</th>
<th>VSGS (n = 46)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>birth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean gestational age in wks</td>
<td>27.1 ± 2.0</td>
<td>26.0 ± 2.1</td>
<td>0.014</td>
</tr>
<tr>
<td>mean weight in kg</td>
<td>0.99 ± 0.27</td>
<td>0.86 ± 0.30</td>
<td>0.037</td>
</tr>
<tr>
<td>mean length of initial stay in days</td>
<td>81.7 ± 50.5</td>
<td>80.9 ± 53.1</td>
<td>0.94</td>
</tr>
<tr>
<td>temporary device insertion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean gestational age in wks</td>
<td>31.8 ± 2.9</td>
<td>30.1 ± 1.9</td>
<td>0.002</td>
</tr>
<tr>
<td>mean weight in kg</td>
<td>1.33 ± 0.37</td>
<td>1.12 ± 0.31</td>
<td>0.004</td>
</tr>
<tr>
<td>IVH Grade III†</td>
<td>23 (52.3)</td>
<td>23 (51.1)</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>IVH Grade IV†</td>
<td>21 (47.7)</td>
<td>22 (48.9)</td>
<td>&gt;0.99</td>
</tr>
</tbody>
</table>

* Values represent the number of patients (%); mean values are presented with SD.
† Papile grades are presented.

### Device Outcomes

After insertion of their respective devices, patients who received the reservoir required a significantly greater number of reservoir taps for PHH management compared with the VSGS patients (reservoir, 10 ± 8.7 taps; VSGS, 1.6 ± 1.7 taps; p < 0.001). Of the VSGS patients, 16 (34.8%) required at least 1 tap while 30 (65.2%) did not require any. Reservoir patients experienced higher, though not statistically significant, rates of CSF culture positivity, with 9 reservoir patients (20.5%) compared with 5 VSGS patients (10.9%) (p = 0.21) (Table 3). CSF culture positivity was associated with higher rates of tapping in both groups; in reservoir patients, those who developed positive cultures experienced on average 19.3 ± 3.6 taps compared with 7.3 ± 0.9 taps in patients who did not develop positive cultures (p < 0.001). In VSGS patients, those with positive cultures underwent 4.0 ± 0.3 taps compared with 1.2 ± 0.2 taps (p < 0.001). Upon detection of device infection, the patients were treated with intravenous antibiotics with or without immediate device removal. The rates of device infection treated by immediate removal were comparable between the 2 groups (reservoir, n = 3 [6.8%]; VSGS, n = 3 [6.5%]; p = 0.96).

During follow-up, 4 VSGS patients (8.7%) developed porencephalic cysts along the ventricular catheter (Fig. 1). These cysts resolved for those patients who underwent VSGS removal and insertion of a VP shunt. None of these patients developed clinically significant signs or symptoms related to the porencephalic cysts. Additionally, of the VSGS patients, 3 patients (6.5%) developed CSF leaks. These patients were managed with device removal and ventricular tapping; 1 patient underwent VSGS replacement and 2 patients eventually underwent VP shunt placement (Table 3). Imaging information for patients treated with the reservoir was incomplete due to the unavailability of imaging studies for review, and rates of cyst formation and CSF leaks could not be determined.

### VP Shunt Outcomes

Of the patients who underwent reservoir placement,
34 (77.3%) underwent removal of the reservoir and replacement with a VP shunt compared with 35 VSGS patients (76.1%); there was no significant difference in VP shunt insertion rates (p = 0.89). However, the patients who were previously treated with the reservoir underwent permanent shunting at significantly lower weights compared with the VSGS patients (reservoir, 2.42 ± 0.63 kg; VSGS, 3.31 ± 2.0 kg; p = 0.016). No significant difference in EGAs at the time of VP shunt insertion was detected (reservoir, 38.6 ± 4.3 weeks; VSGS, 41.6 ± 9.6 weeks; p = 0.10), although a trend toward lower EGAs in the reservoir patients was noted. The reservoir and VSGS patients also experienced an equivalent rate of short-term VP shunt infections within 3 months of insertion (reservoir, n = 5 [11.4%]; VSGS, n = 6 [13.0%]; p = 0.78) (Table 4).

The cumulative rate of VP shunt insertion for the reservoir patients was 15.9% at 1 month after reservoir placement, 56.8% at 2 months, and 78.0% at 5 months. For the VSGS patients, the rate of permanent shunting was 10.9% at 1 month, 43.5% at 2 months, and 67.4% at 5 months (Fig. 2). The type of device did not significantly influence the cumulative risk of VP shunt insertion with the Cox proportional hazards model (HR 0.74 [95% Cl 0.46–1.19], p = 0.22). However, within the subset of patients who underwent permanent shunting, the time to shunt insertion was significantly longer for the VSGS patients compared with the reservoir patients (VSGS, 80.8 ± 67.5 days; reservoir, 48.8 ± 26.4 days; p = 0.012) (Table 4). The cumulative rate of VP shunt revision-free survival for the reservoir patients was 78.2% at 3 months, 75.1% at 6 months, and 71.8% at 9 months and 12 months. For the VSGS patients, the revision-free survival rate was 76.7% at 3 months, 70.5% at 6 months, 67.5% at 9 months, and 64.2% at 12 months (Fig. 3). The type of temporizing device did not significantly influence the cumulative risk of VP shunt revision (HR 1.33 [95% Cl 0.57–3.13], p = 0.50).

Discussion

Posthemorrhagic hydrocephalus is a potentially devastating complication of IVH; however, the optimal management plan and timing of treatment for patients with PHH remains unclear. While previous studies have demonstrated the advantages of placing a temporizing device rather than symptomatic management with serial ventricular taps before permanent VP shunt insertion, guidelines for the use of these devices have not been created. The 2 mainstays are the ventricular reservoir and VSGS, which were compared in this study with respect to short-term outcomes including device infection and VP shunt insertion rates and timing.

Infection Risks

Within our patient population, the reservoir and VSGS cohorts were significantly different at baseline, with VSGS patients born at significantly younger EGAs and weights compared with the reservoir patients. This difference can be explained by the 2 different time periods during which the devices were used. The VSGS cohort, from the later time period, represents infants who were born more prematurely, yet were viable for surgical intervention due to improved overall survival of infants born at younger EGAs with time. Given this difference, one may expect that the more prematurely born VSGS patients would be more prone toward device infection with less developed immune systems. On the other hand, the reservoir group may be considered more prone to infection with the routine requirement for tapping and contamination risks.

The VSGS patients underwent fewer ventricular taps and demonstrated a trend toward fewer positive CSF cultures after insertion of the temporary device. Previous studies have not found an association between the type of device used and infection rates; however, these reports combine positive CSF cultures and positive device cultures in one outcome measure and do not separately examine incidences of positive CSF cultures and overt device infection requiring removal. Despite trends in CSP culture positivity, there were no differences in the rates of device removal between the reservoir and VSGS patients. Consequently, there were reservoir patients with positive CSF cultures who were treated without readily removing the device compared with VSGS patients, which may have reflected different practice patterns between the
Ventricular reservoir versus VSG shunt for PHH

2 time periods. While the increased incidence of culture positivity in the reservoir patients did not lead to device removal in all patients, these infants experienced meningitis, which, even in the absence of sepsis, has been associated with greater morbidity, mortality, and poorer neurodevelopmental outcomes at 2 years.1,24 In addition, CSF culture positivity was treated with long-term intravenous antibiotics, which could increase the risk of further morbidity for these infants.

Compared with reservoir patients, those treated with the VSGS experienced significantly fewer ventricular taps. While one of the advantages of the VSGS is its ability to continuously divert CSF, resulting in fewer fluctuations in ICP, the proposed advantage to ventricular tapping is the removal and rapid clearance of blood products and other metabolites.21,33 However, the infection risks associated with repeated ventricular taps may explain why reservoir patients in our series experienced higher rates of CSF culture positivity. Although Kormanik et al.11 did not find an association between frequent ventricular tapping and reservoir infection, their outcome measure was blood culture–proven sepsis. In our cohort, the 9 reservoir patients who went on to develop positive CSF cultures all underwent at least 1 prior ventricular tap for PHH management, and all 5 VSGS patients who developed overt device infection required ventricular taps. Additionally, CSF culture positivity was associated with higher rates of tapping in our cohort, which may suggest an increased risk of infection with recurrent ventricular access or could reflect a higher probability of culture contamination from a higher sampling rate.

VP Shunting Rates

While temporizing devices and VP shunts share the risks of infection, revisions, occlusion, and skin breakdown, placement of a VP shunt commonly results in long-term shunt dependency.3,4,22 Within our cohort, there was no significant difference in the rates of VP shunting between temporizing device groups, with 77% of reservoir patients and 76% of VSGS patients eventually receiving VP shunts. In addition, the Cox proportional hazards model found a comparable cumulative incidence of VP shunt placement between the reservoir and VSGS groups. Two other reports have also demonstrated a higher, but not statistically significant, rate of permanent shunting in VSGS patients. Limbrick et al.13 noted shunt rates of 75.4% in reservoir patients and 66.7% in VSGS patients. Lam and Heilman12 found that 93.75% of their reservoir patients had VP shunts placed, compared with 71.4% of VSGS patients. However, a multicenter study by Wellons et al.31 found significantly lower rates of permanent shunting in their reservoir patients (69% in reservoir patients vs 86% in VSGS patients). This discrepancy may be in part due to physician preference with respect to the timing of VP shunt insertion and indications for permanent shunting. Within our cohort, the decision to place a VP shunt

![Fig. 2. Kaplan-Meier estimate of cumulative probability of VP shunt insertion by temporizing device. Time to VP shunt placement from insertion of the temporizing device (in months) for patients who were treated with the reservoir (n = 44) and with the VSGS (n = 46) is displayed. There was no significant difference in cumulative permanent shunt rates (HR 0.74 [95% CI 0.46–1.19], p = 0.22).](image)

![Fig. 3. Kaplan-Meier estimate of cumulative probability of VP shunt revision-free survival by temporizing device. Time to shunt revision from insertion of the VP shunt (in months) for patients who were treated with the reservoir (n = 34) and with the VSGS (n = 35) who ultimately underwent permanent shunting is displayed. There was no significant difference in shunt revision rates by temporizing device (HR 1.33 [95% CI 0.57–3.13], p = 0.50).](image)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reservoir (n = 44)</th>
<th>VSGS (n = 46)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP shunt insertion</td>
<td>34 (77.3)</td>
<td>35 (76.1)</td>
<td>0.89</td>
</tr>
<tr>
<td>time from temporary device to VP shunt in days†</td>
<td>48.8 ± 26.4</td>
<td>80.8 ± 67.5</td>
<td>0.012</td>
</tr>
<tr>
<td>values at VP shunt insertion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean gestational age in wks</td>
<td>38.6 ± 4.3</td>
<td>41.6 ± 9.6</td>
<td>0.10</td>
</tr>
<tr>
<td>mean weight in kg</td>
<td>2.42 ± 0.63</td>
<td>3.31 ± 2.0</td>
<td>0.016</td>
</tr>
<tr>
<td>short-term VP shunt infection</td>
<td>5 (11.4)</td>
<td>6 (13.0)</td>
<td>0.78</td>
</tr>
</tbody>
</table>

* Values represent the number of patients (%); mean values are presented with SD.
† Patients who did not undergo VP shunt insertion were not included in the time from ventricular reservoir to VP shunt insertion calculation.

Table 4: VP shunt outcomes

J Neurosurg: Pediatrics / Volume 14 / November 2014
shunt was often made when patients achieved a certain goal weight (>2000 g) in conjunction with other clinical indications of raised ICP, such as progressive ventriculomegaly on ultrasound, rapid increases in head circumference, or vital sign instability.

Although the majority of patients who receive temporizing devices appear to eventually require a VP shunt regardless of the type of temporizing device, the clinical status of the patient at the time of VP shunt placement is an important consideration. Several studies have demonstrated the benefits of delaying VP shunting; namely, higher rates of infection are seen in patients who undergo earlier shunting.8,21,25,33 In our cohort, there was a significant difference in the time from temporary device insertion to VP shunt placement, with VSGS patients undergoing permanent shunting after longer periods of time. Correspondingly, there was a significantly higher mean weight at VP shunt placement in VSGS patients compared with reservoir patients. There was a trend toward greater EGAs at the time of permanent shunting. We did note a discrepancy between EGA and weight, which may have been due to the differences between the subgroups with respect to both parameters at birth. Patients treated with the VSGS may have been afforded more time to catch up with the reservoir patients with respect to age at VP shunt insertion, while their rate of weight gain may have outpaced that of the reservoir patients. There were no differences in the rates of VP shunt infection in the 3-month period immediately following shunt insertion, consistent with previous studies demonstrating comparable infection rates between groups at 6 months postshunt.13,31

Specific Benefits and Risks of the VSGS

The choice of the ventricular reservoir or the VSGS as a temporizing device may have less of an impact on long-term neurodevelopmental outcomes compared with other factors such as patient comorbidities and general health status.21 However, in these premature infants, optimizing all aspects of their treatment and management is important. In our cohort, VSGS patients required fewer ventricular taps and experienced lower, though not reaching statistical significance, rates of CSF culture positivity. Dependence on tapping in reservoir patients can be an ineffective way of managing hydrocephalus due to variance in the amount of CSF removed.2,21 Maertzdorf et al.14 demonstrated that interventions with pretap ICP of less than 6 cm H2O or posttap ICPs of greater than 7 cm H2O do not positively impact cerebral blood flow. Due to the effectiveness of temporary CSF diversion, our VSGS patients also were able to delay VP shunt placement for a longer period of time, corresponding to significantly greater weights in the VSGS group compared with the reservoir group at the time of permanent shunting. Our data suggest that the VSGS offers specific advantages in management compared with the reservoir, of which the impact on long-term patient prognosis remains to be investigated.

In this series, the likely reason why VSGS patients were able to attain greater weights and EGA prior to shunt insertion was the ability to sufficiently divert CSF into large subgaleal pockets for extended periods of time. In the Columbus Children’s experience of VSGS placed in the neonatal ICU, 2 of 17 patients required revisions of the subgaleal pocket that had scarred down.30 In an attempt to prevent the scalp from scarring down, we began to insert a sheath in the pocket to maintain its patency. As a result, none of the 35 patients with the sheath required revisions of the pocket. We did not encounter any complications directly related to this extra element of hardware. The overt device infection rate was similar to the ventricular reservoir group. We found that the durability of the subgaleal pocket was useful in that infants could potentially be quickly transferred back to referring hospitals or subacute facilities because a pediatric neurosurgery service is not needed perform a tap for CSF removal. However, as we found no differences in length of stay between our 2 treatment groups, this potential for transfer was not yet borne out in our study population.

As no guidelines currently exist for the nature and timing of surgical intervention in PHH, many of these decisions ultimately depend on clinical judgment. One of the major limitations of our study is its retrospective nature and the fact that surgeon preference may influence our outcome measures. For example, the desire to curtail the need for further tapping may have impacted the time to permanent shunt insertion in our reservoir patients. Despite this fact, the finding that VP shunting can be delayed to allow patients to become more optimal surgical candidates in our VSGS group is a noteworthy feature of the VSGS that has improved practice at our institution.

The VSGS, however, is associated with certain complications more than the ventricular reservoir. The risk of CSF leak is greater in these infants due to the large subgaleal collections. In our series, 6.5% of infants developed leaks, which is similar to that reported in other series.9,20,28 We make a continual effort to reduce the incidence of leaks even further with such measures as emptying the subgaleal pocket prior to scalp closure, meticulous watertight skin closure, and avoidance of pressure on wounds by hats or respiratory devices.

On follow-up imaging, 8.7% of VSGS patients developed porencephalic cysts adjacent to the device catheters. Although follow-up imaging was not available for all reservoir patients in the comparison cohort, this finding seems to be particular to the VSGS. The significance of these cysts is unknown, but they may represent extraventricular CSF collections related to subgaleal fluid. These cysts resolved with VP shunting but remained in those infants who did not have VP shunts inserted. They were not associated with any neurological deficit. Further study is required to determine which of the VSGS infants are prone to developing these cysts.

Study Limitations

As a single-institution retrospective work, this study has several limitations. The 90 patients in our cohort were treated by 3 different neurosurgeons, which may have resulted in selection bias in treatment and management. In addition, our 2 subgroups, the reservoir patients and VSGS patients, were not matched at baseline with respect to EGA and weight at birth and at temporary device insertion, which allows for potential confounders in comparing outcome measures. The patients treated with the reservoir
also had incomplete follow-up data and imaging. Inherent in this study is the fact that there are few guidelines for the timing of temporizing device placement and VP shunt insertion, further complicating comparisons made between our subgroups and between our results and those from previous studies.

Finally, the majority of our patient population is currently being monitored, and long-term neurodevelopmental outcomes are not yet assessable. Currently, the Hydrocephalus Clinical Research Network (HCRN) is undertaking the Shunting Outcomes in Post-Hemorrhagic Hydrocephalus (SOPHH) trial to compare the reservoir and VSGS with respect to both short-term and long-term outcomes. Our results reaffirm the need for a multicenter prospective study comparing the reservoir and the VSGS to further elucidate the advantages and disadvantages of both procedures.

Conclusions

The optimal management plan for PHH with respect to the use of the ventricular reservoir versus the VSGS as temporizing devices remains unclear. In the current study, patients treated with the VSGS required less invasive management by manual CSF removal. VSGS patients also experienced longer times to VP shunt insertion compared with reservoir patients, corresponding to VSGS patients attaining higher goal weights prior to permanent shunting. These findings suggest that the VSGS may result in more optimal short-term management and outcomes compared with the reservoir. In the future, a randomized controlled trial comparing the VSGS and the reservoir with respect to short-term and long-term developmental and neurological outcomes will be important to sufficiently compare these 2 devices.

Acknowledgment

We would like to thank Dr. Faisal Almayman for his assistance in radiographic data collection.

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: Ahn. Acquisition of data: Wang, Amin. Analysis and interpretation of data: Ahn, Wang, Amin. Drafting the article: Wang. Critically revising the article: Ahn. Reviewed submitted version of manuscript: Ahn, Amin, Jallo. Approved the final version of the manuscript on behalf of all authors: Ahn. Statistical analysis: Wang, Amin. Administrative/technical/material support: Ahn. Study supervision: Ahn.

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