Cost-consequence analysis of antibiotic-impregnated shunts and external ventricular drains in hydrocephalus

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OBJECT Despite multiple preventive strategies for reducing infection, up to 15% of patients with shunt catheters and 27% of patients with external ventricular drains (EVDs) may develop an infection. There are few data on the cost-effectiveness of measures to prevent hydrocephalus catheter infection from the hospital perspective. The objective of this study was to perform a cost-consequence analysis to assess the potential clinical and economic value of antibiotic-impregnated catheter (AIC) shunts and EVDs compared with non-AIC shunts and EVDs in the treatment of hydrocephalus from a hospital perspective.

METHODS The authors used decision analytical techniques to assess the clinical and economic consequences of using antibiotic-impregnated shunts and EVDs from a hospital perspective. Model inputs were derived from the published, peer-reviewed literature. Clinical studies comparing infection rates and the clinical and economic impact of infections associated with the use of AICs and standard catheters (non-AICs) were evaluated. Outcomes assessed included infections, deaths due to infection, surgeries due to infection, and cost associated with shunt- and EVD-related infection. A subanalysis using only AIC shunt and EVD Level I evidence (randomized controlled trial results) was conducted as an alternate to the cumulative analysis of all of the AIC versus non-AIC studies (13 of the 14 shunt studies and 4 of the 6 EVD studies identified were observational). Sensitivity analyses were conducted to determine how changes in the values of uncertain parameters affected the results of the model.

RESULTS In 100 patients requiring shunts, AICs may be associated with 0.5 fewer deaths, 71 fewer hospital days, 11 fewer surgeries, and $128,228 of net savings in hospital costs due to decreased infection. Results of the subanalysis showed that AICs may be associated with 1.9 fewer deaths, 1611 fewer hospital days, 25 fewer surgeries, and $346,616 of net savings in hospital costs due to decreased infection. The rate of decrease in infection with AIC shunts was shown to have the greatest impact on the cost savings realized with use of AIC shunts.

In 100 patients requiring EVDs, AICs may be associated with 2.7 fewer deaths and 82 fewer hospital days due to infection. The relative risk of more severe neurological impairment was estimated to be 5.33 times greater with EVD infection. Decreases in infection with AIC EVDs resulted in an estimated $264,069 of net savings per 100 patients treated with AICs. Results of the subanalysis showed that AIC EVDs may be associated with 1.0 fewer deaths, 31 infection-related hospital days averted, and $74,631 saved per 100 patients treated with AIC EVDs. As was seen with AIC shunts, the rate of decrease in infection with AIC EVDs was shown to have the greatest impact on the cost savings realized with use of AIC EVDs.

CONCLUSIONS The current value analysis demonstrates that evidence supports the use of AICs as effective and potentially cost-saving treatment.

KEY WORDS antibiotic-impregnated; cost-consequence; cost-effectiveness; external ventricular drains; hydrocephalus; shunts
HYDROCEPHALUS is the pathological accumulation of CSF in the cerebral ventricles and is caused by a variety of factors such as intrauterine infection, meningitis, hemorrhage, and tumors.16 Surgical insertion of a catheter to reduce and control intracranial pressure is the standard treatment for hydrocephalus. Surgery for CSF catheter placement or revision is associated with a risk of complications due primarily to mechanical issues and infection. Other possible adverse events include intraabdominal complications, intracerebral hemorrhage, and perioperative epilepsy. Infection from bacterial contamination can lead to shunt failure and serious complications, including reduced intelligence quotient and psychomotor retardation in children and meningitis, endocarditis, and prolonged hospitalization in adults.36

Despite multiple preventive strategies for reducing infection, up to 15% of patients with shunt catheters34 and up to 27% of patients with external ventricular drains (EVDs) may develop an infection.37 These patients face twice the risk of mortality3 and 3 times the number of shunt-related operations.30 The average cost of a CSF catheter–related infection in the US is estimated to be approximately $50,000.3,11,20,25 Even when infections are successfully treated, long-term morbidities, including seizures, cognitive deficits, and psychomotor retardation, can develop.35

Mounting evidence suggests that the use of antimicrobial-impregnated shunt and EVD catheters may help minimize infection rates in hydrocephalus treatment. Antimicrobial impregnated catheter silicone material is impregnated with the antibiotics rifampin and clindamycin (BACTISEAL, DePuy Synthes). These antibiotics release slowly and uniformly from the exterior and interior lumens surfaces of the catheter, reducing gram-positive bacterial colonization for up to 50 days.4 The very low infection rate associated with such catheters in rigorously controlled clinical trials has been shown to translate to routine clinical practice.31

In the current climate of tighter budgets and stricter management guidelines, it is important for hospitals to assess both the clinical and economic value of medical technologies. Conducting cost-effectiveness analyses helps hospital decision makers to make the proper trade-offs in a period of financial constraints and need for optimal resource allocation.6 There are few data on the cost-effectiveness of measures to prevent hydrocephalus catheter infection from the hospital perspective; thus, further high-quality cost-effectiveness assessment is needed to facilitate this decision-making process.

In 2011, Klimo et al.19 conducted a meta-analysis assessing the extent to which antibiotic-impregnated catheter (AIC) shunts reduced the rate of infection compared with standard shunts and estimated the degree to which AIC shunts could decrease infection-related hospital expenses on a national level. The objective of the current analysis was to perform a broader cost-consequence analysis of the use of AIC shunts as well as AIC EVDs compared with non-AIC shunts and EVDs from a hospital perspective using recently published clinical data and cost inputs. Outcomes evaluated include infections, deaths due to infection, surgeries due to infection, and costs associated with shunt- and EVD-related infection.

Methods
Overall Approach

Decision analytical modeling was the approach used in this cost-consequence evaluation. A decision analytical model is a structured representation of real-world health care activities and is used to predict the clinical and economic outcomes that are expected to result with adoption of an intervention. Decision analytical models bring together knowledge from a variety of sources (such as clinical trials, databases, and costs) when adequate experimental and/or long-term data are not available. A decision analysis involves selecting appropriate comparators, creating a decision tree structure modeling the clinical pathways, determining what payoffs or clinical and economic outputs to assess, populating the model with appropriate clinical and economic inputs (event probabilities, resource utilization, and costs), and running the analysis.

Target Audience, Perspective, Comparators, and Outcomes Evaluated

The target audience is US health care decision makers in the hospital setting; thus, a hospital perspective was adopted for this analysis. The time horizon (the analytical horizon that would adequately capture relevant outcomes) was set at 18 months, based on the length of follow-up for the studies evaluating the burden of catheter infection. Clinical outcomes considered included infections, deaths, and surgeries. Only the costs of catheters and infections were included in the economic analysis because these were the only outcomes where differences in costs were expected between AICs and non-AICs. The target patient population includes all inpatients requiring shunt and EVD catheters. The comparators in the evaluation were AIC versus non-AIC shunts and AIC versus non-AIC EVDs. Five separate outcomes were evaluated and compared between treatment arms: number of infections, number of deaths due to infection, number of days of hospitalization due to infection, number of surgeries due to infection, and cost of infection.

Data Sources for Populating the Model

The clinical and economic data used to populate the decision analytical model were obtained from the published literature. A search of peer-reviewed literature was conducted using the MEDLINE (PubMed) database. Clinical studies comparing infection rates and the economic impact associated with the use of AICs and standard non-AICs were evaluated. The results of the analyses were presented separately for shunt and EVD catheters.

Clinical Inputs

A published meta-analysis by Parker et al.22 was used as the foundation of clinical evidence for shunt catheters. A search for studies published since May 2010 (the end search date of the meta-analysis) was performed using the same search terms used by Parker et al. [“(shunt” OR “hydrocephalus”) AND (“infection” OR “antibiotic-impregnated” OR “AIS” (antibiotic-impregnated shunt OR “Bactiseal”))] to update the search. Reference lists of identified articles were reviewed to capture any additional
Economic Inputs
Costs of shunts, EVDs, and infection were included in the analysis. All costs are presented in US dollars. The cost of AIC shunts or EVDs was estimated from a study by Farber et al.,\textsuperscript{11} which estimated that the incremental cost of AIC versus non-AIC catheters was $400. Cost of shunt catheter infections was obtained from a pooled estimate of cases evaluated in studies by Attenello et al.\textsuperscript{3} and Farber et al.\textsuperscript{11} (pooled estimated cost of shunt infection was $46,394). The cost of an EVD catheter infection was obtained from a single published study by Lyke et al.,\textsuperscript{20} which estimated it to be $30,335. The study estimates of cost of infection were not inflated to present-day dollars in an effort to be more conservative in assessing the cost savings resulting from AICs.

Cost-Consequence Analysis
A cost-consequence analysis requires an estimation of the costs as well as the health consequences associated with one intervention compared with an alternative intervention for a health condition. The key distinguishing feature of a cost-consequence analysis is the presentation of the results in a simple, disaggregated format. The goal of the cost-consequence analysis is to give the decision maker as broad a view as possible of the consequences of the alternative interventions.

All pertinent clinical and economic information from the articles obtained through the literature review was extracted and summarized. This included the number of catheters in each arm of the study, the study design, the number of infections, the number of deaths due to infection, the number of days of hospitalization due to infection, and the number of surgeries due to infection with AIC and non-AICs.

A rate of infection was calculated for AIC and non-AIC patients in each study, and the relative decrease in infection with AICs was calculated from the 2 rates for each study. The total number of infections was calculated for AICs and non-AICs, and an overall rate of infection for AICs and non-AICs and an overall rate of decrease in infection with AICs were calculated by weighting each study by the number of catheters evaluated. Overall numbers of deaths due to infection, days of hospitalization due to infection, and number of surgeries due to infection were similarly calculated for AICs and non-AICs, and the deaths, hospital days, and surgeries averted with AICs were derived. The costs per infection from the published literature and the incremental cost of an AIC were used to estimate the overall cost per treatment arm and then the net cost savings that might result from use of AICs.

Subanalysis
The majority of the studies evaluating AICs are observational. According to the Center for Evidence-Based Medicine, Level I evidence requires prospective, randomized, controlled, blinded trials with clearly defined primary outcomes and inclusion/exclusion criteria.\textsuperscript{7} A subanalysis using only AIC shunt and EVD Level I evidence (randomized controlled trial results) was conducted as an alternate to the cumulative analysis of all of the AIC versus non-AIC studies.

Sensitivity and Threshold Analyses
Because the model contained a number of assumptions, it was necessary to conduct sensitivity analyses to determine how changes in the values of uncertain parameters affected the results of the model. The following clinical parameters were tested to measure the robustness of the model and to determine the importance of the individual parameters in model results: percent decrease in rate of infection with AIC shunt and EVD catheters, incremental cost of AIC shunt and EVDs, and cost of a shunt and EVD infections.

The sensitivity analyses were presented as tornado diagrams to illustrate the relative impact of the various model inputs. Threshold analyses were also conducted to determine the value of the above variables at which the impact of non-AICs was cost neutral (i.e., the value at which the cost savings due to averted infections was equal to the incremental cost of using AIC catheters).

Results
Shunt Catheters
Fourteen studies evaluating AIC versus non-AIC shunts in the treatment of hydrocephalus were identified. Thirteen of the studies were observational (9 retrospective and 4 prospective) and did not adjust for confounders, and one study was a randomized controlled trial (RCT). Across the uncontrolled observational studies, demographics, etiology of hydrocephalus, and type of shunt surgery were similar between groups of patients treated with AIC and standard non-AIC shunts. Aggregated results showed an overall decrease in infection of 50.3% with the use of AIC shunt catheters. All shunt studies compared BACTISEAL shunt catheters to standard non-AICs. Table 1 presents the findings of the literature review for studies evaluating pediatric patients, adult patients, and pediatric and adult patients combined.

Twelve of 14 studies of AIC shunts demonstrated a decrease in infection rates. Only 2 of 14 AIC shunt studies did not show a significant decrease in the rate of infection with use of AICs. A greater decrease in the rate of infection was seen with adult patients compared with pediatric patients (83.9% vs 42.5% for pediatric patients).
Five of the studies evaluating shunts also reported rates of mortality due to infection for AIC and non-AIC shunts,1,9,12,24,28 and 2 studies reported the number of hospital days and the number of surgeries from infection for AIC and non-AIC shunts.3,11 Overall rates of mortality, days of hospitalization, and number of surgeries were calculated by weighting these studies’ rates by the number of shunts evaluated, and then multiplying these weighted rates by the rate of infection for AIC and non-AIC shunts.

Figure 1 depicts the clinical and economic consequences and the net effects that may be associated with the use of non-AIC or AIC shunts in 100 patients requiring shunts for hydrocephalus. Results of the modeling evaluation estimated that 7.2 infections would be experienced per 100 patients with non-AICs. This number would be halved if AICs were used instead of non-AICs in the 100 patients. The clinical consequences of these fewer infections would be lower mortality (0.5 deaths averted), decreases in infection-related hospital days (71 hospital days averted), decreases in surgeries (11 surgeries averted), and decreases in cost with the use of AIC shunts instead of non-AIC shunts ($128,228 saved per 100 patients treated with AICs).

A subanalysis using Level I evidence for shunts was performed using only the data from Govender et al.12 The infection rates seen in this RCT were higher than the infection rates seen in the observational shunt AIC studies. This may be due to enhanced monitoring for infection that may occur with an RCT. The relative rate of infection between AIC and non-AIC groups in this study was very similar to the relative rate of infection seen with the observational trials. Results of the subanalysis showed that 13.3 infections would be experienced per 100 patients with non-AIC shunts and 5.0 infections would be experienced per 100 patients with AIC shunts (8.3 infections averted per 100 patients with AIC shunts). The clinical consequences of these fewer infections would be 1.9 infection-related deaths averted, 161 infection-related hospital days averted, 25 infection-related surgeries averted, and $346,616 saved per 100 patients treated with AIC shunts.

**Sensitivity Analyses**

The proportion of decrease in infection with AIC shunt was varied ± 75% based on the significant range of values seen in the literature review. A sensitivity analysis on the baseline infection rate or number of infections would look identical to the sensitivity analysis on the rate of decrease in infection with the AIC because these 2 variables are multiplied together to obtain the number of infections, and therefore varying either produces the same result. The costs of shunt infection presented in the published literature typically were presented as charges and showed significant variability, so a range of ± 50% was presented.

### TABLE 1. Summary of studies comparing AIC versus standard non-AIC shunts

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Infections</th>
<th>Rate of Infection</th>
<th>Decrease Infection w/ AIC Shunt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIC Shunt</td>
<td>Non-AIC Shunt</td>
<td>AIC Shunt</td>
</tr>
<tr>
<td>Adult series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albanese et al., 2009</td>
<td>6</td>
<td>12</td>
<td>0</td>
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<tr>
<td>Eymann et al., 2008</td>
<td>171</td>
<td>98</td>
<td>1</td>
</tr>
<tr>
<td>Farber et al., 2011</td>
<td>250</td>
<td>250</td>
<td>3</td>
</tr>
<tr>
<td>Subtotal/weighted average</td>
<td>427</td>
<td>360</td>
<td>4</td>
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<tr>
<td>Pediatric series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aryan et al., 2005</td>
<td>32</td>
<td>46</td>
<td>1</td>
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<tr>
<td>Eymann et al., 2008</td>
<td>26</td>
<td>22</td>
<td>1</td>
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<td>Hayhurst et al., 2008</td>
<td>214</td>
<td>77</td>
<td>21</td>
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<td>Kan &amp; Kestle, 2007</td>
<td>80</td>
<td>80</td>
<td>4</td>
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<td>Parker et al., 2009</td>
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<td>570</td>
<td>16</td>
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<td>Kandasamy et al., 2011</td>
<td>581</td>
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<td>Combined adult &amp; pediatric series</td>
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<td></td>
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<tr>
<td>Govender et al., 2003</td>
<td>60</td>
<td>75</td>
<td>3</td>
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<td>Pattavilakom et al., 2007</td>
<td>243</td>
<td>551</td>
<td>3</td>
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<tr>
<td>Richards et al., 2009</td>
<td>994</td>
<td>994</td>
<td>30</td>
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<tr>
<td>Ritz et al., 2007</td>
<td>86</td>
<td>172</td>
<td>5</td>
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<tr>
<td>Steinbok et al., 2010</td>
<td>46</td>
<td>387</td>
<td>0</td>
</tr>
<tr>
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<td>2179</td>
<td>41</td>
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<tr>
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<td>3291</td>
<td>5297</td>
<td>118</td>
</tr>
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</table>
in sensitivity analyses. The cost of the AIC shunts was also varied ± 75% in sensitivity analyses to determine the potential impact of this range of cost. Figure 2 presents a tornado diagram illustrating the relative impact of varying the parameter values selected for sensitivity analysis.

The rate of decrease in infection with AIC shunts was shown to have the greatest impact on the cost savings realized with use of AIC shunts. Varying the cost of shunt infection also had a significant impact on model results. The cost of AIC shunts had the smallest impact on net cost savings seen with AIC shunts. Threshold analyses determined the value at which cost savings from averted infection were equal to the incremental cost of using AICs. The thresholds at which AIC shunts were cost neutral occurred when the percent decrease in infection was set at 12.0%, when the cost of shunt infection was set at $11,031, or when the incremental cost of AIC shunts was set at $1682 per device.

External Ventricular Drains

Six studies evaluating AIC versus non-AIC EVDs in the treatment of hydrocephalus were identified. Two of the 6 studies were RCTs in adults, 2 were prospective cohort studies in children, and 2 were prospective cohort studies in pediatric and adult patients combined. As was seen with shunt catheters, patients in the 2 treatment groups of the EVD studies were similar in terms of demographics, etiology of hydrocephalus, and the type of EVD surgery. All EVD studies except the study in adults by Zabramski et al.37 compared BACTISEAL EVD catheters to standard non-AICs. Aggregated results for EVDs also showed a decrease in the rate of infection (overall total decrease of 75.2%) (Table 2).

Although there were fewer published studies available for AIC EVDs, the AIC EVD studies consistently showed a decrease in the rate of infection with the use of AICs. In the case of EVDs, a greater decrease in the rate of infec-

FIG. 1. Clinical and economic impact of 100 AIC shunts versus 100 non-AIC shunts. Figure is available in color online only.

FIG. 2. One-way sensitivity analysis results for the non-AIC versus AIC shunt model. Base case savings of $128,228 with AIC shunts are shown by the point between the red and blue bars. Sensitivity analysis blue bars indicate the range of higher potential savings and red bars indicate the range of lower potential savings. Figure is available in color online only.
tion was seen with pediatric patients compared with adult patients (87.2% vs 67.2% for adult patients).

The study by Lyke et al. reported rates of mortality due to infection and the number of hospital days from infection for AIC and non-AIC EVDs. The study also evaluated the risk of more severe neurological impairment resulting from infection. The reduction in infection seen with antimicrobial-impregnated catheter EVDs translated into improvements in mortality and morbidity, and reduced hospital costs associated with infection (Fig. 3).

In 100 patients requiring EVD catheters, the use of AICs may be associated with 2.7 fewer infection-related deaths and 82 fewer hospital days due to infection. The relative risk of more severe neurological impairment occurring at discharge or in the hospital was estimated to be 5.33 after an EVD infection. Decreases in infection with AIC EVDs resulted in an estimated $264,069 of savings per 100 patients treated with AICs.

A subanalysis using Level I evidence for EVDs was performed using only the combined data from Zabramski et al. and Pople et al. Results of this subanalysis showed that 5.6 infections would be experienced per 100 patients with non-AIC EVDs and 1.8 infections would be experienced per 100 patients with AIC EVDs (3.8 infections averted per 100 patients with AIC EVDs). The clinical consequences of these fewer infections would be 1.0 infection-related deaths averted, 31 infection-related hospital days averted, and $74,631 saved per 100 patients treated with AIC EVDs.

Sensitivity Analyses

The sensitivity analyses of the 3 variables varied in the EVD model are presented as a tornado diagram in Fig. 4. As was seen with AIC shunts, the rate of decrease in infection with AIC EVDs was shown to have the greatest impact on the cost savings realized with use of AIC EVDs. Varying the cost of EVD infection again also had a significant impact on model results. The cost of AIC EVDs had the smallest impact on net cost savings seen with AIC EVDs. The thresholds at which AIC EVDs were cost neutral occurred when the percent decrease in infection with EVD was set at 9.9%, when the cost of EVD infection was set at $3991, or when the incremental cost of AIC EVDs was set at $3041 per device.

### Discussion

**Findings in the Context of Our Current Health Care Delivery Environment**

The challenge to both payers and providers of health care is to maximize the net benefit obtained from health care expenditures. The rising costs of health care delivery pose significant concerns to system viability; thus, improving outcomes while restricting costs is a primary concern of reform efforts around the world. For example, the National Health Service Payment by Results Guidance for 2013–2014 specifies that hospitals will not receive payment for some emergency readmissions within 30 days of discharge following an elective admission.

The current value analysis demonstrates that evidence supports the use of AIC shunts and EVDs as effective and cost-saving treatment strategies. The use of AICs is expected to reduce the number of CSF catheter infections, save lives, decrease hospital days, decrease the number of surgeries required, reduce the incidence and extent of neurological impairment, and reduce overall hospital costs.

This study differs from the 4 other published cost analyses of AICs. First of all, this is the only evaluation that assessed both AIC shunts and AIC EVDs; all others only evaluated AIC shunts. Also, this is the only evaluation that attempted to present more comprehensive clinical consequences of AIC shunts and EVDs; outcomes assessed included infections, deaths from infection, and surgeries due to infection. Three of the previously published AIC cost analyses used data from a single institution to estimate the incidence of shunt infection and the economic impact of

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**TABLE 2. Summary of studies comparing AIC versus standard non-AIC EVDs**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Drains</th>
<th>No. of Infections</th>
<th>Rate of Infection</th>
<th>Decrease Infection w/ AIC EVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zabramski et al., 2003</td>
<td>149</td>
<td>2</td>
<td>1.3%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Pople et al., 2012</td>
<td>176</td>
<td>4</td>
<td>2.3%</td>
<td>2.8%</td>
</tr>
<tr>
<td>Subtotal/weighted average</td>
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<td>6</td>
<td>1.8%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Tamburrini et al., 2008</td>
<td>47</td>
<td>1</td>
<td>2.1%</td>
<td>31.8%</td>
</tr>
<tr>
<td>Rivero-Garviá et al., 2011</td>
<td>248</td>
<td>6</td>
<td>2.4%</td>
<td>17.0%</td>
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<tr>
<td>Subtotal/weighted average</td>
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<td>7</td>
<td>2.4%</td>
<td>18.5%</td>
</tr>
<tr>
<td>Harrop et al., 2010</td>
<td>195</td>
<td>2</td>
<td>1.0%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Muttaiyah et al., 2010</td>
<td>60</td>
<td>14</td>
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<td>76.7%</td>
</tr>
<tr>
<td>Subtotal/weighted average</td>
<td>255</td>
<td>16</td>
<td>6.3%</td>
<td>13.6%</td>
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<td>Total/weighted average</td>
<td>875</td>
<td>29</td>
<td>3.3%</td>
<td>13.3%</td>
</tr>
</tbody>
</table>

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AICs, whereas the current evaluation combined results from all available clinical studies of AICs versus non-AICs. Klimo et al. also used meta-analytical techniques to summarize data for AIC shunts. The current study differs from that by Klimo et al. because it used alternate meta-analytical techniques and different criteria for study inclusion (required that infections be clinically symptomatic events) and assessed a range of clinical consequences for AICs, and included an analysis of EVD AICs as well as AIC shunts.

**Robustness of the Findings**

Twelve of 14 studies of AIC shunts demonstrated a significant decrease in infection rates. Only 2 of 14 AIC shunt studies did not show a decrease in the rate of infection with use of AICs. In the case of Hayhurst et al., more than a quarter of patients with AICs were patients with an especially higher risk for infection due to previous shunt infection, meningitis, EVD-associated ventriculitis, or conversion of an EVD to an indwelling shunt. In the other study by Ritz et al., 3 of the 5 infections in the AIC cohort were the result of skin ulceration or neurosurgical procedures with CSF leakage after shunt implantation. Although there are fewer published studies available for AIC EVDs, the AIC EVD studies consistently showed a substantial decrease in the rate of infection with the use of AICs. A greater decrease in the rate of infection was seen with adult patients compared with pediatric patients.

Results from models are only as credible as the inputs that populate them; therefore, we conducted subanalyses that included data from only Level I studies. Although the subanalyses for both shunts and EVDs resulted in lower effect sizes, they confirmed the overall results of the decision analysis models that AICs are associated with lower infection rates and cost savings. Sensitivity analysis re-

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**FIG. 3.** Clinical and economic impact of 100 AIC EVDs versus 100 non-AIC EVDs. Figure is available in color online only.

**FIG. 4.** One-way sensitivity analysis results for the non-AIC versus AIC EVD model. Base case savings of $264,069 with AIC EVDs are shown by the point between the red and blue bars. Sensitivity analysis blue bars indicate the range of higher potential savings, and red bars indicate the range of lower potential savings. Figure is available in color online only.
results showed that the economic model was most sensitive to the rate of decrease in infection with non-AICs. Cost analyses are inherently proprietary, and published models may provide a starting point for appraising the value of alternate therapies.

Limitations
There are some limitations associated with this analysis. Most of the available evidence comes from nonrandomized studies. Comparisons of baseline characteristics indicated that patients in the AIC and non-AIC groups were similar; however, it is possible that results are confounded, and observed differences between groups are due to other variables. Also, some of the presented data came from studies with numerical trends, not statistically significant results, and not all of the studies contained information on all outcomes (i.e., length of hospital stay, infections, repeat surgeries, morbidity, and mortality). Furthermore, data from retrospective databases may not have been originally collected for the specific research purposes and therefore may be incomplete or have errors.

Simplifying assumptions are required in decision analytical models. Achieving a balance between determining reasonable clinical treatment pathways and creating a transparent model based on published evidence is the desired outcome. The model was built by combining data from multiple sources to identify inputs for effectiveness, resource utilization, and costs. Lack of homogeneity of data sources is a common critique of economic evaluations based on modeling techniques. Data obtained from a retrospective claims analysis might have provided a more homogenous representation of actual costs and utilization; however, properly adjusting for covariates in administrative claims analyses is also difficult, and the populations of a specific database may not be representative of all patients requiring catheters. A prospective, randomized cost-effectiveness evaluation would be another approach to collecting economic evidence first hand.

In terms of the clinical and economic consequences of infection, resource use and cost estimates were mostly derived from studies conducted at a single US site (The Johns Hopkins Hospital) and are not necessarily representative of all settings of care or other countries. Costs presented in the analysis are based on hospital charges (the only published cost data available), which may overestimate actual costs. Nonhospital medical costs and indirect costs such as missed work and lost productivity were not assessed in this study.

Conclusions
This cost-consequence analysis assessed the value of AIC shunts and EVDs in the treatment of hydrocephalus from a hospital perspective. The analysis demonstrated that the evidence supports the use of shunt and EVD AICs as effective and potentially cost-saving treatment strategies. The use of shunt and EVD AICs may be associated with a decrease in the number of infections, fewer deaths from infection, fewer surgeries due to infection, and lower costs associated with shunt and EVD-related infection.

References


Author Contributions
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