Since their clinical introduction in the 1950s, CSF shunt systems have been the chief surgical option in the treatment of pediatric hydrocephalus. Modifications in surgical technique, technological advances in shunt design, and surgical experience have contributed to an overall decrease in shunt-related complications; however, shunt infection remains the one of the most serious challenges facing neurosurgeons today. Even when successfully treated, infections are associated with reduced intelligence quotient and school performance, increased risk of seizures, and psychomotor retardation. Moreover, shunt infection is a common cause of shunt failure, with an associated risk of increased morbidity and mortality rates.

Despite published rates less than 1% for ventricular shunt infection, the North American infection rate averages 5 to 15%. The majority of infections occur within 6 months of shunt placement and chiefly result from perioperative colonization of shunt components by skin flora. Antibiotic-impregnated shunt (AIS) systems have been designed to prevent such colonization. In this study, the authors evaluate the incidence of shunt infection after introduction of an AIS system in a population of children with hydrocephalus.

Methods. The authors retrospectively reviewed all pediatric patients who had undergone cerebrospinal fluid (CSF) shunt insertion at their institution over a 3-year period between April 2001 and March 2004. During the 18 months prior to October 2002, all CSF shunts included standard, nonimpregnated catheters. During the 18 months after October 2002, all CSF shunts included antibiotic-impregnated catheters. All patients were followed up for 6 months after shunt surgery, and all shunt-related complications, including shunt infection, were evaluated. The independent association of AIS catheter use with subsequent shunt infection was assessed via multivariate proportional hazards regression analysis.

A total of 211 pediatric patients underwent 353 shunt placement procedures. In the 18 months prior to October 2002, 208 (59%) shunts were placed with nonimpregnated catheters; 145 (41%) shunts were placed with AIS catheters in the 18 months after October 2002. Of patients with nonimpregnated catheters, 25 (12%) experienced shunt infection, whereas only two patients (1.4%) with antibiotic-impregnated catheters experienced shunt infection within the 6-month follow-up period (p < 0.01). Adjusting for intercohort differences via multivariate analysis, AIS catheters were independently associated with a 2.4-fold decreased likelihood of shunt infection.

Conclusions. The AIS catheter significantly reduced incidence of CSF shunt infection in children with hydrocephalus during the early postoperative period (< 6 months). The AIS system used is an effective instrument to prevent perioperative colonization of CSF shunt components.

Key Words • antibiotic-impregnated catheter • hydrocephalus • infection • shunt • ventriculoperitoneal shunt • pediatric neurosurgery
Fig. 1. Illustrations of the AIS catheters and the traditional shunt system.  
Upper: The surgeon’s preference for placement of a VP shunt.  
Lower Left: Traditional catheter with valve assembly.  
Lower Right: The AIS catheters attached to the valve assembly.
Antibiotic-impregnated catheters in the treatment of hydrocephalus

Clinical Material and Methods

All pediatric patients who had undergone CSF shunt insertion at the Johns Hopkins Hospital over a 3-year period between April 2001 and March 2004 were retrospectively reviewed. Patient demographics, CSF shunt history, clinical presentation, radiological studies, operative variables, and shunt type and configuration were reviewed in all cases. During the 18 months prior to October 2002, more than 90% of CSF shunts (VP, ventriculotrial, or ventriculopleural) included a standard nonimpregnated shunt catheter attached to one of various shunt valve designs: a Medtronic PS Medical Delta valve (Medtronic Neurosurgery, Goleta, CA), Codman-Hakim programmable valve (Codman, Johnson & Johnson, Raynham, MA), or a small minority of other valve designs. During the 18 months after October 2002, more than 90% of CSF shunts included either a medium-pressure unishunt system impregnated with clindamycin and rifampin (Bactis; Codman; Codman & Johnson, Boston, MA) or placement of an antibiotic-impregnated ventricular or distal catheter (also Bactis) to the existing shunt system in cases in which only a proximal or distal shunt revision was indicated, respectively. During this period, the Medtronic Strata valve (Medtronic Neurosurgery) was another valve type brought into use at our institution.

No alteration was made to the technique of shunt insertion over these two time periods. Specifically, all procedures were done in the same surgical suites by one of the two senior authors of this paper. Each patient received antibiotic agents prophylactically prior to skin incision (cefazolin or clindamycin), and no patients received antibiotic irrigation at the time of shunt implantation. Resident and surgical technician assistants were subject to change over these 2 time periods. Specifically, all procedures were done in the same surgical suites by one of the two senior authors of this paper. Each patient received antibiotic agents prophylactically prior to skin incision (cefazolin or clindamycin), and no patients received antibiotic irrigation at the time of shunt implantation. Resident and surgical technician assistants were subject to change over this time period.

All patients were followed up for 6 months after shunt surgery. Shunt-related complications and date and source of shunt failure were recorded. Shunt malfunction was defined as any event leading to shunt removal, replacement, or revision, and causes for malfunction included shunt infection, proximal, distal, or valve obstruction; distal catheter migration; overshunting; shunt disconnection; wound breakdown involving shunt; or any combination of these causes. Shunt infection was further defined as occurring in patients with clinical suspicion of shunt infection (fever, increased white blood cell count, and/or wound breakdown involving the shunt) with positive cultures from CSF and/or hardware.

For intercohort comparison, parametric data were compared using two-way analysis of variance. Nonparametric data were compared using the Mann–Whitney U-test. Percentages were compared using chi-square tests. The independent association of AIS catheter use with subsequent shunt infection was assessed using multivariate proportion hazards regression analysis (StatView, 988 version, SAS Institute, Cary, NC) adjusting for all intercohort covariates differences with a probability valves less than 0.01. Primary shunt placement compared with shunt revision was also adjusted in the multivariate model.

Results

Patient Population

A total of 353 shunt procedures were performed for hydrocephalus in pediatric patients at the Johns Hopkins Hospital between April 2001 and April 2004. Of these operations, 195 (55%) were performed in boys and 158 (45%) were performed in girls, all ranging from 1 to 16 years of age. Causes of hydrocephalus were related to a congenital abnormality in 97 patients (27%), intracranial hemorrhage in 88 (25%), myelodysplasia in 52 (15%), tumor in 23 (7%), Dandy–Walker syndrome in 28 (8%), posterior fossa cyst in 20 (6%), meningitis in 12 (3%), aqueductal stenosis in four (1%), and other causes in 31 (9%). Communicating hydrocephalus was diagnosed in 182 patients (52%), whereas noncommunicating hydrocephalus was present in 156 (44%). Shunt type included 326 VP shunts (92%), 17 ventriculopleural shunts (5%), and 10 ventriculotrial shunts (3%).

In the 18 months after October 2002, 145 shunts (41%) were placed with antibiotic-impregnated catheters; 208 shunts (59%) were placed with nonimpregnated catheters in the 18 months prior to October 2002. The patient cohort receiving AIS catheters was younger, more frequently premature, and more frequently had intracranial hemorrhage as the cause of hydrocephalus, and more frequently used programmable valves, namely Codman Hakim or Medtronic Strata valves (Table 1). Otherwise, there were no significant differences in patient demographics, cause or type of hydrocephalus as the cause of hydrocephalus, and more frequently had intracranial hemorrhage as the cause of hydrocephalus. The shift in valve usage for shunts before and after October 2002 is reflected in the significant differences in valve types between the two groups. The mean age was 10 years for non-AIS patients (range 2–16 years; 208 patients; p < 0.01) and AIS patients (range 1–11 years; 145 patients; p < 0.01). Abbreviations: VAr = ventriculotrial; VPl = ventriculopleural.

### TABLE 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Non-AIS (%)</th>
<th>AIS (%)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex (% female)</td>
<td>90 (43)</td>
<td>68 (47)</td>
<td>0.50</td>
</tr>
<tr>
<td>premature†</td>
<td>44 (21)</td>
<td>53 (37)</td>
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<td>cause of hydrocephalus</td>
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<td>congenital</td>
<td>58 (28)</td>
<td>39 (27)</td>
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<tr>
<td>posthemorrhagic</td>
<td>41 (20)</td>
<td>47 (32)</td>
<td>&lt;0.01</td>
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<tr>
<td>myelodysplasia</td>
<td>32 (15)</td>
<td>20 (14)</td>
<td>0.68</td>
</tr>
<tr>
<td>Dandy–Walker syndrome</td>
<td>19 (9)</td>
<td>9 (6)</td>
<td>0.32</td>
</tr>
<tr>
<td>tumor</td>
<td>18 (10)</td>
<td>5 (3)</td>
<td>0.05</td>
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<tr>
<td>posterior fossa cyst</td>
<td>12 (6)</td>
<td>8 (6)</td>
<td>0.99</td>
</tr>
<tr>
<td>meningitis</td>
<td>8 (4)</td>
<td>4 (3)</td>
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<tr>
<td>aqueductal stenosis</td>
<td>2 (1)</td>
<td>2 (1)</td>
<td>0.99</td>
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<tr>
<td>other</td>
<td>17 (8)</td>
<td>14 (10)</td>
<td>0.99</td>
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<td>type of hydrocephalus</td>
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</tr>
<tr>
<td>noncommunicating</td>
<td>95 (46)</td>
<td>61 (42)</td>
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<td>communicating</td>
<td>104 (50)</td>
<td>78 (54)</td>
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<tr>
<td>unclear</td>
<td>9 (4)</td>
<td>6 (4)</td>
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<td>initial shunt</td>
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<tr>
<td>shunt revision</td>
<td>57 (27)</td>
<td>49 (34)</td>
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</tr>
<tr>
<td>shunt type</td>
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<tr>
<td>VP</td>
<td>190 (91)</td>
<td>136 (94)</td>
<td>0.91</td>
</tr>
<tr>
<td>VPl</td>
<td>10 (5)</td>
<td>7 (5)</td>
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</tr>
<tr>
<td>VAr</td>
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<td>valve type</td>
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<td>programmable</td>
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<td>set pressure</td>
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<td>74 (51)</td>
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<tr>
<td>unspecified</td>
<td>50 (24)</td>
<td>23 (16)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

* The patient cohort receiving AIS catheters had a lower average age, were more frequently premature, and more frequently had intracranial hemorrhage as the cause of hydrocephalus. The shift in valve usage for shunts before and after October 2002 is reflected in the significant differences in valve types between the two groups. The mean age was 10 years for non-AIS patients (range 2–16 years; 208 patients; p < 0.01) and AIS patients (range 1–11 years; 145 patients; p < 0.01). Abbreviations: VAr = ventriculotrial; VPl = ventriculopleural.
of hydrocephalus, or shunt configuration between the two treatment groups.

**Shunt Infection**

The patients receiving AIS catheters had significantly fewer shunt infections. Two patients (1.4%) with antibiotic-impregnated catheters experienced shunt infection within the 6-month follow-up period, whereas 25 patients (12%) with nonimpregnated catheters experienced shunt infection \( (p < 0.01) \). Adjusting for intercohort differences in primary placement compared with shunt revision, prematurity, and posthemorrhagic hydrocephalus by using multivariate analysis, AIS catheters were independently associated with a 2.4-fold decreased likelihood of shunt infection (response rate 0.41; 95% confidence interval 0.32–0.52; \( p < 0.01 \); Fig. 2).

The overwhelming majority of infections (22 [81%] of 27) were caused by Gram-positive organisms, predominately *Staphylococcus* species (18 [67%] of 27; Table 2). In the two patients who received AIS catheters and in whom subsequent shunt infections developed, the times to onset of infection after shunt placement were 3 and 5 weeks, respectively.

**Discussion**

Cerebrospinal fluid shunts have provided a reliable and readily available neurosurgical option for the treatment of hydrocephalus in children. Shunt infection remains a relatively common complication, however, with approximately one in 10 shunts in North America becoming infected. This incidence is three to five times the infection rate of other neurosurgical procedures,\(^9\) and such infection leads to significant neurological morbidity rates in the pediatric population.

Many studies have sought to identify risk factors associated with CSF shunt infection in an effort to decrease the likelihood of infection after placement. Reported independent risk factors include premature birth,\(^3\) patient age at time of surgery,\(^1,2,17,34,37,39,41\) cause of hydrocephalus,\(^7,44\) previous shunt failure,\(^3,41\) duration of shunt surgery,\(^23,29\) postoperative CSF shunt leak,\(^2,3\) intraoperatively breached gloves,\(^32\) and use of endoscopy during shunt placement.\(^2,36\) It is evident from these risk factors that surgical technique may be one of the most important variables in reducing infection.

Cerebrospinal fluid shunt infection most commonly results from colonization of the shunt device by normally nonpathogenic skin flora at the time of surgery.\(^1,9\) Despite thorough antimicrobial skin preparation, organisms can enter the incision during shunt insertion and manipulation.\(^3,21\) Furthermore, by acting as a foreign body, a CSF shunt can interfere with host immune defenses. Borges, et al.,\(^9\) showed that neutrophils and monocytes adhere poorly to shunt system components and phagocytose colonizing bacteria weakly in vitro. Guevara, et al.,\(^22\) demonstrated shunt component surface irregularities such as fissures and holes that might hide bacteria, allowing increased protection from antibiotics. Factors found to influence the progression from colonization to infection include inoculum size,\(^39\) virulence of the organism, and status of host defenses.\(^9\) In this way, the presence of weak immune defenses or infections previously treated with antibiotic agents may explain why prior shunt infections predispose patients to future ones.

In an effort to decrease exposure to skin flora, meticulous surgical technique remains paramount in preventing CSF shunt infections. In addition, the use of prophylactic perioperative antibiotics has been shown to significantly reduce the risk of subsequent infection.\(^3,33,47\) Once infection of the shunt is established, however, eradication of the colonizing organism with intravenous antibiotics alone is often unsuccessful, and shunt replacement is indicated.\(^26\)

Antibiotic-impregnated shunt systems have been developed to decrease the progression of colonization to infection. Such devices mainly act by prevention of staphylococci colonization of the catheter surface rather than by inhibition of adherence.\(^23,30\) The AIS system used in this study contains 0.054% rifampicin and 0.15% clindamycin, antibiotics that have been shown to be bactericidal against multiple species of *S. species*.\(^4,24,29,30,43\) In this study, the overall infection rates varied considerably between the AIS and the control shunt. By 6 months after shunt placement, only two (1.4%) of the AIS catheters were infected compared with 25 (12%) of nonimpregnated shunt catheters. This reported rate of shunt infection when nonimpregnated shunt catheters were used is consistent with accepted rates of pediatric VP shunt infection at other institutions.\(^8,36\)

**FIG. 2.** Incidence of shunt infection as a function of time after shunt insertion in patients receiving AIS and non-AIS catheters for the treatment of pediatric hydrocephalus. By 6 months after shunt placement, only two (1.4%) of the AIS catheters were infected compared with 25 (12%) of the non-AIS catheters. Shunt infections were 2.4-fold less likely to develop during the first 6 months after shunt insertion in patients receiving AIS catheters (response rate 0.41; 95% confidence interval 0.32–0.52; \( p < 0.01 \)).
Antibiotic-impregnated catheters in the treatment of hydrocephalus

The follow-up period was limited to 6 months, it is generally accepted that the majority of shunt infections occur secondary to colonization at the time of surgery, and that such colonization proceeds to infection within the first 6 months postoperatively.16,20,27,42 Baird, et al.2 defined late shunt infections as those occurring more than 9 months postoperatively. They reported rare involvement of skin flora as the causative infectious agent, suggesting that late infections are more likely caused by secondary bacterial seeding than by perioperative inoculation. Furthermore, Vinchon, et al.47 reported that late shunt infection represented only 12.7% of all shunt infections. Although the bactericidal action of AIS catheters has been shown to last for 60 days or more,3,4,24,30,43 such components have not been shown to be protective against reinoculation after 9 months. Thus, efficacy of AIS catheters in preventing late shunt infections is unclear.

The patient population characteristics of the two groups studied were found to be quite similar. The only statistically significant characteristics that differed involved age, prematurity, presence of posthemorrhagic hydrocephalus, and types of shunt valves used. Younger age has been associated with increased risk of shunt infection; however, this increased risk has been associated with very young patients (< 2 years of age).17,37,41 In our population, the mean age was higher both for children with AIS catheters and those without (3 and 10 years, respectively). Furthermore, the population of patients with AIS catheters was younger than the population with standard catheters. Such inequality would drive our results to become less significant if indeed the higher number of younger patients in the AIS group were to yield more shunt infections. This same concept also applies to the patients in our study with a history of prematurity and with a posthemorrhagic cause of hydrocephalus. Both of these characteristics were higher in the population of patients with AIS catheters, yet the infection rate for such patients was still significantly lower than in patients without AIS catheters.

Asymmetry of shunt valve types amongst the two groups is likely the result of the following factors: 1) increased use of Codman valves during later dates because the Bactiseal AIS catheter system used in this study is manufactured by Codman; and 2) increased use of programmable valves over this time period for the treatment of pediatric hydrocephalus. No study to date has clearly demonstrated a link between programmable CSF shunt valves and risk of shunt infection.

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