Prevention of shunt infection is a priority for neurosurgeons, especially when treating pediatric patients. Infection can cause shunt malfunction with all the potential consequences of a nonfunctioning shunt. Shunt infection can lead to scarring and loculation of the ventricles, increasing the complexity of the patient’s hydrocephalus, and it may result in a lower intelligence quotient, increased risk of seizures, and psychomotor retardation.8,26,34,55 Treatment of shunt infections is costly, estimated to be upwards of $50,000 per infection in the United States, making it one of the most costly implant-related infections.12

The identification of modifiable risk factors or interventions to lower the risk of a shunt infection has been the topic of active research for many years. Identified factors include the duration of surgery;7,10,29 the skill and experience of the treating neurosurgeon;7,30,39 the number of personnel in the operating room;22,30,39 and the use of hair shaving.25 Intrathecal prophylactic systemic antibiotics,22,42,56

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**Abbreviations used in this paper:** AIS = antibiotic-impregnated shunt; AANS = American Association of Neurological Surgeons; CNS = Congress of Neurological Surgeons; RR = risk ratio; SS = standard shunt.
antibiotics, wound irrigation, antibiotic-impregnated sutures, and double gloving (or inadvertent exposure of the shunt to breached surgical gloves). Antibiotic-impregnated Silastic catheters were first introduced by Roger Bayston in 1977; they were considered more specifically with shunts in 1989, but did not become available for clinical use in the United States until about 10 years ago. The antibiotic-impregnated shunt (AIS) systems currently on the market contain 0.054% rifampin and 0.15% clindamycin, which target the most common pathogens: Staphylococcus epidermidis and Staphylococcus aureus. Although rifampin and clindamycin do not reduce bacterial adherence, this combination of antibiotics kills bacteria and has been shown to prevent colonization for up to 56 days in vitro studies and up to 127 days in vivo.

Many studies have evaluated the efficacy of AISs compared with standard shunts (SSs) in the prevention of shunt infections, including two recent systematic reviews and meta-analyses. The purpose of this evidence-based review is to examine data on the use of AISs and SSs and compare these treatments in the prevention of shunt infections in the pediatric population.

Methods

Search Terms

We searched the US National Library of Medicine PubMed/MEDLINE database and the Cochrane Database of Systematic Reviews for the period January 1966 through March 2012 using the following MeSH subject headings: (“cerebrospinal fluid shunts” OR (“cerebrospinal fluid” AND (shunt* OR catheter*))) OR “shunt system” AND (“antibiotic-impregnated” OR (antibiotic AND impregnated)) AND infection.

Search Strategy

We reviewed the titles and abstracts of the papers we retrieved with attention to those titles addressing the rate of shunt infection in patients treated with AISs compared with those treated with SSs. Uncontrolled studies were excluded, as were studies that evaluated antimicrobial shunts unavailable in the US market. In all papers, we required that the authors state that the only variable that changed was the type of shunt implanted; all other aspects of the surgery and technique needed to remain unchanged.

Meta-Analysis

For each study, we identified the number of infections resulting from implantation of SSs and AISs and then computed the risk of an infection associated with AISs relative to that associated with SSs, yielding a risk ratio (RR). An RR less than 1 is indicative of protection against infection for the AIS. The overall RR was computed using the method of DerSimonian and Laird.

We conducted a random-effects meta-analysis of the selected studies. A random-effects model—as opposed to a fixed-effects model—does not assume that the measure of association (that is, RR) is uniform across strata (that is, among studies) and, consequently, yields a more conservative estimate of the effect. We assessed heterogeneity by way of the chi-square test of heterogeneity and the I^2 statistic, in which the former returns a chi-square distributed test statistic and corresponding p value and the latter returns a value bound between 0% and 100%, with higher values denoting increasing heterogeneity. We regarded a chi-square test of heterogeneity p value less than alpha = 0.10 and an I^2 value in the range of 30% to 60% as suggestive of moderate heterogeneity. An examination of publication bias was not conducted since the number of studies included in this analysis was not large enough to provide adequate power (i.e., fewer than 10 studies).

Search Results

Our search returned 41 articles; another 3 articles were found from an examination of the articles’ bibliographies (Fig. 1). Nineteen full-length papers were reviewed, 13 of which were rejected for the following reasons: studies enrolled either adults only or enrolled mixed populations, but separate results for children were not provided, or studies contained patient data that had also been reported in separate publications. In fact, 1 group of researchers published no less than 9 papers on AISs that included patients from overlapping time periods. Therefore, 6 articles satisfied inclusion for this systematic review and meta-analysis (Table 1).

Results

The review process identified no papers providing Class I or II data specifically addressing the issue of shunt infection and the use of AISs compared with SSs in children. The 6 articles that satisfied our entry criteria were all Class III cohort studies, all but one of which were conducted within a single institution. The primary outcome of interest—shunt infection—was defined by authors of individual studies, but in general, it was a patient who underwent a recent shunt surgery and subsequently developed signs and symptoms of a shunt malfunction or an infection with an organism cultured from CSF, the shunt apparatus, purulence from the shunt wound(s), or abdominal fluid/pseudocyst. Some investigators also considered a patient to have an infection if there were highly suggestive findings such as fever, redness along the shunt, or CSF pleocytosis in the absence of a positive culture. Overall, 2 studies produced findings that AISs are protective against shunt infection, whereas the remaining studies did not.

Sciubba et al. reported one of the earliest large series comparing AISs with SSs in a pediatric population. During an 18-month period, 208 SSs were placed; this was followed by another 18-month period during which AISs were used 145 times. The AIS patient group was younger, more frequently premature, and thus had a greater incidence of intracranial hemorrhage as the cause of hydrocephalus. The primary outcome was the development of a shunt infection, defined as clinical suspicion (fever, increased white blood cell count, and/or wound breakdown involving the shunt) with positive cultures from CSF and/or hardware. Patients who received AIS

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Part 7: AIS systems versus conventional shunts in children

catheters had significantly fewer shunt infections: 2 patients (1.4%) with antibiotic-impregnated catheters within the 6-month follow-up period compared with 25 patients (12%) with non–antibiotic-impregnated catheters. After we adjusted for intercohort differences in primary placement compared with shunt revision, prematurity, and posthemorrhagic hydrocephalus, we found AIS catheters to be independently associated with a 2.4-fold decreased likelihood of shunt infection.

Aryan et al. detailed their 1-year experience using the Bactiseal system (Codman, Johnson & Johnson). Although the rate of shunt infection was lower in the Bactiseal group (1 of 32 [3.1%]) compared with the standard group (7 of 46 [15.2%]), the difference was not statistically significant (p = 0.09). Kan and Kestler reported on a similar retrospective cohort in which 80 consecutive patients received the Bactiseal shunt and were compared with an earlier group of 80 patients who had received an

**TABLE 1: Antibiotic-impregnated shunt systems versus conventional shunt systems: summary of evidence**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Study Description</th>
<th>Data Class, Quality, &amp; Reasons</th>
<th>Results* &amp; Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kandasamy et al., 2011</td>
<td>Ambispective, multiinstitutional.</td>
<td>Class III Ambispective cohort w/ historical controls.</td>
<td>AIS Group: 30 of 581 (5.2%); SS Group: 155 of 1963 (7.9%). AIS reduced shunt infection rate.</td>
</tr>
<tr>
<td>Eymann et al., 2008</td>
<td>Retrospective, single institution.</td>
<td>Class III Retrospective cohort.</td>
<td>AIS Group: 1 of 26 (3.8%); SS Group: 3 of 22 (13.6%). No statistically significant difference.†</td>
</tr>
<tr>
<td>Aryan et al., 2005</td>
<td>Retrospective, single institution.</td>
<td>Class III Retrospective cohort.</td>
<td>AIS Group: 1 of 32 (3.1%); SS group: 7 of 46 (15.2%). No statistically significant difference.</td>
</tr>
<tr>
<td>Hayhurst et al., 2008</td>
<td>Retrospective, single institution.</td>
<td>Class III Historical controls were used.</td>
<td>AIS Group: 21 of 214 (9.8%); SS Group: 8 of 77 (10.4%). No statistically significant difference.</td>
</tr>
<tr>
<td>Kan &amp; Kestle, 2007</td>
<td>Retrospective, single institution.</td>
<td>Class III Retrospective cohort.</td>
<td>AIS Group: 4 of 80 (5%); SS Group: 7 of 80 (8.8%). No statistically significant difference.</td>
</tr>
<tr>
<td>Sciubba et al., 2005</td>
<td>Retrospective, single institution.</td>
<td>Class III Retrospective cohort.</td>
<td>AIS Group: 2 of 145 (1.4%); SS Group: 25 of 208 (12%). AIS reduced shunt infection rate.</td>
</tr>
</tbody>
</table>

* Percentages represent per shunt procedure, not per patient.
† Fisher’s exact test was used.
SS. There was no statistically significant difference in the shunt infection rate (5.0% vs 8.8%), even when the authors controlled for patient age at surgery, type of revision, cause of hydrocephalus, and previous revisions or infections within the past 6 months.

In their retrospective cohort study, Hayhurst and coworkers looked at 4 groups of patients in whom AISs had been implanted de novo (Group 1), during noninfectious revisional surgery (Group 2), and after an external ventricular drain had been replaced by the shunt (sterile CSF [Group 3] and infected CSF [Group 4]). There were 214 shunt procedures performed using the Bactiseal system in 150 children. The historical control group comprised 77 operations in 65 children. Again, there was no statistically significant difference in the infection rate (21 of 214 [9.8%] in the antibiotic group and 8 of 77 [10.4%] in the standard group). Although the authors emphasized the difference in the infection rate among neonates—27% in the standard group versus 11% in the antibiotic group—this difference too was not significant (p = 0.208). Eyman et al. presented clinical and cost data for both adult and pediatric patients. Using Fisher’s exact test, the pediatric infection rates of 13.6% in the standard group and 3.8% in the Bactiseal group were not statistically different. However, when the authors combined both adult and pediatric outcomes, they did find a protective benefit with the Bactiseal system and a net savings of $51,651 in the 197 Bactiseal procedures.

The study with the largest number of patients was conducted by Kandasamy et al. This multicenter study (5 pediatric neurosurgery centers in the United Kingdom) was ambispective: patients treated with AISs were prospectively followed, whereas patients treated with SSs at earlier time periods were retrospectively reviewed (historical control). Operations were divided into those that were de novo and those that were clean revisions. There was some intercenter variability in the choice of preoperative antibiotics and surgical technique, but there was no intracenter variability. For example, centers at Leeds and Liverpool used a single dose of cefuroxime, whereas London used fluoxacillin and amikacin. The overall pooled treatment effect estimate statistically favored AISs for de novo and clean revisions combined (the incidence of infection in the AIS Group was 30 of 581 [5.2%] and that in the SS Group was 155 of 1963 [7.9%]) as well as for the subgroup of de novo shunts only and the subgroup of children younger than 1 year of age; the pooled treatment effect estimate for clean revisions only did not reach statistical significance.

Meta-Analysis Results

In total, there were 2396 procedures in which a standard catheter system had been placed and 205 infections occurred, yielding a pooled infection rate of 8.6%. In the AIS population, 59 infections occurred after 1078 shunt operations for an overall infection rate of 5.5%. Thus, the absolute and relative risk reductions were 3.1% and 36%, respectively. The overall RR was 0.51 (95% CI 0.29–0.89, p < 0.001), making a shunt infection 1.96 times more likely when an SS system is used (Fig. 2). Although the chi-square test did not indicate heterogeneity (p = 0.129), the I² test did show moderate heterogeneity (41.5%).

To explore the uncertainty of statistical significance in
the RR meta-analysis, a stepwise sensitivity analysis was performed (Table 2). When subtracting studies from the meta-analysis (and thus reducing the power of the analysis), the effect size remains relatively stable, but confidence intervals widen to the point of statistical nonsignificance. Based on significant findings in large studies comparing AISs with SSs and significant findings in a meta-analysis with a high number of studies, it is likely that the meta-analysis shown in Fig. 2 accurately represents a statistically significant effect in favor of using AISs.

**Number Needed to Treat**

There is a certain difficulty with interpreting an RR of 0.51, in that the number of people who benefited from AIS treatment is masked by the interpretation of an RR (i.e., a “50% reduced risk of infection”). In fact the infection rate in the AIS patient group in this meta-analysis was 5.47% compared with 8.55% in the SS patient group. These infection rates come close to approximating a “50% reduced risk of infection.”

To better understand the analysis of AISs versus SSs, absolute values calculated as the number of cases needed to treat and the number of infections avoided per 1000 cases treated with AISs were calculated (Table 2). According to the data reported in the literature, for every 24 cases treated with an AIS, 1 infection is prevented. Alternatively, 42 infections are avoided for every 1000 cases treated with AISs. As a convenience, several population infection rates (that is, infection rates unique to particular locations/practices) are presented in Table 3. Not surprisingly, the higher an infection rate in a population, the “better” the AIS becomes at preventing infection.

**Conclusions**

**Recommendation:** Antibiotic-impregnated shunt (AIS)

The clinical and financial consequences of a shunt infection are substantial as is the emotional stress borne by patients and their families. Neurosurgeons have evaluated many interventions in the hopes of finding ones that can decrease the risk of developing a shunt infection. Based on the available Class III evidence, we have demonstrated that antibiotic-impregnated shunts (AISs containing rifampin and clindamycin) can lower the shunt infection risk substantially. Although only 2 of the 6 studies that met our inclusion criteria showed a protective benefit with AISs, when the data from all 6 studies were pooled together (meta-analysis), a benefit was shown, with an infection rate almost twice as high in patients receiving a standard shunt (SS). Given the large number of patients that would be needed to definitively demonstrate superior efficacy of AISs over SSs in children, it is unlikely that a clinical trial will be conducted or is even needed.

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**TABLE 2: Results of the sensitivity analysis: summary of evidence**

<table>
<thead>
<tr>
<th>No. of Largest Studies</th>
<th>RR (95% CI)</th>
<th>Heterogeneity ($I^2$)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>All studies (Fig. 1)</td>
<td>0.51 (0.29–0.89)</td>
<td>41.5%</td>
<td>Statistically significant</td>
</tr>
<tr>
<td>5 largest studies</td>
<td>0.52 (0.28–0.95)</td>
<td>50.5%</td>
<td>Statistically significant</td>
</tr>
<tr>
<td>4 largest studies</td>
<td>0.55 (0.29–1.05)</td>
<td>56.6%</td>
<td>Not significant</td>
</tr>
<tr>
<td>3 largest studies</td>
<td>0.52 (0.23–1.20)</td>
<td>71.0%</td>
<td>Not significant</td>
</tr>
<tr>
<td>2 largest studies</td>
<td>0.31 (0.06–1.75)</td>
<td>82.1%</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

**TABLE 3: Number of cases needed to treat: summary of evidence**

<table>
<thead>
<tr>
<th>Assumed Population Infection Rate (%)</th>
<th>No. of Cases Needed to Treat</th>
<th>No. of Infections Avoided per 1000 Cases Treated w/ AIS (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>41</td>
<td>24 (5–35)</td>
</tr>
<tr>
<td>8.6*</td>
<td>24</td>
<td>42 (9–60)</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>49 (11–70)</td>
</tr>
<tr>
<td>12.5</td>
<td>17</td>
<td>61 (14–88)</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td>73 (16–106)</td>
</tr>
</tbody>
</table>

* Infection rate found in the present meta-analysis.
References


