Hydrocephalus is the most commonly encountered condition in pediatric neurosurgical practice, and the mainstay of surgical management remains insertion of a CSF shunt. This is typically a ventriculo-peritoneal system, consisting of Silastic ventricular and peritoneal catheters connected by a valve. Although this system is an effective treatment for hydrocephalus, associated morbidity, especially shunt infection, remains common, expensive to deal with, and potentially devastating for individual patients.

Shunt infection rates for primary insertions are around 10%, as reported in a recent large series. Infection rates after revision surgery are higher, being around 3 times higher after a first revision and becoming even more frequent with each additional surgery. A 2005 study estimated the health care cost for shunt infection...

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Clinical article

Effect of introduction of antibiotic-impregnated shunt catheters on cerebrospinal fluid shunt infection in children: a large single-center retrospective study

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Object. Infection after both primary and revision shunt surgeries remains a major problem in pediatric neurosurgical practice. Antibiotic-impregnated shunt (AIS) tubing has been proposed to reduce infection rates. The authors report their experience with AIS catheters in their large pediatric neurosurgery department.


Results. The historical control group consisted of 1592 consecutive shunt operations (657 primary insertions), and the AIS study group consisted of 500 consecutive shunt operations (184 primary insertions). Patients ranged in age from 0–17 years. In the historical group, 135 infections were identified (8.4%). In the AIS study group, 25 infections were identified (5%), representing a significant reduction (p < 0.005). The latency to diagnosis of infection was 23 days in the historical group and 139 days in the AIS study group. The infection rates in infants 0–6 months of age were 12.2% (historical group) and 6.7% (AIS group, p < 0.005), and in infants 7–12 months of age the rates were 7.9% (historical group) and 2.7% (AIS group, p < 0.005). In the historical control group, the frequency rank order of causative organisms was coagulase-negative staphylococcus (51.9%), Staphylococcus aureus (31.6%), streptococcus or enterococcus spp. (8.8%), gram-negative organisms (4.4%), and Propionibacterium acnes (2.2%). Organisms responsible for infections in AIS were S. aureus (40%), followed by streptococcus or enterococcus spp. (20%), P. acnes and coagulase-negative staphylococcus (both 16%), and gram-negative organisms (4%). No unusually antibiotic-resistant bacteria were identified in either group. The authors further subdivided the AIS group into those undergoing primary AIS insertion (Subgroup 1), those undergoing revision of non-AIS systems using AIS components (Subgroup 2), and those undergoing revision of AIS systems using AIS components (Subgroup 3). Infection rates were 1.6% in Subgroup 1, 2.5% in Subgroup 2, and 11.7% in Subgroup 3. Staphylococcus aureus was the most common organism identified in infections of the Subgroups 2 and 3.

Conclusions. Use of AIS tubing significantly improves shunt infection rates in both general pediatric and infant populations with no evidence of increased antibiotic resistance, which is in agreement with previous studies. However, the increased infection rate in revision surgery in children with AIS catheters in situ raises questions about their long-term application.

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Key Words • antibiotic-impregnated shunt • shunt infection • pediatrics

Abbreviation used in this paper: AIS = antibiotic-impregnated shunt.
at $35,000 per admission. In individual patient terms, shunt infection and subsequent revision surgery carry risks including neurodevelopmental compromise, seizures, and even death. It is therefore unsurprising that neurosurgeons have been keen to adopt products claiming to reduce shunt infection rates, such as antibiotic-impregnated shunt (AIS) catheters.

The majority of shunt infections are thought to result from the colonization of the shunt hardware usually by nonpathogenic skin flora, particularly gram-positive cocci such as staphylococcus species Staphylococcus epidermidis and Staphylococcus aureus. Therefore, bactericidal agents used in AIS catheter tubing are targeted at these organisms. Antibiotic-impregnated shunt catheters have been available for more than a decade, and several studies have been published in attempt to establish their role in reducing shunt infection. These studies are somewhat heterogeneous in terms of follow-up, patient population (pediatric only, adult only, or mixed), whether primary insertion only or revision surgeries also were included, and in reporting of causative pathogens. Some recent studies have highlighted the possibility of AIS catheters promoting selection of antibiotic-resistant organisms. There has also been increasing recognition of the role of Propionibacterium acnes in causing shunt infection, often with an atypical or indolent presentation.

We describe a large, single-center retrospective cohort study examining outcome in both primary and revision shunt surgeries using AIS tubing, comparing these with our historical series with non-AIS tubing. In addition to clinical outcomes, we report which organisms were responsible for the infections in the 2 series.

Methods

Our institution maintains a computerized prospective surgical database of all procedures performed since 1993, which records patient demographics, along with details of diagnosis, nature and date of operation, shunt components used, and complications. All primary shunt insertions and shunt revisions were identified, and 2 cohorts containing consecutive cases were selected; a historical group from before introduction of AIS catheters at our institution (1993–2003), and an AIS study group following 100% adoption of the use of AIS catheters (2005–2009). Case note review and interrogation of the separate pathology database were used to confirm shunt infections in these groups. The minimum follow-up was 24 months. The criteria for CSF shunt infection were defined as follows: CSF microscopy or culture that yielded an organism; or CSF pleocytosis associated with fever, shunt malfunction, or neurological symptoms that required shunt removal and subsequent antimicrobial treatment. Superficial incisional or deep incisional infections that did not lead to shunt removal were not classed as CSF shunt infection. In the United Kingdom, conventional surgical site infection surveillance stops at 1 year for implants; however, infections presenting after 1 year were included if no other procedure was likely to have led to the CSF infection.

A uniform surgical protocol for shunt operations, including the double-gloving, “no touch” technique and perioperative prophylactic antibiotics, has been in place at our institution for the entire study period (both historical and AIS groups) and was unaltered during this time, although individual compliance was not audited. Prophylactic antibiotic use changed during the study; in the early control period use was intermittent but in 1999 it was introduced formally for all patients younger than 6 months, and subsequently for all patients (compliance not audited).

Antibiotic-impregnated shunt tubing was used uniformly (Codman Bactiseal, DePuy, Inc., clindamycin 0.15% and rifampicin 0.054%). For primary ventriculoperitoneal shunts in the study group, both ventricular and distal catheters were always AISs. For ventriculostriatal shunts, only the ventricular catheter was AIS. Valve choice was dependent on clinical factors and varied between patients (no antibiotic-impregnated valves were used in any patient).

In regard to the microbiological laboratory methods used, throughout both study periods all CSF was submitted for cell count, Gram staining, and primary culture. During the historical study group period, further microbiological techniques were introduced as standard: first, additional overnight enrichment, followed by extended primary anaerobic culture and extended anaerobic broth culture. Therefore, in the historical group not all CSF samples were subjected to these investigations, but all specimens from the AIS group did undergo these techniques.

Statistical analysis was carried out using Fisher’s exact test with the aid of SPSS statistical software (SPSS, Inc.).

Results

Study Group Characteristics

After reviewing the database, we identified 1592 shunt operations in the historical group. Of these, 657 were primary insertions and 935 were revisions. The mean age at the time of surgery was 2.5 years (range 0–17 years).

In the AIS group, 500 shunt operations were identified. Of these, 184 were primary insertions and 316 were revisions, and the mean age was 3.9 years (range 0–17 years). For the AIS group, we further subdivided the 316 revision surgeries into initially non-AIS shunts being revised using at least one AIS component (n = 162) and AIS primary insertion requiring surgical revision due to infection or blockage (n = 154). The most common presentation diagnosis for the AIS study group was posthemorrhagic hydrocephalus, and there was a diverse group of congenital and acquired conditions (Table 1). In this group, the majority of patients (465; 93%) had a ventriculoperitoneal shunt. Eleven patients (2%) underwent a concurrent endoscopic procedure. Forty-three patients (9%) had a period of external ventricular drainage prior to shunt insertion. Other than external drains, no patients had alternative CSF diversion procedures such as ventriculostriatal shunt or ventricular access device prior to primary shunt insertion.
Antibiotic-impregnated shunts: effects in pediatric population

Shunt Infection Rates

In the historical group of 1592 operations, 135 shunt infections (8.4%) were identified, occurring in 114 children. The mean patient age at the time of diagnosis was 1.1 years, and the median latency (time between operation and diagnosis of infection) was 23 days (range 1–925 days). In the AIS study group of 500 operations, we identified 25 infections (5%) occurring in 4 patients. The mean patient age at time of infection was 4.4 years, with a median latency of 139 days (range 5–1825 days). The difference in infection rate and the difference in latency were both significant (p < 0.005; Fig. 1).

We performed subgroup analyses to examine infection rates in children younger than 12 months of age. In the historical group, the infection rates were 12.2% in children 0–6 months of age, and 7.9% in those 7–12 months. In the AIS study group, the rates were 6.7% in children 0–6 months old and 2.7% in those 7–12 months old. The difference in infection rate and the difference in latency were both significant (p < 0.005; Fig. 1).

When comparing rates of infection by species in the 2 groups, there was a significant decrease in coagulase-negative staphylococcus infection from the historical to AIS study group (p < 0.05) and an increase in the rate of P. acnes infection (p < 0.05; Table 2). There were no unusually antibiotic-resistant organisms identified in either group. Infection latency was increased in the AIS study group predominantly due to the effect of P. acnes infection, which had a significantly longer latency than other organisms (Fig. 3).

Subgroup Analysis of the AIS Study Group: Infection Rates and Causative Organisms

To further examine infection rates and causative pathogen, we subdivided the AIS study group into 3 subgroups. Subgroup 1 (n = 184) comprised primary shunt insertions using AIS tubing. Subgroup 2 (n = 162) comprised revisions in which previously completely non-AIS systems were revised using 1 or more AIS components (ventricular catheter, peritoneal catheter, or both). Subgroup 3 (n = 154) comprised revisions to existing AIS systems, using AIS components in the revision as well. There were no significant differences between the 3 subgroups in terms of age, sex, or diagnosis.

There were 3 (1.6%) infections in Subgroup 1, 4 (2.5%) in Subgroup 2, and 18 (11.7%) in Subgroup 3. This higher rate of infection in Subgroup 3 did not quite reach significance (p = 0.053; Table 3).

No infections in Subgroup 1 were caused by S. aureus, although this was the most common causative organism in the other 2 subgroups (Fig. 4). None of the causative organisms were antibiotic resistant in any subgroup.
Discussion

Overall, our results are comparable with the majority of previous studies in terms of showing a significant reduction in shunt infections with the use of AIS catheters. Although 2 earlier studies did not find any effect on infection rates from AIS catheter use,11,21 larger studies, including meta-analyses, have reported a reduction largely in line with that reported in the present study.2,7–10,12–17,20,22,24,28 This study supports previous recommendations made in favor of universal adoption of AISs. There is increasing evidence that, in addition to improvement in clinical outcome, there are strong economic and cost-effectiveness arguments for the use of AIS catheters.3,6,13,22 In addition to the overall effect in an unselected group of pediatric patients on whom we report, there was a significant improvement with respect to infection rates in the 0–6-month age group. This
group of patients, particularly those with posthemorrhagic hydrocephalus, appear to be at greater risk of shunt-related morbidity and mortality.19,27 and it is encouraging that in this study AIS tubing appears to be effective in improving outcomes in this group.

Some previous studies have questioned whether the use of AIS catheters may select out or promote certain causative organisms, with particular concerns raised regarding a possible increased rate of infections caused by antibiotic-resistant bacteria.5,12 We did not find any shunt infections caused by resistant strains in the current study. However, we did see a change in the profile of causative agents, with a decrease in infections secondary to coagulase-negative staphylococcus and S. aureus in the AIS group. This is likely to reflect the known efficacy of action of rifampicin and clindamycin against these organisms.16,25 We did see a higher rate of P. acnes infection in the AIS group, which may reflect the fact that the antibiotics in AIS catheters are less effective against this organism,4 or perhaps increasing recognition, with the introduction of extended culture times (used in our institution since 2008). Propionibacterium acnes shunt infections are typically indolent, with vague clinical and laboratory findings when compared with, for example, staphylococcus infection,1 and are

![Fig. 1. Reduced shunt infection rate and increased latency of infection in AIS catheters. Upper: Statistically significant reduction in shunt infection rate demonstrated after introduction of an AIS. p < 0.005, Fisher's exact test. Lower: Statistically significant increase in latency in time to presentation with shunt infection in the AIS group. p < 0.005, Fisher's exact test. Bars denote SEM.](image)

![Fig. 2. Bar graph showing the reduced shunt infection rate with AIS systems in neonates and infants by age group.](image)

**TABLE 2: Causative organisms in non-AIS (control) and AIS groups**

<table>
<thead>
<tr>
<th>Causative Organism</th>
<th>Control Group</th>
<th>AIS Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. aureus</td>
<td>42 (31.1)</td>
<td>10 (40.0)</td>
</tr>
<tr>
<td>CONS</td>
<td>69 (51.0)</td>
<td>4 (16.0)</td>
</tr>
<tr>
<td>P. acnes</td>
<td>2 (1.5)</td>
<td>4 (16.0)</td>
</tr>
<tr>
<td>streptococcus/enterococcus spp.</td>
<td>10 (7.4)</td>
<td>5 (20.0)</td>
</tr>
<tr>
<td>gram-negative</td>
<td>5 (3.7)</td>
<td>1 (4.0)</td>
</tr>
<tr>
<td>no growth</td>
<td>7 (5.2)</td>
<td>1 (4.0)</td>
</tr>
<tr>
<td>total</td>
<td>135/1592</td>
<td>25/500</td>
</tr>
</tbody>
</table>

*Values are the number of patients (%). CONS = coagulase-negative staphylococcus species.
sometimes misdiagnosed as noninfective shunt blockage. It may be that increasing awareness of this has influenced increased diagnostic rates in the more recent AIS study group. It was these *P. acnes* infections, with their delayed nature, that led to the increase in the infection latency period in the AIS group. When these were excluded, the latency was not significantly different between the 2 groups. Due to the factors mentioned above regarding diagnosis of *P. acnes* infection, it is difficult to state categorically that there is a higher rate of delayed infection associated with AIS catheters. A previous study specifically looking for late infection (> 6 months) found no evidence of increased risk with AIS tubing.23

While there is increasing evidence that primary shunt insertion utilizing AIS tubing reduces shunt infection compared with traditional tubing, there is little in the literature specifically examining the role of AIS in shunt revision surgery. As many patients with shunts undergo such surgery, this is an important question to address. In the current study, we performed a subgroup analysis to study this question.

We subdivided the AIS study group into 3 subgroups. Subgroup 1 consisted of primary shunt insertions, whereas Subgroups 2 and 3 comprised revisions. In Subgroup 2, traditional non-AIS catheters were revised using AIS components for some or all of the shunt, whereas in Subgroup 3, AIS catheters were revised using new AIS components. Interestingly, we saw no *S. aureus* infection in Subgroup 1. However, this organism was seen in both revision groups. It is recognized that the antibiotic action of an AIS catheter has a time limit of action, estimated in one study at 127 days postimplantation in vivo.6 It may be after this time, if bacterial colonization occurs, the profile of causative organisms may “revert” to those seen infecting non-AIS systems, with the reappearance of important organisms such as *S. aureus*.

Of even greater note, the shunt infection rate was higher in Subgroup 3 (11.7%; AIS revised with AIS) than Subgroup 2 (2.5%; non-AIS revised with AIS), although this did not reach statistical significance. This finding raises the concerning possibility that AIS tubing, after its initial period of antibacterial action, is in fact more susceptible to infection than traditional tubing. This clearly has implications for revisions, where it may be advisable to revise the entire system, even if existing components are functioning well, to “renew” the antibacterial effectiveness. We would support future prospective, randomized controlled studies focusing specifically on primary and revision surgery to shed further light onto this important question.

**Conclusions**

Use of AIS catheters appears to significantly improve shunt infection rates in both general pediatric and neonatal populations, and is not associated with antibiotic-resistant organism infection. The increased rate of *P. acnes* infection may reflect increased diagnosis rather than an actual increase in risk. In any case, this study supports the use of AIS tubing in pediatric neurosurgical practice, although we support further research into outcomes with AIS tubing in revisions, as we have demonstrated an increased infection risk in this subgroup. It may well be that an altered surgical strategy may negate this increased risk.

**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: Ternier, Hartley. Acquisition of data: Ternier, Hartley, Morgan. Analysis and interpretation of data: all authors. Drafting the article: Ternier, James. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ternier. Statistical analysis: Ternier, Morgan. Study supervision: Ternier.

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