Surgical shunt infection: significant reduction when using intraventricular and systemic antibiotic agents

BRIAN T. RAGEL, M.D., SAMUEL R. BROWD, M.D., PH.D., AND RICHARD H. SCHMIDT, M.D., PH.D.

Department of Neurosurgery, University of Utah Health Sciences Center, Salt Lake City, Utah

Object. Infection represents the most common serious complication of shunt surgery, and typically its incidence ranges between 5 and 15%, despite the use of systemic antibiotic agents. Because systemic antibiotic medications generally penetrate the cerebrospinal fluid (CSF) poorly, the authors investigated, in a controlled study, whether the addition of intraventricular antibiotic treatment decreases the incidence of perioperative infection in adult patients.

Methods. Data pertaining to all CSF shunt procedures conducted at the authors’ institution during an 11-year period were reviewed. Perioperative infection was defined as culture-positive CSF and the clinical presence of infection-related symptoms occurring within 90 days of surgery. All patients underwent intraoperative systemic antistaphylococcal antibiotic therapy. Before May 16, 1999, the senior author (R.H.S.) also administered 4 mg of gentamicin intraventricularly at surgery (Group I); thereafter, 10 mg of vancomycin was additionally administered (Group II). Other neurosurgeons at this institution did not use intraventricular antibiotic therapy, and their patients served as additional controls in identical time periods (Groups III and IV).

A total of 802 shunt procedures were performed in 534 patients. Control infection rates were 5.4% (eight of 147) in Group I; 6.2% (nine of 145) in Group III; and 6.7% (18 of 267) in Group IV. With the combination of systemic antibiotic and intraventricular gentamicin and vancomycin (Group II), the infection rate fell significantly to 0.4% (one of 243). No complications were noted in association with intraventricular antibiotic administration.

Conclusions. The combination of intraventricular gentamicin and vancomycin with systemic antibiotic therapy significantly decreased the incidence of perioperative shunt infection. It is presumed that intraventricular antibiotic therapy extends prophylactic antibiotic coverage into the CSF and prevents bacterial seeding.

Key Words • shunt infection • hydrocephalus • cerebrospinal fluid shunt • intraventricular antibiotic medication • antibiotic prophylaxis

HYDROCEPHALUS has many underlying causes, including spina bifida, aqueductal stenosis, brain tumor, head injury, intracranial hemorrhage, and meningitis. In the US, nearly 70,000 hospital admissions for hydrocephalus occur each year. In most patients with hydrocephalus treatment entails the placement of a CSF shunt. Unfortunately, such therapy is associated with several complications, including a 2-year failure rate of greater than 40% and typically an infection rate of 5 to 15%. According to the Nationwide Inpatient Sample database (year 2000), shunt infection was the primary diagnosis in 7.2% of hospital admissions for hydrocephalus. Most shunt infections occur within 2 months of surgery (70%), with staphylococcal species accounting for approximately 62 to 75% of infections. Even when patients receive appropriate care, CSF infections are associated with a substantial risk of morbidity, including seizure disorder, decreased intellectual capacity, and neurological deficit. Despite attempts to prevent shunt infection, its incidence remains vastly higher than that in other neurosurgical procedures that involve implanted hardware. For example, deep brain stimulators are associated with a 1.8 to 6% risk of infection. The infection rate for implantation of vagus nerve stimulators ranges from 1 to 3.5% (personal communication, VNS Patient Outcome Registry, Cyberonics, Inc., Houston, TX). Of other implanted medical devices, breast implants, which have a silicone rubber envelope similar to shunt materials, have a surgical infection rate of 2 to 2.5%. Thus, shunt surgery seems to carry an intrinsically higher risk for infection than equivalent procedures.

The mainstays of attempts to decrease perioperative shunt infections include the use of systemic antibiotic medication and attention to operative technique. In one meta-analysis investigators reported a 48% risk reduction when using perioperative systemic antibiotic agents; however, infection rates remained elevated compared with those recorded in other neurological procedures. Antibiotic-impregnated shunt systems have been introduced but are not yet in widespread use. Intraventricular antibiotic agents have been safely used as an adjunct to systemic antibiotic therapy in the treatment of CSF bacterial infections, including shunt infections. In two studies researchers have examined the administration of intraventricular vancomycin for prophylaxis against infection in shunt surgery. The authors of one study found no

Abbreviations used in this paper: BBB = blood–brain barrier; CNS = central nervous system; CSF = cerebrospinal fluid; OR = odds ratio; RR = relative risk; VP = ventriculoperitoneal.
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benefit when intraventricular vancomycin was used without systemic antibiotic therapy. The other study, a prospective trial, was terminated without significant results because an adequate patient population could not be accrued. We are unaware of any adequately powered studies in which the investigators have combined intraventricular and systemic antibiotic medications.

Systemic antibiotic agents, in the absence of active inflammation, are known to penetrate into the CSF space poorly, resulting in levels below the antimicrobial threshold when used for surgical prophylaxis. Cerebrospinal fluid is an excellent growth medium for bacteria, consisting of an isotonic, ionically balanced glucose solution virtually free of leukocytes and protective antibodies. We have hypothesized that the key to reducing surgical shunt infections is to cover both the CSF and the systemic compartments with adequate levels of prophylactic antibiotic medication at the time of surgery. This hypothesis has now been tested in a nonrandomized controlled manner at our institution. Starting in May 1999, the senior author (R.H.S.) began routinely using intraventricular vancomycin and gentamicin in combination with systemic antibiotic medication in all adults undergoing shunt surgery. Prior to this, he had used only intraventricular gentamicin and systemic antibiotic therapy, providing an adequate control group for the effect of intraventricular vancomycin. An additional control group was provided by all other patients who had undergone shunt procedures at the institution where the standard practice was to administer systemic antibiotic medication alone.

Clinical Material and Methods

We reviewed data pertaining to all CSF shunt procedures performed by the senior author (R.H.S.) at the University of Utah between August 1, 1993, and December 31, 2004 (duration 11.42 years). The procedures included all those in which shunts (VP, ventriculopleural, ventriculocarotid, and lumbo-peritoneal) or Ommaya reservoirs were placed or revised but not procedures in which hardware was merely removed. These data were collected prospectively using a database that tracks surgical outcomes. In addition, all CSF shunt procedures performed by the other attending neurosurgery surgeons at our institution between July 1, 1996, and December 31, 2004, were collected and reviewed retrospectively. Data were derived from chart review, electronic medical records, and departmental operative databases with authorization from the University of Utah Institutional Review Board (No. 10497).

Antibiotic Therapy and Surgical Protocol

In all surgeries, systemic antibiotic prophylaxis was routinely used. It generally consisted of antistaphylococcal cephalosporins (cefazolin 1–2 g intravenously) or vancomycin (1 g intravenously) administered prior to skin incision. The senior author also used a single intraoperative intravenous dose of gentamicin 2 mg/kg. Systemic antibiotic agents were typically continued postoperatively for 24 hours.

Until May 15, 1999, the senior author consistently used a single intraoperative, intraventricular 4-mg dose of preservative-free gentamicin in 2 ml of sterile saline introduced into the ventricular catheter or shunt reservoir prior to surgical closure of the wound. Starting on May 16, 1999, 10 mg of preservative-free vancomycin in 2 ml of normal saline was given in combination with 4 mg of gentamicin in 2 ml saline intraventricularly.

The patients treated prior to May 16, 1999 (Group I) served as the control group for the effect of adding intraventricular vancomycin (Group II). None of the other attending physicians at the University of Utah used intraventricular antibiotic medication during the study period, and their patients were subdivided into two groups, those treated before (Group III) and those treated after (Group IV) May 16, 1999, as additional controls for the effect of intraventricular antibiotic therapy. All attending physicians routinely used bacitracin irrigation intraoperatively and soaked the shunt hardware in bacitracin solution prior to implantation.

Details of the surgical procedures were generally similar among all attending physicians throughout the study period. Surgical draping included the use of iodine-impregnated sterile skin barrier (Ioband; 3M Corporation, Minneapolis, MN). There were no special considerations with regard to the surgery suite, time of day at which the operation was performed, or surgery personnel, and resident staff and medical students freely participated in these cases. Only one other protocol change was adopted by the senior author during the study period: in February 1999, the use of two separate full-skin preparations was introduced prior to draping. Antibiotic-impregnated shunts were not used in any group.

Outcome Measures

The primary outcome measure was the incidence of shunt infection causing ventriculitis, peritonitis, or other distal terminus infection within 90 days of surgery. Infection was defined as the presence of positive CSF- or catheter-based cultures in conjunction with at least one clinical component of infection (headache, meningitis, peritonitis, fever, CSF leukocytosis, or elevated peripheral leukocyte count). Superficial wound infections not involving the shunt, such as a suture abscess, were not regarded as a shunt infection and generally did not require removal of the device.

Data Analysis

The primary data analysis consisted of comparing the number of operative procedures resulting in a postoperative infection with the number of operations without infection in each of the four groups. Intergroup comparisons were made using the Fisher exact probability test (Prism 4.0; GraphPad Software, San Diego, CA) with significance established when the probability value was less than or equal to 0.05.

Results

A total of 802 shunt procedures were performed in 534 patients during the study period. Fifty percent of the 534 patients were male; the mean age of all patients was 43.1 years (range 14–92 years). The 802 shunt procedures comprised 411 primary shunt insertions and 391 shunt revisions. Of the 534 patients, 147 underwent placement of the shunt for tumor, 85 for subarachnoid hemorrhage, 69 for congenital lesions (for example, spina bifida, Chiari malformation Types I and II, and Dandy–Walker syndrome), 58 for intraventricular hemorrhage of prematurity, 46 for normal-
pressure hydrocephalus, 38 for pseudotumor cerebri, 33 following traumatic injury, 16 after CNS infection, 14 for subarachnoid cysts, 13 after intraparenchymal or intraventricular hemorrhage, one for a spinal cord syrinx, and 14 for undetermined causes.

Thirty-six infections occurred during the defined postoperative period (infection rate 4.49%). In more than half (56% or 20 of 36), the shunt infections occurred within 1 month of surgery, in 33% (12) within 2 months, and in only 11% (four) more than 2 months after surgery (but within 3 months). Of these 36 infections, 30 were VP shunts, one was ventriculopleural, one was ventriculostial, one was lumbopteroneal, and three were Ommaya reservoirs (Table 1). Staphylococcal species were the most common pathogens, accounting for 22 (61%) shunt infections. Of these species infections, 11 were methicillin-sensitive Staphylococcus aureus, six were methicillin-resistant S. aureus, and five were coagulase-negative Staphylococcus. The remaining 14 identified infections were caused by Propionibacter (three), Klebsiella (two), Enterobacter (one), Streptococcus sanguis (one), Pseudomonas (one), Corynebacterium (one), diphtheroid (one), Enteroccus (one), E. Cloacae (one), and unknown origin (two) (Table 2).

Shunt infections stratified by antibiotic treatment group are shown in Table 3. In Group I (systemic antibiotics plus intraventricular gentamicin), there were eight infections in 147 procedures (infection rate 5.44%). These infections were composed of seven Staphylococcus species and one Klebsiella infection. Following the addition of intraventricular vancomycin to the antibiotic regimen (Group II), the infection rate dropped to 0.412% or one in 243 procedures (p = 0.0022, RR 0.41 [0.1–0.54], OR 0.07 [0.01–0.58]). The single shunt infection in this group was a coagulase-negative Staphylococcus peritoneal infection that did not result in any ventriculitis.

Departmental control infection rates were 6.21% (nine infections in 145 procedures) during the earlier period (Group III, before 5/16/1999) and 6.74% (18 infections in 267 procedures) in the second time period (Group IV, after 5/16/1999), reflecting no change in the rate of infection over time (p = 1.000, RR 1.06 [0.61–1.84], OR 1.09 [0.48–2.50]).

In the senior author’s cases, the infection rate prior to introducing intraventricular vancomycin was not statistically different from the departmental control infection rate (Group I compared with Group III (p = 0.8079, RR 1.074 [0.64–1.80], OR 1.15 [0.43–0.07]). This indicates that there was no real value in adding intraventricular gentamicin alone to systemic antibiotic therapy for prophylaxis.

Comparing Group II with all other control groups combined (Groups I + III + IV), intraventricular vancomycin combined with intraventricular gentamicin for antibiotic prophylaxis had a highly significant benefit (p < 0.0001, RR 0.70 [0.65–0.76], OR 0.062 [0.008–0.454]).

The distribution over time of all shunt procedures and infections is shown in Fig. 1 for the control groups and the group treated with intraventricular antibiotic drugs. This shows that up until the introduction of intraventricular vancomycin in May 1999, the incidence of infections was steady and then dropped precipitously (Fig. 1 upper). Even after the senior author introduced the double-skin preparation protocol in early 1999, shunt infections continued to occur. Infections among the departmental controls continued to develop at a constant rate throughout the entire study period, which ruled out the influence of some unknown extrinsic factor (Fig. 1 lower).

We identified no adverse effects of using intraventricular gentamicin alone or in combination with intraventricular vancomycin. There were no cases of allergic reaction, neurological worsening, or aseptic meningitis attributed to these drugs.

**Table 1**

<table>
<thead>
<tr>
<th>Shunt Type</th>
<th>No. of Shunts</th>
<th>No. of Infections</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP</td>
<td>587</td>
<td>30</td>
</tr>
<tr>
<td>ventriculopleural</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>ventriculoatrial</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>lumbopteroneal</td>
<td>46</td>
<td>1</td>
</tr>
<tr>
<td>Ommaya reservoir</td>
<td>70</td>
<td>3</td>
</tr>
<tr>
<td>other</td>
<td>47</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>802</td>
<td>36</td>
</tr>
</tbody>
</table>

**Discussion**

This is the first adequately statistically powered and controlled clinical trial to examine the effectiveness of intraventricular antibiotic medications when added to systemic antibiotic therapy for the prevention of perioperative shunt infections. The benefit of intraventricular gentamicin (4 mg) in combination with intraventricular vancomycin (10 mg), when instilled into the CSF in a single dose at the time of surgery, was strongly demonstrated. Because this study was not designed as a randomized prospective trial, the evidence does not represent Class I status but can be considered strong Class II evidence.1,2 The infection rates seen in the control groups in this study (range 5.4–7.2%) are comparable to rates reported in the last two decades (range 5–15%), indicating an institutional performance on par with other neurosurgical groups.3,6,7,8,10,15,21,3,3,3 Thus, the striking reduction in infection rate associated with intraventricular antibiotic administration seems to reflect a true biological effect.

In the present study, it is clear that the use of intraventricular gentamicin by itself did not confer a significant benefit over the use of systemic antibiotic therapy alone. Whether the reduction in infections seen with the combination of intraventricular gentamicin and intraventricular vancomycin is due to the influence of vancomycin alone cannot be conclusively deduced from the data obtained in this study. When used alone, intraventricular gentamicin was associated with only one Gram-negative organism shunt infection; the other seven shunt infections were caused by Gram-positive organisms. This vulnerability prompted the routine inclusion of intraventricular vancomycin in the senior author’s antibiotic protocol starting on May 16, 1999. After this change in protocol, only a single shunt infection occurred in 243 cases, and this infection was caused by a Gram-positive organism. It may be that intraventricular gentamicin does play a role in reducing infection with Gram-negative organisms. Gentamicin may also exert a synergistic effect with vancomycin against Gram-positive organisms. Because intraventricular gentamicin did not cause any recognized toxicity or adverse effect, even in patients undergoing as many as 17 shunt procedures, we would currently recommend a...
combination of each intraventricular drug for antibiotic prophylaxis. The neurotoxicity associated with gentamicin is directed at the spiral organ, which is outside of the CSF compartment and thus not affected by intraventricular administration.29

Pharmacology of Intraventricular Antibiotic Drugs

The goal of antibiotic prophylaxis in shunt surgery is to prevent seeding of the CSF or the shunt hardware with bacterial pathogens, which usually consist of skin flora. Historically, Staphylococcus species account for most postoperative shunt infections (range 62–75%), with other Gram-positive and -negative organisms making up the balance.8

The CSF is protected from the systemic circulation by the BBB. Drugs cross the BBB primarily by passive diffusion. Drugs that are lipophilic such as quinolones and rifampin cross the BBB more readily than hydrophilic drugs such as β-lactams and vancomycin. Drug clearance is mostly a function of CSF circulation and diffusion from the CSF space back into the blood. Intraventricular administration of drugs provides higher peak concentrations and better therapeutic maintenance of CSF concentrations, thus ensuring better surgical prophylaxis against organisms within the CSF.17

In current surgical antibiotic prophylaxis theory it is held that, for maximum effectiveness, the antibiotic agent must have perfused the tissue when any bacteria arrive.8 This is adequate for preventing most surgery-related wound infections involving soft tissue, even when implants are involved. Systemic antibiotic drugs alone consistently have been shown to be of only minor benefit, however, in lowering the risk of perioperative shunt infection.12 Our strategy is based on the hypothesis that CSF, in which there are no protective levels of antibiotic at the time of surgery, acts as a permissive reservoir for infection, potentially allowing seeding of the CSF during operation and ultimately allowing colonization of the shunt hardware. Thus, we believe that antibiotic sterilization of the CSF at surgery is imperative. Common systemic antistaphylococcal agents (for example, cefazolin) penetrate the CSF poorly. It has been shown that the CSF-to-blood concentration ratios of systemically administered antibiotic agents reach only 0 to 30% (β-lactam 1–21%, gentamicin 0–30%, and vancomycin 7–14%).17 Thus, a much higher systemic dosing schedule is needed for antibiotic materials to reach bactericidal activity within the CSF.

The bactericidal activity of antibiotic agents within the CNS can be divided into drugs that are time dependent and those that are concentration dependent. The bactericidal activity of β-lactam and vancomycin depends on the time their concentrations exceed the minimum inhibitory concentration of the infecting organism, whereas gentamicin has an ability to kill bacteria that is dependent on high concentrations.15

Cephalosporins have broad coverage against both Gram-negative and -positive organisms, but first- and second-generation cephalosporins penetrate the CSF poorly. Intraventricularly administered cephalosporins have been shown to have severe side effects, including seizures.27 Systemically administered third-generation cephalosporins are commonly used in treating meningitis but have been shown to be insufficient in reaching the minimum inhibitory concentration of 90 necessary to treat coagulase-negative staphylococcal species.17 Furthermore, the bactericidal activity of CNS cephalosporins is time dependent, and the drug is best administered in a regularly scheduled dose plan. Protracted antibiotic therapy is not routinely used with surgical prophylaxis.17 We believe that cefazolin is unable to prevent shunt infections because they are unable to sterilize the CSF effectively against staphylococcal species. They do, however, perform well in the blood and soft tissues, sufficient for prophylaxis in those compartments.

Vancomycin shows excellent Gram-positive coverage but penetrates the CSF poorly and has been routinely administered intrathecally without toxic effect.17 After intravenous administration of 1 g of vancomycin 1 hour preoperatively, LeRoux, et al.,16 obtained CSF samples in patients with hydrocephalus undergoing shunt procedures and found that vancomycin levels in the CSF ranged from 0.1 to 1.5 μg/ml. The authors of a recent in vitro pharmacodynamic study have recommended CSF vancomycin levels between 5 and 10 μg/ml for maximum bactericidal activity, with no additional benefit in bacterial killing noted when CSF concentrations exceeded 10 μg/ml.19 The same authors reported mean CSF concentrations of 300 μg/ml 1 hour after administration of 10 mg of vancomycin daily for 5 to 13 days (mean trough levels 7.6 μg/ml). The senior author’s intraventricular protocol utilizes 10 mg of vancomycin.

### TABLE 2

<table>
<thead>
<tr>
<th>Causative Agent</th>
<th>No. of Cases (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>staphylococcal species</td>
<td></td>
</tr>
<tr>
<td>MSSA</td>
<td>11 (31)</td>
</tr>
<tr>
<td>MRSA</td>
<td>6 (17)</td>
</tr>
<tr>
<td>coagulase-negative Staphylococcus</td>
<td>5 (14)</td>
</tr>
<tr>
<td>Propionibacter</td>
<td>3 (8)</td>
</tr>
<tr>
<td>Klebsiella</td>
<td>2 (6)</td>
</tr>
<tr>
<td>Enterobacter</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Streptococcus sanguis</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Pseudomonas</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Corynebacterium</td>
<td>1 (3)</td>
</tr>
<tr>
<td>diphtheroid</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Enterococcus</td>
<td>1 (3)</td>
</tr>
<tr>
<td>E. cloacae</td>
<td>1 (3)</td>
</tr>
<tr>
<td>unknown</td>
<td>2 (6)</td>
</tr>
<tr>
<td>total</td>
<td>36</td>
</tr>
</tbody>
</table>

* MRSA = methicillin-resistant S. aureus; MSSA = methicillin-sensitive S. aureus.

### TABLE 3

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Procedures</th>
<th>No. of Infections (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: IVT gentamicin &amp; systemic antibiotics</td>
<td>147</td>
<td>8 (5.45)</td>
</tr>
<tr>
<td>II: IVT gentamicin &amp; IVT vancomycin &amp; systemic antibiotics</td>
<td>243</td>
<td>1 (0.41)†</td>
</tr>
<tr>
<td>III: systemic antibiotics only, before 5/16/99</td>
<td>145</td>
<td>9 (6.21)</td>
</tr>
<tr>
<td>IV: systemic antibiotics only, after 5/16/99</td>
<td>267</td>
<td>18 (6.74)</td>
</tr>
</tbody>
</table>

* IVT = intraventricular.
† Significantly different from Group I, Group IV, and combined Groups I, III, IV (p = 0.0022, p = 0.0001, and p = 0.0001, respectively, Fisher exact probability test).
Potential Toxicity of Intraventricular Antibiotic Therapy

Although no antibiotic agent has been specifically approved by the US Food and Drug Administration for intraventricular use, both gentamicin and vancomycin have been used extensively in this way for the treatment of CNS infections. In a 1992 review of intraventricular antibiotic therapies, Wen, et al., found considerable evidence that intraventricular therapy with the appropriate antibiotic medications is “both efficacious and safe.” In humans, potential toxicities of these drugs have only been reported in the setting of repeated intraventricular administration for the treatment of infection.

With respect to vancomycin, Gollende and McKenzie have reported finding a transient change in mental status in one patient who received 5-mg doses daily for 4 days. No other cases of neurotoxicity involving intraventricular vancomycin have been reported. Neurotoxicity is associated with serum levels above 80 μg/ml; however, such a level would not occur with the dose used in our protocol.

With gentamicin, in a model in rabbits treated with a super–high intraventricular dose, there has been pathological evidence of ventriculitis, glial necrosis, axonal degeneration, and myelin swelling as well as neurological changes, but not when the doses were up to 10-fold that of the human therapeutic equivalent.12,20 Ototoxicity has been reported in association with intraventricular gentamicin in cats and in one infant also receiving systemic gentamicin but not in a larger series of patients receiving intraventricular drug administration alone.18,20,30 The absence of neurotoxicity has been shown with CSF levels of the drug up to 450 μg/ml.14 In the presence of a working shunt, the level of intraventricularly administered drugs in the CSF will decrease more rapidly than it would were it injected into a closed ventricle, further decreasing any potential for toxicity. In this study, no apparent neurotoxicity was associated with either drug, although detailed vestibular and audiometric testing was not performed.

Conclusions

The data obtained in this controlled mixed prospective–retrospective study represent strong Class II evidence favoring the use of systemic antibiotic prophylaxis in the prevention of postoperative shunt infections in adults. The benefit of intraventricular antibiotic therapy is likely the result of the production of sufficient CSF drug levels to effect prophylaxis, in combination with adequate blood and soft-tissue infection rates associated with conventional shunt surgery.11,12,23 To date, the clinical experience with these systems is limited. The authors of one pediatric series reported a 3.2% infection rate in 31 patients in whom antibiotic-impregnated catheters were implanted.3 Govender, et al., have reported that in a small randomized prospective trial involving 110 patients, antibiotic-soaked shunts reduced the perioperative infection rate from 13.3 to 2%, and the devices seemed to be especially effective against staphylococcal organisms. Although promising, the data involving antibiotic-impregnated shunts are not currently as strongly powered as those derived from the present study. The use of intraventricular antibiotic medications, as described here, may be more cost effective than using drug-impregnated shunts. It may also be that the combination of intraventricular antibiotic drugs and antibiotic-impregnated shunts will represent the ultimate weapon against the devastating costs and personal consequences of shunt infection.

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tissue levels from a systemically administered antibiotic agent. A randomized blinded prospective trial of this protocol is currently being organized at our institution. Additionally, further studies will be necessary to determine whether the benefits of intraventricular antibiotic administration extend to shunt procedures in the pediatric population.

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Disclaimer

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Address reprint requests to: Richard H. Schmidt, M.D., Ph.D., Department of Neurosurgery, University of Utah Health Sciences Center, 30 North 1900 East, Suite 3B409 SOM, Salt Lake City, Utah 84132-2303, email: rhs@suzy.med.utah.edu.