All CSF shunt infections are medicosurgical failures, and this is doubly true for recurrent shunt infections after failure of treatment. Recurrent infections are both time- and resource-consuming neurosurgical complications, simple in concept, and commonly believed to result from incomplete eradication of preexisting infections. Neurosurgeons are inconsistent in their management of shunt infections with regard to the reuse of cranial entry sites for temporary CSF drainage and for shunt reinsertion, but the time-honored and customary practice is to never reuse a ventricular entry site that has been associated with infection. Many surgeons prefer to insert the new shunt in a different quadrant of the head, often on the contralateral side. Switching to a new site is perceived by its advocates as conservative practice, and the rationale for this is based on two closely related beliefs: a contaminated shunt track cannot be reliably sterilized, and the risk of recurrent infection is less if a new ventricular entry is made in a faraway location.6,7,18,21,27 A diametrically contrary approach, perceived by its advocates as more conservative, holds that the original site can be reliably sterilized, and that making a new bur hole and ventricular puncture introduces unnecessary additional risks for most patients. The tradition, intuition, and gestalt on which these contradictory opinions are based have little if any reliable data-based support.

The reuse of ventricular drain sites for first-time CSF shunt insertions, following a period of ventricular drainage not associated with infection, has been reported to...
have quite a low incidence of shunt infection.\textsuperscript{28,40} It is therefore reasonable to wonder if the reuse of ventricular entry sites associated with infected CSF shunts is also relatively safe. If reuse of contaminated sites is as safe as switching to new sites, then the risks of complications associated with making additional bur holes and ventricular punctures can be avoided.

This investigation examines recurrent CSF shunt infection in a consecutive series of patients treated for shunt infection, in which new ventricular entry sites were infrequently used during the period of external drainage and for shunt reinsertion.

**Methods**

All patients treated for CSF shunt infection at Children’s Hospital Colorado between the inclusive dates of January 1, 2001, and June 30, 2011, constitute the basis of this investigation. Most patients received all prior neurosurgical care at Children’s Hospital Colorado; however, patients who underwent CSF shunt surgery at other hospitals but were admitted to Children’s Hospital Colorado with shunt infections were also included. Cases were identified from records of the Shunt Infection Committee, a multidisciplinary committee that meets quarterly to validate all prior diagnoses of shunt infection and to review all suspected and questionable cases of CSF shunt infection.\textsuperscript{41} Diagnoses of shunt infection were made by taking into consideration all relevant information, which, depending upon availability and case details, included microbiology reports from CSF, peritoneal fluid, and shunt hardware, glucose and protein concentrations in CSF, presence of purulence in contact with hardware, cell counts in CSF and blood, exposure of shunt hardware, cellulitis near shunt hardware, CSF leakage through skin, presence of a peritoneal pseudocyst, and history of recent surgery involving a CSF-containing space. Consistent with National Healthcare Safety Network criteria, cases with less than 12 months of follow-up after shunt implantation were excluded.\textsuperscript{6} A positive culture was considered to be strong supportive evidence for shunt infection but not a sine qua non requirement. An unexpected positive culture from a shunt revision was followed by a shunt tap a few days later for repeat culture. Negative cultures and absence of cultures did not preclude the diagnosis of shunt infection. We reviewed the details of interest in the existing medical records. This study was done with approval of the Colorado Multi-Institutional Review Board.

All cases of shunt infection were treated by removing the shunt hardware, inserting a ventricular drain, initiating a course of intravenous antibiotics, and reinserting the shunt. All disconnected or isolated hardware was removed. The day on which the contaminated CSF shunt hardware was removed at the start of treatment for shunt infection is considered the date of case entry into this study. Consistent with National Healthcare Safety Network criteria, infection occurring within 12 months following shunt implantation, in this case reimplantation, starts on the date of reimplantation.\textsuperscript{6} The following terminology was used for categorizing recurrent shunt infections: “persistent reinfection” refers to recurrent shunt infection with the same organism as the original, and “new reinfection” refers to recurrent shunt infection with an organism different from the original. The schema used for the classification of recurrent CSF shunt infections and for their attributions is shown in Table 1. The term “culture-negative” shunt infection is used for cases in which the diagnosis was made on the basis of strong clinical and laboratory evidence that did not include the identification of any microbiological organism. The Fisher exact test was used to compare proportions in 2 × k contingency tables (http://www.graphpad.com/quickcalc/). The 95% confidence intervals express the reliability with which individually calculated infection rates are known (http://www.graphpad.com/quickcalc/).\textsuperscript{55}

**Results**

One hundred twenty-one CSF shunt infections were diagnosed and treated at Children’s Hospital Colorado over a span of 10.5 years, and 107 of these were positive cultures. The median age at diagnosis of shunt infection was 23 months (range 2 weeks to 23 years). There were 51 females and 70 males (ratio 1:1.4) (Table 2). Organisms from the 107 positive cultures included 28 species of bacteria and 2 fungal species (Candida albicans and C. parapsilosis). Eighty (74.8%) of the 107 positive cultures included at least 1 species of staphylococcus: 36 were S. aureus (8 methicillin resistant), 36 were S. epidermidis, and 8 were other staphylococcal species. Eight patients had multigorganism infections, and 6 of these included 1 or more species of staphylococcus. Cultures were negative at the time of diagnosis of the original shunt infections in 16 cases; these were accepted as valid shunt infections on the basis of other compelling evidence.\textsuperscript{41} One patient’s recurrent infection followed shortly after fundoplication and another patient’s recurrent infection occurred shortly after posterior fossa craniotomy; the organisms identified at these recurrences were different from the original organisms. These 2 reinfections are included in the calculation of total recurrence but are not included in the detailed analyses of cases because, from a neurosurgical management perspective, the outcome would not have been altered by any different neurosurgical management of the original shunt infection.

The incidence of recurrent shunt infection attributable to original shunt infections was 11.6% (14 of 121 cases), but inclusion of the 2 cases not attributable to shunt surgery gives an overall rate of 13.2%. Among the 14 patients with recurrent shunt infection, 11 were male (78.6%) and 12 (85.7%) were younger than 2 years (p > 0.05 for both sex and age). If culture-negative diagnoses are excluded from both the original infections and from the recurrences, there remain 10 recurrent infections in the 102 cases of original shunt infection for a 9.8% incidence of recurrent shunt infection. The occurrence of recurrent shunt infection did not correlate with diagnostic category, but all 14 recurrent infections occurred in 3 diagnostic categories (birth defect, congenital hydrocephalus, and prematurity with intraventricular hemorrhage). The median time between shunt reinsertion and the diagnosis of recurrent infection was 31 days (range

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5–301 days); the time to recurrence did not correlate with species of pathogen at original infection.

Three of the recurrent infections were culture negative. All 11 culture-positive recurrent infections occurred with single organisms. There were no recurrent infections in patients with original multiorganism infections and also none among the 8 cases with methicillin-resistant *S. aureus*. Three (12.0%) of the 25 patients initially infected with methicillin-sensitive *S. aureus* experienced recurrent shunt infection but only 1 was infected with the same species (Table 3). There were 6 recurrent shunt infections among the 36 original cases of *S. epidermidis* (16.7%), and only 2 of these were persistent infections. Four species accounted for 11 of the culture-positive recurrent infections (Table 3), 7 of which were staphylococci (5 were *S. aureus* and 2 were *S. epidermidis*).

The distribution of recurrent infections by recurrence category is shown in Table 4. There were 3 recurrences with the same organisms as those identified from the original infections (all staphylococci), and these were therefore classified as persistent-type reinfections caused by incomplete eradication of the original infecting organisms. Seven recurrences were classified as new-type infections caused by microbial contaminations that occurred near the time of shunt reinserterion. Four recurrent shunt infections had to be classified as indeterminate on the basis of negative cultures. Three (21.4%) of the 14 patients who subsequently developed reinfection and 35 (32.7%) of the 107 patients who did not experience reinfection had a history of prior shunt infection (p > 0.05).

The shunt system included more than 1 ventricular catheter in 3 (21.4%) of the 14 patients with recurrent shunt infection and in 9 (8.4%) of the 107 patients with no recurrent shunt infection (p > 0.05). Eight of the recurrent shunt infections were associated with 1 surgeon, and 5 of these were new-type recurrences.

Ventricular drains were replaced at least once during treatment in 4 (28.6%) of 14 patients who experienced recurrent infection and in 26 (24.3%) of 107 patients who did not experience recurrent infection (p > 0.05). Indications for replacement included accidental removal, CSF leak, obstruction, persistent positive cultures or appearance of a new organism, wound dehiscence, and unclear reason. The most common indication was persistent positive culture or appearance of a new organism in surveillance cultures of ventricular drainage.

The median duration of ventricular drainage during treatment of shunt infection was 14 days for those who had recurrent infection and for those who did not, but the ranges were different (Table 2). Longer periods of ventricular drainage were associated with a need for catheter replacement during the course of treatment. Twelve (86%) of the 14 recurrent infections occurred within 80 days after shunt reinserterion.

### TABLE 1: Schema for classification and attribution of recurrent CSF shunt infections

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Attribution for Recurrent Infection</th>
<th>Shunt Reinfection Category</th>
<th>Strategic Emphases for Prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td>organism from original infection vs that from recurrence</td>
<td>same: incomplete eradication</td>
<td>persistent</td>
<td>1) antibiotic choice, dosage, &amp; duration; 2) ventricular drain replacement</td>
</tr>
<tr>
<td></td>
<td>different: periop contamination</td>
<td>new</td>
<td>1) scalp preparation; 2) ventricular drain management; 3) surgical technique at reinplantaion; 4) antibiotic prophylaxis</td>
</tr>
<tr>
<td></td>
<td>no growth*: incomplete eradication or periop contamination</td>
<td>indeterminate</td>
<td>not determinable</td>
</tr>
<tr>
<td>recurrence not related to initial shunt infection</td>
<td>contamination (not from shunt surgery) or sepsis</td>
<td>other</td>
<td>issues related to nonshunt surgery; antibiotic prophylaxis</td>
</tr>
</tbody>
</table>

* On either initial infection or recurrent infection.

### TABLE 2: Comparison of patients with and without recurrent shunt infection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Persistent (n = 3)</th>
<th>New (n = 7)</th>
<th>Indeterminate (n = 4)</th>
<th>No Recurrence (n = 107)</th>
</tr>
</thead>
<tbody>
<tr>
<td>median age (range)</td>
<td>1.6 mos (0.1–0.4 yrs)</td>
<td>19 mos (0.2–10 yrs)</td>
<td>6 yrs (0.5–8 yrs)</td>
<td>23 mos (0.0–23 yrs)</td>
</tr>
<tr>
<td>F/M</td>
<td>1.2</td>
<td>2.5</td>
<td>0.4</td>
<td>48.59</td>
</tr>
<tr>
<td>median days of external ventricular drainage (range)</td>
<td>14 (10–16)</td>
<td>14 (7–25)</td>
<td>10 (9–22)</td>
<td>14 (4–90)</td>
</tr>
<tr>
<td>median days to diagnosis of recurrent infection (range)</td>
<td>35 (31–80)</td>
<td>29 (3–301)</td>
<td>45 (13–280)</td>
<td></td>
</tr>
<tr>
<td>no. w/ prior shunt infection w/in 1 yr</td>
<td>0</td>
<td>3 (43%)</td>
<td>0</td>
<td>35 (33%)</td>
</tr>
<tr>
<td>no. w/ &gt;1 ventricular catheter</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>
Reuse of the original ventricular entry site in 107 cases was followed by 12 recurrent shunt infections (11.2%), whereas change to a new entry site in 14 cases was followed by 2 recurrent infections (14.3%) as shown in Table 5 (p > 0.05). One of these patients had a severely eroded scalp at the original site, and the other had a brain abscess adjacent to the ventricular catheter.

**Discussion**

Recurrent CSF shunt infections are a heterogeneous group, and their origins are not unicausal. For this reason the all-inclusive incidence of recurrent infection, 11.6% in this series, does not have the same implication for medical-surgical management as does an infection rate for first shunt insertions. One hundred seven of our 121 consecutively treated cases of CSF shunt infection experienced no recurrent shunt infections, and another 7 experienced recurrent infections with organisms different from the original organism. Therefore, initial pathogens were successfully eradicated in 114 cases, giving a cure rate of at least 94.2%. There were 4 cases for which the attribution of recurrent infection was indeterminate; it is possible that the original pathogens were eradicated in 1 or more of these cases, thereby raising the rate for total eradication.

Recurrent shunt infection can result either from incomplete eradication of infecting organisms or from new organisms being introduced in the course of treatment of the shunt infection. Three recurrent infections in this series were in the persistent infection category, thus accounting for at least 2.5% of recurrences in the 121 treated cases and for 21.4% of the 14 recurrent infections (Table 5). A strategy to prevent this category of recurrent shunt infection requires that attention be focused on issues of therapy such as antibiotic choice, dosage, duration, and on the need for replacement of ventricular drains. Interestingly Kestle et al. found that 12 of their 18 recurrent infections were with original organisms.

Recurrent shunt infections with new pathogens are epidemiologically different from persistent-type infections and, because they reflect both therapeutic success and failure, their recognition is of critical importance to neurosurgeons and infection preventionists. The original pathogens were successfully eradicated, but new bacteria gained entry, either at the time of shunt reinsertion or perhaps during the period of ventricular drainage, but were missed in late surveillance cultures. The category of new infection accounted for 5.8% of recurrent infections in the series of 121 cases but half of the 14 recurrences (Table 4). Recurrent shunt infection in the new infection category is causally and conceptually quite similar to shunt infection that follows clean CSF shunt revision; this topic has been extensively addressed in the neurosurgical literature and will not be reviewed here. The observation by Kestle et al. that longer durations of ventricular drainage before shunt reimplantation do not

### TABLE 3: Bacterial species cultured from patients who experienced recurrent shunt infection, correlating the original species with species cultured at time of recurrences

<table>
<thead>
<tr>
<th>Organisms Cultured From Recurrent Infection</th>
<th>Candida parapsilosis</th>
<th>Pseudomonas aeruginosa</th>
<th>Staphylococcus aureus, MS</th>
<th>Staphylococcus epidermidis</th>
<th>No Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rothia dentocariosa</td>
<td>1 (22; 58)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus aureus, MS</td>
<td>2 (25, 25; 5, 69)</td>
<td>1 (16; 35)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus capitis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus epidermidis</td>
<td>1 (13; 301)</td>
<td>2 (10, 14; 14, 29)</td>
<td>2 (10, 13; 31, 80)</td>
<td>1 (9; 280)</td>
<td></td>
</tr>
<tr>
<td>Streptococcus β, group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streptococcus viridans</td>
<td></td>
<td>1 (23; 30)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no growth</td>
<td>1 (11; 31)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Values in parentheses represent the number of days of ventricular drainage; number of days to diagnosed recurrent infection. Other values indicate the number of cases. Abbreviations: MS = methicillin-sensitive.

### TABLE 4: Distribution by category of recurrent CSF shunt infections related to management of prior shunt infections

<table>
<thead>
<tr>
<th>Recurrence Category</th>
<th>No. of Recurrent Shunt Infections</th>
<th>% Distribution of Recurrent Infections in Series (n = 121)*</th>
<th>% Distribution of Recurrent Infections by Recurrence Category (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>persistent</td>
<td>3</td>
<td>2.5 (0.5–7.4)</td>
<td>21.4</td>
</tr>
<tr>
<td>new</td>
<td>7</td>
<td>5.8 (2.6–11.7)</td>
<td>50.0</td>
</tr>
<tr>
<td>indeterminate</td>
<td>4</td>
<td>3.3 (1.0–8.5)</td>
<td>28.6</td>
</tr>
<tr>
<td>negative initial infection culture</td>
<td>4</td>
<td>3.3 (1.0–8.5)</td>
<td>28.6</td>
</tr>
<tr>
<td>negative recurrent infection culture</td>
<td>1</td>
<td>0.8</td>
<td>7.1</td>
</tr>
<tr>
<td>total</td>
<td>14</td>
<td>11.6 (6.9–18.6)</td>
<td>100</td>
</tr>
</tbody>
</table>

* Values in parentheses are 95% CIs.
reduce the incidence of recurrent shunt infection is likely explained, at least in part, by the 33% occurrence in their recurrence pool by new-type recurrent shunt infections. A strategy to prevent new-type recurrent shunt infection necessitates attention to such issues as skin preparation, sterile management of ventricular drainage systems, meticulous surgical technique at reimplantation, and antibiotic prophylaxis. Longer periods of ventricular drainage and antibiotic therapy cannot be expected to reduce this category of recurrent shunt infection. Based on studies of shunt infections and wound cultures at time of shunt insertion, Thompson et al.36 suggested that vulnerability to bacterial colonization of shunts may even extend well beyond the surgical procedure and into the period of wound healing.

The dominance of staphylococci in both the culture-positive initial shunt infections (73.4%) and in the recurrent infections (63.6%) is consistent with many published reports (Table 5).2,3,13,22,29,37 It is interesting, however, that the most common recurrences in this series after staphylococcal infections were not with the same species, but with newly appearing pathogens.

The 11.2% shunt reinfection rate associated with using original ventricular entry sites in 107 cases was lower than the 14.3% rate associated with switching to new entry sites in our 14 cases of recurrence, but the difference did not approach statistical significance (Table 5). A much larger sample of recurrent shunt infections, with more cases in each category, would allow stronger conclusions. A decision to switch to a new ventricular entry site was always based on the surgeon's subjective concern about reuse of the old site and was never done randomly or as a routine or standard of practice. Six of the 12 recurrent infections associated with reuse of original ventricular entry sites were of the new type. It seems very unlikely that these shunt reinfections with new organisms could have been avoided by making bur holes and ventriculostomies in new and faraway sites. A possible explanation may lie in the greater ease in preparing a sterile surgical field in a fresh site. Sutures or staples placed in the scalp at the time of shunt removal and ventricular drain insertion are often still present at the time of shunt reimplantation, and their presence may compromise preparation of the scalp for reimplanting Silastic shunt material. These sites can harbor any type of endogenous flora of the patient and hospital environment. Better attention to surgical-site preparation should offset this source of risk.

Either the original shunt site is colonized at the time of shunt reimplantation or it is not. If not colonized, then the original site is bacteriologically safe for reuse. If the old track remains colonized, then reuse of any part of the track will expose the patient to a high risk of persistent infection. If dormant or active bacteria lie anywhere within brain parenchyma or along any CSF pathway, then the risk of recurrent shunt infection approaches certainty, regardless of the site chosen for reinsertion. There are no data to convincingly support beliefs that CSF shunt tracks previously associated with infection remain forever colonized, that these tracks cannot be rendered bacteria free by antibiotics used in the treatment of shunt infections, or that safety from recurrent infection is enhanced by increasing the distance from a sterile track previously associated with infection. If bacteria anywhere along a previously infected track survive through days or weeks of antibiotic therapy, they are very unlikely to be eradicated by a short postoperative continuation of antibiotics administered for prophylaxis, regardless of the location of a ventricular catheter.

Kulkarni et al.23 in a study focusing on recurrent shunt infections, reported a recurrent infection rate of 19.6% in 51 children, and Kestle et al.15 reported recurrent infections in 26%. It is particularly interesting to compare the current series with a series of first-time shunt insertions using ventricular drain sites not associated with prior infection because both series are from the same hospital, from overlapping time spans, and most of the operations were done by the same neurosurgeons; however, persistent-type recurrent infections in the current series must be excluded because, by definition, there was no risk of persistent reinfection in the published series having no prior associated infections.40 The difference between the 5.8% (95% CI 2.6%–11.7%) new-type recurrent shunt infection rate in this series and the 2.0% (95% CI 0.0%–11.5%) infection rate in that series is insignificantly different (p > 0.05).40 Interestingly, Kestle et al.16 did report that shunt surgery after ventricular drainage, regardless of prior infection, was associated with an elevated rate of infection.

Most reports on the incidence of shunt infection have not focused on recurrent infections. Differences in experimental design, including inclusion criteria, between this study and most published reports on shunt infection limit most conclusions. A sampling of peer-reviewed reports published within the last decade, reflecting smaller data sets and various clinical subcategories, diagnostic criteria, and inclusion criteria, encompasses a spectacular range of shunt infection rates8,11,13,14,16,19,25,29,31,37 going from 0.4% at 90 days in 243 patients receiving systemic and intraventricular antibiotics26 to 40.7% in 59 neonates with myelomeningocele who did not receive antibiotics.7 However Simon et al.33 found in data collected from 41 hospitals on 7071 initial shunt operations that 24-month infection rates ranged from 2.5% to 12.3% per shunt operation. One report indicates that the hazard ratio after

**TABLE 5: Shunt reinfection by site of shunt reinsertion after treatment of shunt infection**

<table>
<thead>
<tr>
<th>Ventricular Entry Site Used for New Shunt</th>
<th>Category of Recurrent Shunt Infection</th>
<th>Persistent</th>
<th>New Type</th>
<th>Indeterminate</th>
<th>Total</th>
<th>% (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>old site reused (n = 107)</td>
<td></td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>12</td>
<td>11.2 (6.4–18.7)</td>
</tr>
<tr>
<td>new site used (n = 14)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>14.3 (2.8–41.2)</td>
</tr>
<tr>
<td>all sites (n = 121)</td>
<td></td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>14</td>
<td>11.8 (6.9–18.6)</td>
</tr>
</tbody>
</table>
shunt revision is significantly greater than that after initial shunt revision, and another indicates the hazard ratio after shunt revision to be significantly greater than that after initial shunt revision.

Clinical characteristics of patients who experienced recurrent shunt infections were not significantly different from those of the entire series with respect to age, sex, diagnostic category, number of patients with more than 1 ventricular catheter, duration of ventricular drainage, number of prior shunt infections, and number of changes of ventricular drains during treatment (Table 2). The interval between shunt reinsertion and diagnosis of recurrent shunt infection was not significantly different for genera and species of original infecting organisms or for organisms identified at the time of recurrent infection (Table 3). Kulkarni et al. were unable to identify risk factors for recurrent shunt infections. Other authors have reported a spectrum of risk factors for shunt infection (not limited to recurrent infection) in a variety of databases and small subgroups. The lack of identifiable risk factors in this and other series can be interpreted in several ways: 1) clinical features that predisposed to the original infection, if such exist, were also operant for recurrent infections, 2) the series was too small to reflect differences, or 3) the clinical features examined were not ones that contributed to recurrent infection. It is also likely that risk factors for recurrence vary with surgeons and institutions, and therefore, factors not identified in this series could be important in other series.

Inclusion of culture-negative cases as valid shunt infections appreciably impacted our calculated reinfection rates. Had culture-negative diagnoses been rejected, our overall recurrent infection rate would have been 9.8%, with 3 persistent infections and 7 new-type infections. Their inclusion may seem troubling or even unjustified to some clinicians, but their exclusion is more problematic. Cases with strong clinical evidence of shunt infection but without bacterial confirmation should still be considered as cases of shunt infection. Although a requirement for culture positivity is occasionally mentioned among inclusion criteria, culture-negative cases are not commonly addressed in published reports on shunt infections, perhaps because of inclusion criteria, stated or not stated, that require microbiological confirmation. A detailed discussion of sources of errors and biases in diagnosing and reporting shunt infections has been addressed in a prior publication.

Recurrent shunt infection with the same genus and species as cultured from an original infection may not always be the result of incomplete eradication. *Staphylococcus epidermidis*, a ubiquitous organism on human skin, is the most common organism cultured from both CSF shunt infections and recurrent infections. When *S. epidermidis* is the identified pathogen in both, it is difficult, if not impossible, to determine whether the recurrent infection is from incomplete eradication or from reintroduction of the same species after eradication of the original. It is therefore reasonable to believe that some recurrent infections with *S. epidermidis* are actually new-type recurrent infections resulting from contamination by the same species. At this time the only practical choice is to continue to assign these cases to the persistent category. Also, staphylococci are likely, on a statistical basis, to be the major contributor to the indeterminate category of recurrent shunt infections.

Reuse of ventricular entry sites has important benefits. The track is already present and, if the site has a history of serving well in the past, it will likely continue to do so if it is reused. Switching to a new site may require multiple passes to achieve satisfactory catheter placement, particularly if the ventricles are small. Each pass, regardless of professional expertise has a risk of malposition and also a risk of causing bleeding into the parenchyma or ventricle. In a series of 96 ventricular drain insertions in 66 patients, Ngo et al. reported misplacement in 6.3%, hemorrhage in 4.2%, and obstruction or malfunction in another 3.2%. In 212 consecutive ventricular drainage procedures, 12.3% of catheters were misplaced according to a report from the Mayo Clinic. Anderson et al. reported 12 hemorrhagic complications from the insertion of ventricular drains in 62 children with head trauma. Also, each cortical puncture introduces a small, albeit extremely important, risk of producing a seizure focus. Children who develop epilepsy after CSF shunt insertion most often have focal epilepsy, and the focus is typically at the anatomical site of shunt entry. It is reasonable to believe that adding ventricular entry sites increases the risk of producing an epileptogenic focus. Reusing an existing track requires less time than making a new scalp incision, new bur hole, and track through the cerebral mantle, and it also avoids additional scarring of the scalp. Very importantly, reuse totally avoids the risks associated with making a new puncture through brain parenchyma.

Sound reasons exist for abandoning an original ventricular entry site, and these include erosion of overlying scalp, persistent purulence in close proximity, underlying brain abscess, and of course unsatisfactory location of the original shunt track. Any factor that would predictably compromise the secure closure of an incision, for example, very thin or extensively scarred overlying scalp, is a satisfactory, if not compulsory, reason to choose a new site. However, prior existence of shunt infection alone is not a sufficient reason to abandon a previously well-functioning site.

Weaknesses of this investigation include the small number of recurrent shunt infections and the resulting small number of cases in each subcategory. The identification of distinct categories of reinfection is not compromised by small numbers, but comparison of percentages within these categories is not valid. A larger number of recurrent infections would be desirable; however, 20,000 new shunt operations would be required to have 100 re-infection cases for analysis, if the new shunt infection rate were 5% and the reinfection rate were 10%. Until such a study is done, clinicians working in the imperfect medical domain of hydrocephalus and CSF shunt infection must rely on sound logic applied to available data to make their decisions.

Conclusions

Two distinct causal categories of recurrent CSF shunt
infection are identified: persistent infection resulting from incomplete eradication of original infection and new infection caused by the introduction of new species of bacteria. As their labels denote, the causes and the actions needed for prevention are importantly different. Recent shunt infection is not, alone, a sufficient reason to switch to a new ventricular entry site either for external CSF drainage or for the implantation of a new shunt. Reuse of ventricular entry sites that were associated with infection was not associated with a higher incidence of recurrent infection than was the making of fresh ventricular entry sites. In addition, reuse of prior sites avoids the adversities and complications associated with making new entry sites.

**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: Winston. Acquisition of data: Winston. Ho. Analysis and interpretation of data: all authors. Drafting the article: Winston, Ho. 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: Winston. Statistical analysis: Winston. Study supervision: Winston.

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