VENTRICULOSTOMY-RELATED INFECTIONS: A CRITICAL REVIEW OF THE LITERATURE

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OBJECTIVE: To provide a critical evaluation of the published literature describing risk factors for ventriculostomy-related infections (VRIs) and the efficacy of prophylactic catheter exchange.

METHODS: A MEDLINE literature search was performed, and data were extracted from studies published from 1941 through 2001.

RESULTS: Published criteria for diagnosing VRIs are highly variable. Intraventricular hemorrhage, subarachnoid hemorrhage, cranial fracture with cerebrospinal fluid leak, craniotomy, systemic infections, and catheter irrigation all predispose patients to the development of VRIs. Extended duration of catheterization is correlated with an increasing risk of cerebrospinal fluid infections during the first 10 days of catheterization. Prophylactic catheter exchange does not modify the risk of developing later VRIs in retrospective studies.

CONCLUSION: Categorizing suspected cerebrospinal fluid infections as contaminants, colonization, suspected or confirmed VRIs, or ventriculitis more accurately describes the patient's clinical condition and may indicate different management strategies. A prospective, randomized clinical trial is required to further evaluate the efficacy of prophylactic catheter exchange in limiting the incidence of VRIs during prolonged catheterization. Although prophylactic catheter exchange remains a practice option, the available data suggest that this procedure is not currently justified.

KEY WORDS: Central nervous system infections, Cerebrospinal fluid shunts, Indwelling catheters, Neurosurgical procedures, Postoperative complications, Risk factors, Ventriculostomy

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Ventriculostomy catheters (also called *external ventricular drains* [EVDs]) are unique among intracranial pressure (ICP) monitors in that they afford the surgeon the option of therapeutic drainage of cerebrospinal fluid (CSF). Temporary intraventricular catheters are particularly useful for the management of patients with elevated ICP secondary to acute hydrocephalus caused by subarachnoid hemorrhage (SAH), intracerebral hemorrhage (ICH), intraventricular hemorrhage (IVH), and neoplasms obstructing the CSF circulation. Enthusiasm for the use of EVDs has always been tempered somewhat by the increased risk of ventriculomeningitis associated with this modality of ICP monitoring. Infection rates of 0 to 22% have been reported, but more commonly they are close to 10% (1, 2, 5, 6, 10, 12, 14, 18–22, 24, 25, 27, 29–34, 37, 38). Factors that predispose a patient with a ventriculostomy to developing ventriculomeningitis have been investigated extensively. Many of the factors that have been identified (e.g., craniotomy, systemic infection, depressed cranial fracture, IVH) are already pervasive in the patient population and thus confound the relationship between EVDs and meningitis.

Long-standing controversy surrounds the relationship between the duration of ventriculostomy and the risk of developing ventriculomeningitis. The relevant literature is rife with contradiction, retrospective studies, erratic use of antibiotics, and widely varying definitions of CSF infection. A related issue is whether prophylactic catheter exchange at a predefined interval is beneficial in limiting the risk of infection. The duration of ICP monitoring or ventricular drainage that is required generally is assessed by the patient's clinical course and not by routine. Catheter exchange is much more likely to remain under the phy-

sician's control, but well-recognized exceptions exist. Mechanical failure or obstruction may necessitate early exchange; collapsed ventricles in an edematous brain or the development of a coagulopathy may prevent safe catheter exchange. Nevertheless, for the majority of patients, it is possible to attempt to decrease the risk of infection by limiting the duration of monitoring with the use of any one catheter. In this article, we review the body of literature relevant to ventriculostomy-related infections (VRIs) and prophylactic catheter exchange.

METHODS

We performed a MEDLINE literature search (i.e., from 1966 through 2001) using the key words *ventriculostomy* and *infection*. The combination of these key words generated 79 references, the titles and abstracts of which were then reviewed for evidence of relevance. Twenty-five articles directly addressed CSF infections related to ventriculostomy. A review of the reference sections of these articles yielded seven additional citations. Further MEDLINE searches using the key words *external ventricular drain* and *intracranial pressure monitor* failed to reveal any new references. Thus, 32 original articles published from 1941 through 2001 comprised the database for this review.

LITERATURE REVIEW

Bering (4) first reported the occurrence of CSF infections in patients with ventriculostomies in 1951. Since then, many authors have reported the incidence of VRIs and the risk factors associated with their development. The majority of these studies were retrospective in nature and highly variable in terms of study population, definition of infection, use of antibiotics, and duration of monitoring. These differences make it difficult to compare infection rates among studies. Nevertheless, several variables have been consistently associated with CSF infections in patients with ventriculostomies. First, we review the criteria that different authors have used to define and to detect a VRI, then we address the strength of the data supporting the putative role of reported risk factors for VRI.

Defining CSF Infections in Patients with Ventriculostomies

The majority of the published series that we reviewed described CSF infections as *ventriculitis* or *meningitis,* whereas others used the more specific term *catheter-related infections*. Regardless of the terminology used, most articles defined CSF infections according to the criteria advocated by Mayhall et al. (21)—namely, a positive CSF culture obtained from the ventricular catheter or from CSF drawn via lumbar puncture (6, 12, 16, 18, 20, 21, 24, 25, 27, 29, 32, 37). Few studies required more than a single positive culture (11, 30, 32). Only a handful of investigators considered positive cultures in conjunction with CSF pleocytosis, low glucose level, or high protein level in defining CSF infections (2, 19, 20, 30). In the absence of positive cultures, some researchers accepted CSF pleocytosis alone (5, 12, 27) or low CSF glucose level alone (12) as evidence of CSF infections. A minority of investigators incorporated clinically relevant factors such as fever and change in mental status when reporting the incidence of CSF infections in patients undergoing ventriculostomy (28). We elaborate on the definitions put forth in these studies below (5, 6, 31, 33, 34).

Sundbarg et al. (34) classified a positive CSF culture as a definite VRI if it was associated with CSF pleocytosis (defined as at least 11 leukocytes/mm^3 with 50% or more polymorphonuclear neutrophils) and clinical symptoms that could not be attributed to causes other than ventriculitis. Patients with positive CSF cultures and CSF pleocytosis who lacked clinical symptoms or had other likely sources of infection were classified as having suspected VRIs. Isolated positive CSF cultures with normal CSF cell counts and the absence of clinical symptoms were designated as contaminants. Hader and Steinbok (11) further restricted the Sundbarg et al. (34) definition of contaminants by requiring a negative Gram's stain coincident with the positive CSF culture. Rosner and Becker (28), on the basis of the presence or absence of a number of risk factors (i.e., basal or compound cranial fracture, craniotomy, excessively long surgery, or operative reexploration), classified complications as definitely monitor related, probably monitor related, or probably not monitor related. Schultz et al. (30) and Hader and Steinbok (11) narrowed the Sundbarg et al. (34) definition of suspected VRI by requiring two positive CSF cultures with the same organism on different days.

Several authors excluded patients with positive CSF cultures from the ventriculitis cohort on the ground that their infections were not primarily catheter related. The most widely accepted of such criteria required an initial sterile CSF culture obtained at the time of EVD insertion (11, 12, 20, 21, 30). Patients with positive CSF cultures at EVD insertion were diagnosed with preexisting meningitis. More controversial were the exclusion criteria developed by Mayhall et al. (21), which eliminated patients on the basis of other sources of infection, such as CSF leaks (16, 21, 22), concurrent bacteremia with the same organism that was isolated from the CSF (16, 21, 37), or penetrating injury to the central nervous system (16, 21, 22).

CSF Sampling Method

One of two CSF surveillance techniques was used in the majority of studies. Many investigators obtained CSF samples directly from EVDs on a scheduled (usually daily) basis (18, 24, 29, 30, 33, 37). Other authors collected CSF only at EVD insertion, removal, and when clinically indicated (e.g., fever, clinical signs of meningitis [2, 12, 20, 21, 25, 31]). Many studies included cultures of catheter tips as well as CSF samples (14, 31, 33, 34). Several authors also collected CSF via lumbar puncture up to 2 weeks after ventriculostomy removal (21, 25, 34).

Incidence of Ventriculostomy Infections

The reported incidence of VRIs per patient was between 0 and 22.0% (1, 2, 5, 6, 10, 12, 14, 18–22, 24, 25, 27, 29–34, 37, 38). Methodological differences, variable definitions of infection, and sporadic use of antibiotics made differences in the incidence of VRIs difficult to interpret. Nevertheless, the majority of studies that required some clinical indication of infection reported lower infection rates than did those that relied on positive cultures alone. When the data from 23 major studies of ventriculostomy comprising 5733 EVD insertions in 5261 patients were pooled, the cumulative rate of positive CSF cultures was 8.80%/patient or 8.08%/EVD (*Table 1*). Applying the definition of Sundbarg et al. (34) of definite VRI to studies in which clinical data were reported (27, 31, 33, 34), the incidence of infections declined to 6.62%/patient or 6.10%/EVD.

Bacteriology

Sixteen studies reported bacteriological identification of isolates obtained from EVDs (1, 2, 6, 11, 14, 20, 21, 24, 25, 27, 31–34, 37, 38). Gram-positive cocci consistent with skin flora comprise the majority of isolates in ten investigations (6, 11, 14, 24, 25, 27, 31–33, 37, 38). Gram-negative rods (6, 11, 14, 20,

TABLE 1. Previous series reporting the incidence of cerebrospinal fluid infection in patients with ventriculostomies[a]

Series (ref. no.)	Patients	EVD	Positive culture	Rate/patient (%)	Rate/EVD (%)
Sundbarg et al., 1972 (33)	938	997	97	10.34	9.73
Wyler and Kelly, 1972 (38)	70	102	11	15.71	10.78
Smith and Alksne, 1976 (31)	56	65	3	5.36	4.62
Narayan et al., 1982 (22)	207	207	19	9.18	9.18
Mayhall et al., 1984 (21)	172	213	19	11.05	8.92
Winfield et al., 1993 (37)	177	184	9	5.08	4.89
Aucoin et al., 1986 (2)	41	41	9	21.95	21.95
Stenager et al., 1986 (32)	85	87	15	17.65	17.24
Sundbarg et al., 1988 (34)	540	540	54	10.00	10.00
Clark et al., 1989 (6)	17	17	2	11.76	11.76
Ohrstrom et al., 1989 (24)	256	256	27	10.55	10.55
Bogdahn et al., 1992 (5)	94	94	2	2.13	2.13
Luerssen et al., 1993 (19)	211	211	25	11.85	11.85
Schultz et al., 1993 (30)	78	94	16	20.51	17.02
Paramore and Turner, 1994 (25)	161	253	9	5.59	3.56
Kim et al., 1995 (18)	61	70	7	11.48	10.00
Holloway et al., 1996 (12)	584	712	61	10.45	8.57
Guyot et al., 1998 (10)	274	274	20	7.30	7.30
Khan et al., 1998 (14)	104	104	7	6.73	6.73
Poon et al., 1998 (27)	228	266	15	6.58	5.64
Rossi et al., 1998 (29)	442	442	13	2.94	2.94
Alleyne et al., 2000 (1)	308	308	12	3.90	3.90
Lyke et al., 2001 (20)	157	196	11	5.61	7.01
Composite data	5261	5733	463	8.80	8.08

[a] The data from all 23 studies were combined to generate the composite data set from which the composite infection rates were calculated. EVD, external ventricular drain.

24, 25, 27, 31–33, 37, 38), gram-positive rods (11, 32), fungi (2, 11, 27), and antibiotic-resistant isolates (27) also were observed. *Table 2* lists bacteriological profiles in two large studies, one of which was dominated by gram-positive cocci (34) and the other of which had a broader range of isolates (27).

TABLE 2. Representative microbiological spectra reported in two large studies of ventriculostomy infection[a]

Organism	Sundbarg et al., 1988 (34)	Poon et al., 1998 (27)
Staphylococcus epidermidis	41	2
Staphylococcus aureus	6	2
***Streptococcus* sp.**	2	0
Micrococcus	1	0
Methicillin-resistant *Staphylococcus aureus*	0	2
Enterococcus faecalis	3	0
Sarcina	1	0
Bacillus	0	1
Pseudomonas	1	0
Aeromonas	0	1
Xanthomonas	0	1
Klebsiella	0	2
Escherichia coli	0	2
Acinetobacter	2	1
Serratia	1	0
Enterobacter	1	0
Candida albicans	0	1
Total positive cultures	59	15
Total number of patients	540	228
Positive cultures (%)	10.93%	6.58%
Skin flora (%)	84.75%	26.67%

[a] All positive cerebrospinal fluid (CSF) cultures that were obtained are reported. Sundbarg et al. (34) did not administer prophylactic or periprocedural antibiotics; nevertheless, 56% of patients received antibiotics for other indications while the ventriculostomy was in place. Note the predominance of normal skin flora (boldface type). Forty-seven percent of skin flora isolates were classified as contaminants. In contradistinction, all patients studied by Poon et al. (27) received either periprocedural or prolonged prophylactic antibiotics. Normal skin flora comprise the minority of CSF isolates. A statistically significantly higher infection rate was observed in the periprocedural group. Additional isolates reported in other studies include *Corynebacterium* (11), *Proprionibacterium* (11), *Proteus mirabilis* (25), and *Providencia stuartii* (21).

The discrepancies in bacteriological profiles may be influenced by differences in antibiotic usage and local flora.

Factors Associated with CSF Infections

Seventeen studies (2, 6, 12, 18–22, 24, 25, 30–34, 37, 38) reported in the literature were aimed at the identification of risk factors for VRI. The degree of scientific rigor varied among these reports, with some studies basing their recommendations more on anecdotal observations than on actual data. Nevertheless, several factors associated with VRIs surfaced repeatedly (*Table 3*). These risk factors were the diagnoses of IVH, SAH, or cranial fracture with CSF leak; craniotomy; ventriculostomy irrigation; concomitant systemic infections; and duration of catheterization.

IVH and SAH

Eight studies specifically addressed the contribution of patient diagnoses to the development of VRIs (2, 12, 19–21, 30, 32, 34). Of the six investigations that included patients with IVH and SAH in their cohorts (2, 12, 21, 30, 32, 34), all but one (30) found a strong association between hemorrhagic CSF and the development of VRI. Sundbarg et al. (34) reported a 10% infection rate in patients with SAH (n = 110) and a 13.2% infection rate for patients with "other spontaneous hemorrhage (n = 53)" as compared with rates of 0 to 2.6% for patients with all other diagnoses (n = 377). Holloway et al. (12) found a 13.7% infection rate in patients with IVH (n =

TABLE 3. Risk factors for cerebrospinal fluid infection in patients who underwent ventriculostomy[a]

Factors associated with CSF infection
- *Intraventricular hemorrhage*
- *Subarachnoid hemorrhage*
- *Operative depressed cranial fracture*
- *Basilar cranial fracture with CSF leak*
- *Neurosurgical operation*
- *Ventriculostomy irrigation*
- *Systemic infection*
- *Duration of catheterization*

Factors possibly associated with CSF infection
- *Venue of ventriculostomy insertion*
- *Corticosteroids*
- *CSF pleocytosis*
- *Catheter manipulations and leaks*

Factors not associated with CSF infection
- *Multiple catheters*
- *Concomitant ICP monitors*
- *CSF drainage*
- *Closed head trauma*
- *Tumor*
- *Intracerebral hemorrhage*

[a] CSF, cerebrospinal fluid; ICP, intracranial pressure.

306) as compared with an infection rate of only 6.8% in patients without IVH (n = 278, $P = 0.01$). Mayhall et al. (21) noted that among patients with VRIs (n = 19), 16% had a diagnosis of ICH with IVH as compared with only 3% of the uninfected population (n = 189, $P = 0.03$). Stenager et al. (32) found hemorrhagic CSF of all causes to be four times more prevalent in patients with VRIs (n = 15) than in uninfected patients (n = 72) ($P = 0.03$). Aucoin et al. (2) demonstrated a 28.6% infection rate in patients with vascular disease as compared with 18.5% for patients with all other diagnoses. Only Schultz et al. (30) were unable to demonstrate an association between hemorrhagic CSF and VRIs (n = 78).

Trauma, Cranial Fracture, and CSF Leak

Seven studies specifically addressed the relationship between cranial fracture with CSF leak and VRIs (2, 12, 19, 21, 30, 32, 34). Holloway et al. (12) noted that 33% of patients with depressed cranial fractures (n = 21) developed VRIs as compared with only 9.6% of patients without this diagnosis. Luerssen et al. (19) noted a 2.6-fold excess risk of VRI in patients with basilar cranial fractures ($P = 0.04$). They also observed a 2.8-fold excess risk associated with operated depressed cranial fracture, but this difference failed to reach statistical significance, owing to their small sample size. Aucoin et al. (2) also reported an association between open trauma and VRIs, but their conclusion was based on a sample of only two patients. Several authors (20, 21, 32, 34) found no association between head trauma and VRIs; however, these investigators did not report specifically on the presence or absence of cranial fracture. Only Schultz et al. (30) noted no association between CSF otorrhea (n = 2) or rhinorrhea (n = 3) and the development of VRIs. Their analysis of this relationship is limited by their small sample size.

Neurosurgical Operation

Six studies directly addressed the relationship between neurosurgical procedures and VRIs (12, 19–21, 30, 33). All but one of these studies (20) demonstrated a positive association. Sundbarg et al. (33) made the anecdotal observation that all 11 patients in their series with definite VRIs, which they accumulated from 1960 to 1971, had undergone craniotomies, and 3 of these patients had had more than one procedure. Mayhall et al. (21) noted that 68% of patients with VRIs as compared with only 40% of uninfected patients ($P = 0.02$) underwent neurosurgical procedures. Holloway et al. (12) demonstrated a 15.2% infection rate in patients who underwent craniotomies (n = 211) as compared with only a 7.8% infection rate in those who received nonsurgical treatment (n = 373). Luerssen et al. (19) observed an increase in the CSF infection rate from 7.5% in patients who underwent ventriculostomy alone to 11.8% in patients who also underwent craniotomy. This difference was not observed in patients who were monitored with subarachnoid bolts and therefore is unlikely to be attributable to craniotomy alone. Schultz et al. (30) reported a positive association between craniotomy and VRIs ($P = 0.04$).

Catheter Manipulation, Leak, and Irrigation

Although maintenance of a closed ventriculostomy system has been suggested to be important in limiting the risk of infection (3, 31, 33), only catheter irrigation has consistently been associated with increased CSF infection rates. Sundbarg et al. (33) and Smith and Alksne (31) reported anecdotal decreases in infection rates after modifying their ventriculostomy technique to ensure antisepsis and a closed system. Mayhall et al. (21) demonstrated a higher incidence of catheter irrigation in patients who developed VRIs than in those who did not ($P = 0.02$). Aucoin et al. (2) noted a 24% infection rate in patients in whom EVDs were flushed with a bacitracin solution (n = 25) as compared with 18.7% in those in whom no flush was used (n = 16). In a novel, continuous pressure controlled EVD system, Bogdahn et al. (5) documented a 13% rate of secondary CSF infection in patients with CSF leak as compared with only 1.6% in patients in whom the exit site was dry ($P < 0.05$). Using standard tunneled ventriculostomies, neither Mayhall et al. (21) nor Schultz et al. (30) demonstrated an association between VRIs and system or site leaks, disconnections, or component changes. In contradistinction, Lyke et al. (20) reported a significant ($P = 0.003$) association between CSF leakage around the EVD and the development of CSF infections. However, they found no link between ventriculitis and involuntary disconnection or system irrigation.

Systemic Infections

Three studies examined the relationship between systemic infections and VRIs (6, 12, 30). Holloway et al. (12) reported a 20.7% incidence of VRIs in patients with sepsis (n = 87) as compared with only 8.6% in those without sepsis (n = 497, $P = 0.001$). Likewise, the incidence of VRIs was 15.4% in patients with pneumonia (n = 233) and 7.1% in unaffected patients (n = 351, $P = 0.001$). Clark et al. (6) noted that patients with infected monitors (including but not limited to ventriculostomies) experienced significantly higher rates of systemic infections (66.6%, n = 18) than did those with uninfected monitors (30.3%, n = 122). Interestingly, the organisms that were isolated from sites of systemic infection usually were not the same organisms that were isolated from the culture monitor. Schultz et al. (30) found no difference in the incidence of systemic infections in patients with or without ventriculitis.

Duration of Catheterization

Seventeen studies examined the duration of catheterization as a risk factor for VRIs (2, 6, 12, 18–22, 24, 25, 30–34, 37, 38). Ten studies comprising 2046 catheterizations in 1698 patients reported an association between the duration of catheterization and CSF infections (2, 6, 12, 19–22, 25, 30, 38). Wyler and Kelly (38) observed that increased ventriculostomy duration increases the risk of CSF infections in both antibiotic-treated and untreated groups. Narayan et al. (22) noted that no monitor infections occurred before Day 3, whereas 85% of infections occurred in patients who had been monitored for 5 days or more. In a prospective study of risk factors for CSF infec-

tion, Mayhall et al. (21) found a significantly (n = 172, P = 0.02) increased risk of VRIs in patients who had catheters in place for more than 5 days. Aucoin et al. (2) and Clark et al. (6) corroborated the findings of Mayhall et al. (21) in retrospective studies with limited sample size. Schultz et al. (30) found a significantly higher VRI rate in patients with a mean catheter duration of 11 days or longer (n = 78, P = 0.004). Luerssen et al. (19) observed a progressive increase in the VRI rate in patients who were monitored for longer than 5 days without catheter replacement (infection rates were 7.6, 10.4, and 22.2% for patients monitored for less than 5 d [n = 79], for 5 to 10 d [n = 77], and more than 10 d [n = 18], respectively). Paramore and Turner (25) demonstrated a progressive increase in the daily infection rate and hazard function with each successive day of catheterization (maximal risk, 6.9% at Day 6). The study used a prophylactic catheter exchange protocol that limited the scope of their analysis to catheter durations of less than 7 days. In 10 patients, however, catheters were left in place for 7 days or more without prophylactic exchange. No infections occurred in this subgroup. Furthermore, these study results are consistent with a time-independent risk with the elimination of as few as two infections at Day 5 or 6 (n = 161). Holloway et al. (12) found an increasing risk of infections during the first 10 days of catheterization (peak, 6.7% on Day 10) and a markedly decreased risk thereafter, despite a population that continued to be at risk (*Fig. 1*). The increasing infection rate during the first 10 days was statistically significant according to linear regression analysis (P = 0.009). The mean time until the onset of infection was 6.8 days in patients who underwent a single ventricular catheterization. Most recently, Lyke et al. (20) found that patients with VRIs experienced significantly longer catheterizations than did their uninfected counterparts (mean, 8.5 versus 5.7 d; P = 0.007).

Seven investigations comprising 2199 catheterizations in 2113 patients demonstrated no association between duration of catheterization and CSF infection (18, 24, 31–34, 37). Sundbarg et al. (33, 34) studied more than half of the patients in this group. Winfield et al. (37), on the basis of linear regression analysis, reported that the daily rate of infection in their study was nearly constant during a 28-day monitoring period (n = 177, P = 0.60). An examination of their raw data, however, suggested a gradual increase in the daily infection rate, with a peak at Days 9 to 11. This peak was followed by a rapid decline in the incidence of infections. These trends are strikingly similar to those observed by Holloway et al. (12).

Factors Possibly Associated with CSF Infections

Venue of Ventriculostomy Insertion

Five studies investigated the relationship between the venue of EVD placement and the subsequent infection rate (6, 21, 30, 32, 37). No significant differences in infection rates were noted between operating room and intensive care unit or emergency department EVD placement in all five studies. In contradistinction, Clark et al. (6) noted that the incidence of major infectious complications (e.g., clinical ventriculitis, subdural empyema, brain abscesses) was higher in the group that had received implants in the intensive care unit. Nevertheless, the greater body of data does not support the setting of implantation as a major risk factor for VRI.

Corticosteroids

Four studies addressed the effect of corticosteroid usage on VRIs (2, 6, 12, 30). Schultz et al. (30) found a statistically significant higher rate of VRIs in patients who received corticosteroids (n = 57) than among untreated patients (n = 21, P = 0.03). Holloway et al. (12) found no difference in the VRI rate between treated (10.1%, n = 278) and untreated patients (10.8%, n = 306, P = 0.80). Aucoin et al. (2) and Clark et al. (6) provided conflicting data regarding the effect of corticosteroid usage on ICP monitor infections. Both of these studies included several types of ICP monitors, and neither stratified the corticosteroid effect by monitor type, limiting any conclusions that might be drawn from their results.

Prophylactic Antibiotics

Ten studies addressed the possibility that prophylactic antibiotic administration may mitigate VRIs (1, 2, 6, 21, 27, 30–32, 34, 38). In 1972, Wyler and Kelly (38) reported that prophy-

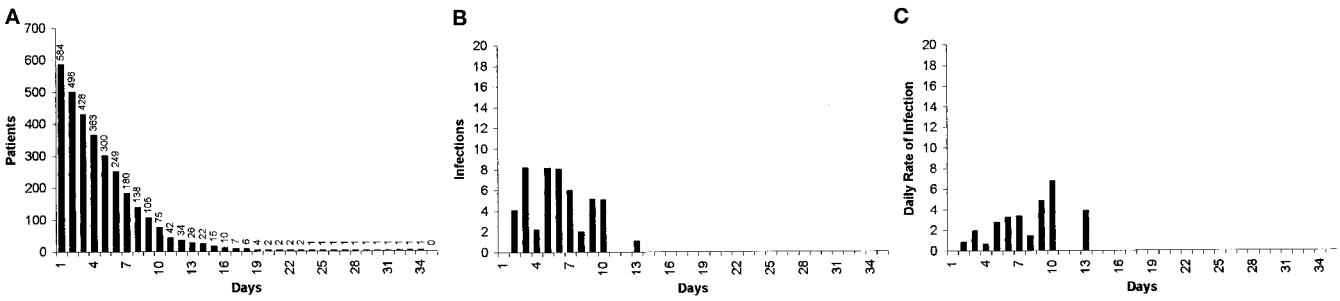

FIGURE 1. *Graphs of VRI rates according to various measurement parameters.* A, *the number of patients with clean first ventriculostomy catheters per day, representing the number of patients at risk for infection on any given day.* B, *the number of infections that occurred on any given day.* C, *the daily infection rate for all catheters. Only one infection occurred after Day 10 despite a substantial population (n = 42) that continued to be at risk (*data from, *Holloway K, Barnes T, Choi SC, Bullock R, Marshall LF, Elsenberg H, Jane J, Ward JD, Young HF, Marmarou A: Ventriculostomy infections: The effect of monitoring duration and catheter exchange in 584 patients.* ***J Neurosurg*** *85:419–424, 1996 [12]).*

lactic antibiotic administration decreased the VRI rate from 27 to 9%. Eight later studies were unable to corroborate this finding (1, 2, 6, 21, 30–32, 34). All of these studies lacked adequate statistical power to detect the relatively small absolute differences in infection rates that might have resulted from the use of antibiotics (*Table 4*). For example, Alleyne et al. (1) conducted a retrospective review of the efficacy of prophylactic and periprocedural antibiotics in reducing the rate of ventriculitis in 308 patients with EVDs in place for more than 3 days. Two hundred nine patients received prophylactic antibiotics for the duration of catheterization, and 99 patients received only periprocedural antibiotics. The infection rates for the prophylactic antibiotic and periprocedural antibiotic groups were almost identical, at 3.8 and 4.0%, respectively. However, the authors failed to note that with this sample size and an underlying infection rate of approximately 4%, their study had a statistical power of only 0.16 to detect a 50% reduction (from 4 to 2%) in the VRI rate at the 95% confidence interval ($P < 0.05$). More recently, Poon et al. (27) conducted a prospective, randomized, open trial of periprocedural antibiotics versus prolonged antibiotic prophylaxis in 228 patients who underwent ventricular catheterization. Patients in the prophylactic antibiotic group had significantly reduced CSF (11 versus 3%, $P = 0.001$) and systemic (42 versus 20%, $P = 0.002$) infection rates. These authors were fortunate to detect this difference in infection rates, because with the reported sample sizes and an underlying infection rate of 11%, their study's statistical power was 0.70 at the 95% confidence interval.

In both of the aforementioned studies, the use of prophylactic antibiotics selected for more resistant organisms when VRIs occurred. Poon et al. (27) observed methicillin-resistant *Staphylococcus aureus* and *Candida* in the prophylactic antibiotic group as opposed to staphylococci, *Escherichia coli*, and *Klebsiella* in the periprocedural group. Alleyne et al. (1) noted a higher incidence of gram-negative CSF infections in patients treated with prophylactic antibiotics than in those treated with periprocedural antibiotics alone (75 versus 50% of total infections, respectively).

CSF Pleocytosis

Only two studies examined CSF pleocytosis as a risk factor for CSF infections (21, 31). Smith and Alksne (31) noted that white blood cell counts in CSF ranged from 0 to 8050 in uninfected patients and that there seemed to be a trend toward an increasing CSF white blood cell count with ventriculostomy duration. There was no correlation between CSF white

TABLE 4. Previous studies reporting the efficacy of prophylactic antibiotics in preventing cerebrospinal fluid infection[a]

Series (ref. no.)	No. of patients	Antibiotic	Protocol (A/B)	Infection rate, Protocol A	Infection rate, Protocol B	Power[b]	Power 50% drop[b]
Wyler and Kelly, 1972 (38)	70	Ampicillin	Proph/none	9.1%	26.9%	49%	28%
Smith and Alksne, 1976 (31)	68	Ampicillin or methicillin	Proph/none	4.6%	0%	11%	—
Mayhall et al., 1984 (21)	208	Nafcillin	Peri/none	12.9%	6.1%	40%	18%
Aucoin et al., 1986 (2)	270	Nafcillin or cephalothin	Peri/none	10.2%	12.5%	8%	41%
Stenager et al., 1986 (32)	87	Penicillin[c]	Proph/none	10.0%	18.2%	11%	12%
Sundbarg et al., 1988 (34)	648	NA	OI/none	4.3%	4.9%	6%	39%
Clark et al., 1989 (6)	140	NA	NA	13.0%	12.5%	3%	19%
Poon et al., 1998 (27)	228	Unasyn[d] and aztreonam	Proph/peri	2.6%	10.6%	73%	32%
Alleyne et al., 2000 (1)	308	Cefuroxime	Proph/peri	3.8%	4.0%	3%	16%
Pooled estimate	1616			5.3%	8.1%		

[a] Proph, prophylactic administration while external ventricular drain was in place; Peri, perioperative administration for <48 hours; OI, antibiotic provided for another indication (e.g., pneumonia); NA, data not available; —, no data.
[b] Power analysis reveals that none of the listed studies has adequate power (80%) to demonstrate that the observed differences in cerebrospinal fluid infection rates are statistically significantly different at the 95% confidence level. Additionally, no study has adequate power to demonstrate a 50% decrease from the presumed underlying infection without antibiotics. Despite being underpowered, the differences shown by Poon et al. (27) reach statistical significance at the $P < 0.05$ level. The antibiotics and treatment protocols used were variable among the studies.
[c] Antibiotics administered only in instances of complicated cranial fractures.
[d] Unasyn (Roerig, New York, NY).

blood cell count and CSF red blood cell count, suggesting that some reportedly uninfected patients may actually have had culture-negative, antibiotic-suppressed, low-grade infections. Mayhall et al. (21) analyzed the predictive value of CSF pleocytosis in 70 patients, 8 of whom had positive CSF cultures. The relationship between CSF pleocytosis and ventriculomeningitis was significant ($P = 0.00001$) despite the fact that 4 of 18 patients with confirmed ventriculomeningitis did not have elevated CSF white blood cell counts. However, 23% of patients with negative CSF cultures exhibited CSF pleocytosis. The positive predictive value of CSF pleocytosis was only 0.54.

Factors Not Associated with CSF Infections

Multiple Catheters

Four studies examined the effect of serial catheters on CSF infection rates (6, 12, 20, 21). Holloway et al. (12) noted no significant differences in infection rates among first (n = 584), second (n = 97), and third (n = 25) catheters (8.6, 10.9, and 5.3%, respectively). Both Mayhall et al. (21) and Lyke et al. (20) found no association between ventriculitis and previous catheterization. Clark et al. (6) found a significant difference in infection rates between first and second monitors as compared with third monitors (6.7 versus 80.0%, $P < 0.05$). However, the conclusions that can be drawn from this study are limited by its small sample size (n = 5 third monitors).

Prophylactic Catheter Exchange

Mayhall et al. (21) asserted that prophylactic fifth-day catheter exchange should decrease the risk of CSF infection. This claim was made on the basis of the observation that catheterization for more than 5 days is associated with ventriculitis, whereas previous catheterization is not. Paramore and Turner (25) argued that the duration of catheterization-dependent risk of infection warrants catheter replacement when the risk of infectious complications exceeds the risk of procedural complications. In their study, this break-even point occurred on Day 6, when the daily infection rate was 6.9% as compared with an overall complication rate of 5.6% for EVD insertions. Unfortunately, these arguments ignore the fact that the effect of prophylactic catheter exchange on the development of subsequent infections is unknown.

Two retrospective studies subsequently attempted to test the hypothesis that prophylactic catheter exchange reduces the incidence of subsequent CSF infections (12, 19). Holloway et al. (12) divided patients receiving multiple catheters into two groups on the basis of the frequency of catheter exchange. Patients whose longest catheterizations were between 1 and 4 days (n = 18) had an infection rate of 22%, as compared with 19% among those with catheters in place for 5 or more days (n = 59). This difference is the opposite of what would be expected and is not statistically significant ($P = 0.67$). Luerssen et al. (19) found no association between elective monitor replacement and CSF infection ($P = 0.98$). In centers that routinely exchange ventricular catheters, the CSF infection rate is 16.8% (n = 95), as compared with 7.8% (n = 116) at those centers that do not. This difference is again the opposite of that predicted by Mayhall et al. (21) and approaches statistical significance ($P = 0.054$), albeit in unmatched populations.

Concomitant ICP Monitors

Intraparenchymal and subarachnoid bolt ICP monitors are associated with exceedingly low rates of meningitis (≤0.6% [2, 10, 14]). Holloway et al. (12) found no additional risk of CSF infection with concomitant ICP monitors of either type (n = 140, $P = 0.66$). Likewise, Mayhall et al. found no difference in the rate of CSF infection between patients with or without other central nervous system instrumentation (n = 67, $P = 0.74$) (21).

CSF Drainage

Smith and Alksne (31) suggested that the use of the ventriculostomy as an EVD rather than an as an ICP monitor may predispose the patient to CSF infection. Sundbarg et al. (33), Schultz et al. (30), and Mayhall et al. (21) found no association between CSF drainage and an increased risk of infection.

Diagnoses Other than IVH, SAH, or Cranial Fracture with CSF Leak

Six studies (19–21, 30, 32, 34) investigated the relationship of the following diagnoses to CSF infections: tumor (20, 21, 30, 32, 34), closed head trauma (19–21, 30, 32, 34), ICH (20, 21, 34), and hydrocephalus (32, 34). No statistically significant associations were observed.

DISCUSSION

The rate of VRIs in any given population depends on the incidence of predisposing diagnoses (i.e., IVH, SAH, cranial fracture with CSF leak), craniotomy, and systemic infections. These rates are also influenced by the need for prolonged catheterization and system irrigation. The 8.80%/patient composite incidence of positive CSF cultures that we found in the studies we reviewed serves as a reasonable benchmark. Positive culture rates significantly higher than 10% should prompt an examination of the institutional ventriculostomy protocol.

Defining CSF Infections in Patients with Ventriculostomy

The variability in the definition of CSF infections in the studies included in this review makes it difficult to ascertain whether reports of ventriculitis, catheter-related infections, and positive CSF cultures describe the same clinical entity. We agree with Sundbarg et al. (33, 34) that an effort must be made to identify clinically relevant infections. We propose the criteria listed in *Table 5* to describe CSF infections in the setting of ventriculostomy.

A contaminant constitutes an isolated positive CSF culture and/or Gram's stain, an expected CSF glucose and protein profile, and an expected CSF cell count. Ventriculostomy colonization is defined by multiple positive CSF cultures and/or

TABLE 5. Defining cerebrospinal fluid infections in patients who underwent ventriculostomy[a]

Term	Definition
Contamination	Isolated positive CSF culture and/or Gram's stain Expected CSF glucose and protein profile Expected CSF cell count
Ventriculostomy colonization	Multiple positive CSF cultures and/or Gram's stains Expected CSF profile Expected cell count Lack of clinical symptoms other than fever
Suspected ventriculostomy-related infection	Progressively declining CSF glucose level Increasing CSF protein profiles Advancing CSF pleocytosis Absence of positive CSF cultures or Gram's stains
Ventriculostomy-related infection	Progressively declining CSF glucose level Increasing CSF protein profiles Advancing CSF pleocytosis One or more positive CSF culture or Gram's stain Paucity of clinical symptoms other than fever
Ventriculitis	Low CSF glucose level High CSF protein CSF pleocytosis Fever Clinical signs of meningitis, including nuchal rigidity, photophobia, decreased mental status, seizures, or moribund appearance

[a] CSF, cerebrospinal fluid.

Gram's stains with expected CSF profiles and cell counts and lack of clinical symptoms other than fever. Progressively declining CSF glucose and increasing CSF protein profiles accompanied by advancing CSF pleocytosis in the absence of positive CSF cultures or Gram's stains characterize suspected VRIs. The addition of a positive CSF culture or Gram's stain with a paucity of clinical symptoms other than fever defines VRI. VRI progresses to ventriculitis when it is accompanied by high-grade fever and clinical signs of meningitis, including nuchal rigidity, photophobia, decreased mental status, seizures, or moribund appearance.

We decline to state absolute criteria for acceptable CSF glucose and protein levels or cell counts because these parameters vary in a predictable manner, depending on the given clinical situation. For instance, SAH is often accompanied by progressive, moderate hypoglycorrhachia as inflammatory cells migrate into and begin to degrade the clot (26, 35, 36). Although this trend warrants vigilant surveillance, such a change is expected and should not be mistaken out of clinical context for evidence of infection in this patient population. In contradistinction, the same findings in a patient being treated for obstructive hydrocephalus secondary to a thalamic mass would be highly suspicious for infection, even in the absence of positive cultures.

The method of CSF surveillance may also affect the incidence of positive CSF cultures. Daily CSF sampling is more likely to yield positive CSF cultures than sporadic sampling because of the sheer number of samples obtained. However, the majority of these additional positive cultures likely represent contaminants. Alternatively, more frequent access to a closed drainage system may increase the chance of iatrogenic infection. A recent retrospective study suggested that daily CSF sampling does not decrease the time to detection of clinically relevant infections in children (11). This relationship remains to be demonstrated in the adult population in a prospective manner. The predictive value of following CSF cell counts seems to be limited, and that of CSF chemistry has not been investigated. The efficacy of CSF pleocytosis and altered CSF chemistry in predicting VRI warrants further study. We advocate the practice option (8) of periodic CSF sampling only for patients with predisposing diagnoses such as SAH, IVH, and cranial fracture with CSF leak. The high frequency of hyperthermia in patients with these diagnoses obscures the distinction between periodic and clinically indicated CSF sampling.

Ventriculostomy Technique

The method of ventriculostomy insertion may influence the likelihood of developing a VRI. Ingraham and Campbell (13) were the first to practice ventriculostomy clinically in 1941. They used a silver cannula that directly penetrated the skin, the cranium, the meninges, and the brain in an untunneled fashion. Until 1980, almost all ventriculostomy catheterization procedures were based on this direct, untunneled technique. Friedman and Vries (9) recognized that the majority of organisms responsible for catheter-related infections were skin flora. Contamination of the ventricular catheter at the scalp tract overlying the twist drill site is thus a potentially important source of infections. Borrowing from principles already in use for long-term hyperalimentation lines, Friedman and Vries tunneled the distal end of the ventricular catheter between the dermis and the galea to an exit site approximately 5 cm away from the burr hole. After using this technique in 100 consecutive procedures in 66 patients, the authors reported that they observed no infectious complications in these patients. Khanna et al. (17) extended this concept by developing long, percutaneous tunnels to the anterior chest wall or the upper abdomen. They also reported no infectious complications within the first 16 days of drainage in 100 consecutive patients. In spite of these promising results, the next lowest VRI rate

described in the literature was reported by Sundbarg et al. (33, 34), who continued to use an untunneled technique. Furthermore, the majority of studies of VRIs published after 1980 used a tunneled technique, demonstrating that the lack of infectious complication reported by Friedman and Vries (9) cannot be attributed to their methodology alone.

A meticulous, sterile technique is thought to limit the development of VRIs. This logical assumption has been difficult to prove. CSF drainage system leaks and disconnections have rarely been associated with increased infection rates despite the seemingly obvious risk of infection that they pose (20). Operating room placement of ventriculostomies has never been demonstrated to decrease the incidence of CSF infections as compared with procedures performed in the intensive care unit. One study suggested that intensive care unit procedures may be linked to more severe infections than those that occur as a result of operating room procedures (6). We interpret the apparent lack of support for operating room placement of EVDs as suggesting that proper sterile technique and vigilant catheter care are practiced without regard to the venue of catheter insertion. Nevertheless, we advocate an operating room procedure rather than those performed in other theaters as the preferred practice option (8) whenever circumstances permit.

Common Themes among Risk Factors for VRI

Major risk factors for VRI (i.e., IVH, SAH, cranial fracture with CSF leak, catheter irrigation, craniotomy, duration of catheterization) fall into one of two broad categories: 1) those that promote bacterial growth or 2) those that promote bacterial access to the CSF. Subarachnoid or intraventricular blood most likely facilitates CSF infections by serving as a culture medium for bacterial growth. Basilar cranial fracture with CSF leak and catheter irrigation provide skin flora with a portal of entry to the CSF space. Craniotomy entails an independent risk of local wound infections and meningitis that may simply be reflected by, but may not be primarily attributable to, ventricular catheterization and CSF surveillance. The association between systemic infections and VRIs probably reflects the overall competence of the patient's immune system response to infection.

Prophylactic Antibiotics

The use of prophylactic antibiotics decreases the incidence of CSF infections and systemic infections (27) at the expense of predisposing the patient to infection by more resistant organisms when infections do occur (1, 20, 27). Although retrospective reviews (including a large series reported by Alleyne et al. [1]) have been unable to demonstrate the efficacy of prophylactic antibiotics in reducing CSF infections, the prospective study presented by Poon et al. (27) is convincing with regard to this matter. Because clinical ventriculitis is a devastating consequence of VRI, we advocate the practice option (8) of using prophylactic antibiotics in all patients with ventriculostomies. It may be reasonable to restrict the use of prophylactic antibiotics to patients with predisposing diagnoses when there is heightened concern regarding iatrogenic overselection of antibiotic-resistant organisms.

Duration of Catheterization and Prophylactic Catheter Exchange

Although considerable controversy regarding the relationship between the duration of catheterization and the risk of infection is evident in the literature, we found that the duration of catheterization is a significant risk factor for VRI. Review of the literature is complicated by researchers' inconsistency regarding the form of analysis used, with some investigators using cumulative infection rates (2, 6, 12, 16, 18–22, 31–34, 38) and others advocating the use of daily infection rates (12, 15, 16, 25, 37). The situation is complicated further because sometimes cumulative infection rates are corrected for censoring by the use of life-table analysis (16, 19, 21, 37), and sometimes uncorrected rates are used (2, 6, 12, 18–20, 22, 31–34, 38). In fact, these approaches are complementary, with the daily infection rate—otherwise known as the *hazard rate*—having a direct mathematical relationship to the cumulative infection rate corrected for censoring. Furthermore, it is possible to devise a direct test of whether the hazard function varies over time, as demonstrated by Nelson (23). In the current application, Nelson's method involves plotting the cumulative infection rate (y axis) against the day after catheter insertion (x axis) for all days on which infections occur. A straight line intercepting the origin indicates a constant risk of infection. Application of this test to the data of Kanter et al. (16) and Holloway et al. (12) demonstrated clear departures from linearity that were consistent with changing risks of infection over time (*Fig. 2*).

A time-varying risk of infection raises the question whether a fixed regimen of catheter replacement would be efficacious in reducing the risk of developing subsequent infections. The

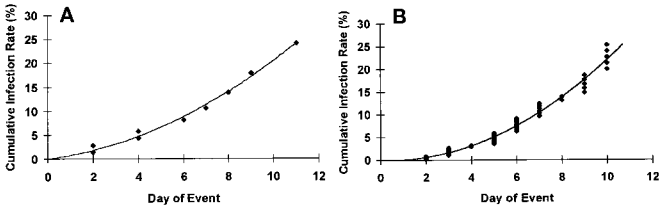

FIGURE 2. *Graphs based on analysis of the constancy of VRI risk. They depict the relationship between the cumulative infection rate as corrected for censoring and the time at which events occur. Under the assumption of constant risk, the relationship is a straight line through the origin, with the slope equal to the hazard rate. Both graphs show clear departures from linearity, with the risk of infection increasing with duration of catheterization.* (A, data from, *Kanter RK, Weiner LB, Patti A, Robson L: Infectious complications and duration of intracranial pressure monitoring.* ***Crit Care Med*** *13:837–839, 1985 [16];* B, data from, *Holloway K, Barnes T, Choi SC, Bullock R, Marshall LF, Elsenberg H, Jane J, Ward JD, Young HF, Marmarou A: Ventriculostomy infections: The effect of monitoring duration and catheter exchange in 584 patients.* ***J Neurosurg*** *85:419–424, 1996 [12]).*

retrospective analyses by Holloway et al. (12) and Luerssen et al. (19) failed to demonstrate any reduction in the cumulative infection rate between cohorts that underwent or deferred fifth-day catheter exchange. To answer this question in a prospective manner, a randomized clinical trial is required in which catheter replacement is conducted at a fixed time point such as 5 days. Such a trial would enroll only the approximately 50% of patients who had clean catheters at 5 days who required continued monitoring, and it would test the hypothesis that catheter replacement reduces the incidence of subsequent CSF infections.

Based on the data of Holloway et al. (12) regarding first catheterizations (*Fig. 1*), the cumulative rate of infection after 5 days for patients with clean catheters up until that point is 10.8%. If a randomized clinical trial of catheter replacement at Day 5 were to be conducted, a sample size of 200 per group would be required to have an 80% chance of detecting a decrease in the cumulative infection rate to 3.8% in the catheter replacement group. That event rate would equal the cumulative infection rate for the first 5 days after the initial catheterization and probably would represent the lowest rate obtainable even if catheter replacement were completely successful in eliminating the excess risk of infection. More conservatively, if the infection rate were reduced to 5.4% (i.e., 50% reduction), 388 patients would be required in each group to have an 80% chance of detecting a significant effect, whereas 1826 would be required in each group if the infection rate were reduced to 8.1% (i.e., 25% reduction). Thus, it is quite likely that only a multicenter trial would be capable of addressing this question, even under the most optimistic scenarios. Such a trial has already been conducted to study the prophylactic replacement of central venous catheters, a practice that led to no reduction in the infection rate but increased the incidence of iatrogenic complications (7).

Prolonged Catheterizations

Studies that used daily hazard rates demonstrated increasing rates of infection during the first 10 days of catheterization (12, 25, 37). Evaluating the risk of infection in catheterizations extending longer than 10 days is problematic because of the rarity of prolonged external ventricular drainage in the majority of studies. In the largest study, Holloway et al. (12) observed only one infection after 10 days despite a substantial population (n = 42) that continued to be at risk. In smaller data sets, Winfield et al. (37) and Ohrstrom et al. (24) documented substantially higher incidences of late infections. Nevertheless, the available data are simply too few to draw firm conclusions regarding the risk of infection from indwelling catheters left in place for longer than 10 days.

Catheter Quandaries

The most problematic patients are those with IVH. These patients often require extended external CSF diversion to combat obstructive hydrocephalus. The presence of intraventricular blood serves as a culture medium for bacterial growth. These patients often undergo craniotomies to address their primary disease and receive postoperative corticosteroids in the setting of SAH. The incidence of systemic infections in this population is high. Patients with IVH cannot undergo early ventriculoperitoneal shunting, because the incidence of shunt occlusion by thrombus degradation products is high. For the same reason, they often require frequent catheter exchange for mechanical occlusion, which makes them poor candidates for long-tunnel ventriculostomies.

Should high-risk patients such as these undergo prophylactic catheter exchange to attempt to limit their risk of developing meningitis? Do the potential benefits outweigh the risks of ventriculostomy-related ICH and malpositioning, which are reported to be as high as 3.3 and 20.1%, respectively (10)? Unfortunately, the present body of knowledge is inadequate to effectively guide this management decision. The analysis by Mayhall et al. (21), the only prospective study of risk factors for VRI, was unsound and cannot serve as a rational justification for a prophylactic catheter exchange policy. The corpus of retrospective data suggests that catheter exchange is ineffective in preventing VRI. Nevertheless, prophylactic catheter exchange is still widely practiced in the hope of reducing the incidence of VRI. Based on the example set with regard to central venous catheters (7), if prophylactic ventriculostomy exchange is to continue to be practiced, its efficacy should be demonstrated in a properly designed, prospective, randomized clinical trial.

CONCLUSIONS

Published criteria for diagnosing VRIs are highly variable. Categorizing suspected CSF infections as contaminants, colonization, suspected or confirmed VRIs, or ventriculitis more accurately describes the patient's clinical condition and may indicate different management strategies. IVH, SAH, cranial fracture with CSF leak, craniotomy, systemic infections, and catheter irrigation all predispose patients to the development of VRIs. Extended duration of ventriculostomy is correlated with an increasing risk of CSF infections during the first 10 days of catheterization. The use of prophylactic antibiotics decreases the incidence of both CSF and systemic infections at the expense of predisposing the patient to infection by more resistant organisms when VRIs do occur. Retrospective studies have not shown that prophylactic catheter exchange modifies the patient's risk of developing subsequent VRIs. A prospective, randomized clinical trial is required to further evaluate the efficacy of this practice in limiting the incidence of VRIs during catheterization extending for longer than 5 days. Although prophylactic catheter exchange remains a practice option (8), the available data suggest that this procedure is not currently justified.

REFERENCES

1. Alleyne CH Jr, Hassan M, Zabramski JM: The efficacy and cost of prophylactic and periprocedural antibiotics in patients with external ventricular drains. **Neurosurgery** 47:1124–1129, 2000.

2. Aucoin PJ, Kotilainen HR, Gantz NM, Davidson R, Kellogg P, Stone B: Intracranial pressure monitors: Epidemiologic study of risk factors and infections. **Am J Med** 80:369–376, 1986.
3. Bader MK, Littlejohns L, Palmer S: Ventriculostomy and intracranial pressure monitoring: In search of a 0% infection rate. **Heart Lung** 24:166–172, 1995.
4. Bering E: A simplified apparatus for constant ventricular drainage. **J Neurosurg** 8:450–452, 1951.
5. Bogdahn U, Lau W, Hassel W, Gunreben G, Mertens HG, Brawanski A: Continuous-pressure controlled, external ventricular drainage for treatment of acute hydrocephalus: Evaluation of risk factors. **Neurosurgery** 31:898–904, 1992.
6. Clark WC, Muhlbauer MS, Lowrey R, Hartman M, Ray MW, Watridge CB: Complications of intracranial pressure monitoring in trauma patients. **Neurosurgery** 25:20–24, 1989.
7. Cobb DK, High KP, Sawyer RG, Sable CA, Adams RB, Lindley DA, Pruett TL, Schwenzer KJ, Farr BM: A controlled trial of scheduled replacement of central venous and pulmonary-artery catheters. **N Engl J Med** 327:1062–1068, 1992.
8. Eddy DM: Clinical decision making: From theory to practice—Designing a practice policy: Standards, guidelines, and options. **JAMA** 263:3077, 3081, 3084, 1990.
9. Friedman WA, Vries JK: Percutaneous tunnel ventriculostomy: Summary of 100 procedures. **J Neurosurg** 53:662–665, 1980.
10. Guyot LL, Dowling C, Diaz FG, Michael DB: Cerebral monitoring devices: Analysis of complications. **Acta Neurochir Suppl** 71:47–49, 1998.
11. Hader WJ, Steinbok P: The value of routine cultures of the cerebrospinal fluid in patients with external ventricular drains. **Neurosurgery** 46:1149–1155, 2000.
12. Holloway KL, Barnes T, Choi S, Bullock R, Marshall LF, Eisenberg HM, Jane JA, Ward JD, Young HF, Marmarou A: Ventriculostomy infections: The effect of monitoring duration and catheter exchange in 584 patients. **J Neurosurg** 85:419–424, 1996.
13. Ingraham F, Campbell J: An apparatus for closed drainage of the ventricular system. **Ann Surg** 114:1096–1098, 1941.
14. Khan SH, Kureshi IU, Mulgrew T, Ho SY, Onyiuke HC: Comparison of percutaneous ventriculostomies and intraparenchymal monitor: A retrospective evaluation of 156 patients. **Acta Neurochir Suppl** 71:50–52, 1998.
15. Kanter RK, Weiner LB: Ventriculostomy-related infections. **N Engl J Med** 311:987, 1984 (letter).
16. Kanter RK, Weiner LB, Patti AM, Robson LK: Infectious complications and duration of intracranial pressure monitoring. **Crit Care Med** 13:837–839, 1985.
17. Khanna RK, Rosenblum ML, Rock JP, Malik GM: Prolonged external ventricular drainage with percutaneous long-tunnel ventriculostomies. **J Neurosurg** 83:791–794, 1995.
18. Kim DK, Uttley D, Bell BA, Marsh HT, Moore AJ: Comparison of rates of infection of two methods of emergency ventricular drainage. **J Neurol Neurosurg Psychiatry** 58:444–446, 1995.
19. Luerssen TG, Chesnut RM, Van Berkum-Clark M, Marshall LF, Klauber MR, Blunt BA: Post traumatic cerebrospinal fluid infections in the Traumatic Coma Data Bank: The influence of the type and management of ICP monitors, in Avezaat CJJ, van Eijndhoven JHM, Maas AIR, Tans JTJ (eds): *Intracranial Pressure VIII: Proceedings of the 8th International Symposium on Intracranial Pressure, Held in Rotterdam, The Netherlands, June 16–20, 1991*. Berlin, Springer-Verlag, 1993, pp 42–45.
20. Lyke KE, Obasanjo OO, Williams MA, O'Brien M, Chotani R, Perl TM: Ventriculitis complicating use of intraventricular catheters in adult neurosurgical patients. **Clin Infect Dis** 33:2028–2033, 2001.
21. Mayhall CG, Archer NH, Lamb VA, Spadora AC, Baggett JW, Ward JD, Narayan RK: Ventriculostomy-related infections: A prospective epidemiologic study. **N Engl J Med** 310:553–559, 1984.
22. Narayan RK, Kishore PR, Becker DP, Ward JD, Enas GG, Greenberg RP, Domingues Da Silva A, Lipper MH, Choi SC, Mayhall CG, Lutz HA III, Young HF: Intracranial pressure: To monitor or not to monitor? A review of our experience with severe head injury. **J Neurosurg** 56:650–659, 1982.
23. Nelson W: Theory and application of hazard plotting for censored failure data. **Technometrics** 14:945–965, 1972.
24. Ohrstrom JK, Skou JK, Ejlertsen T, Kosteljanetz M: Infected ventriculostomy: Bacteriology and treatment. **Acta Neurochir (Wien)** 100:67–69, 1989.
25. Paramore CG, Turner DA: Relative risks of ventriculostomy infection and morbidity. **Acta Neurochir (Wien)** 127:79–84, 1994.
26. Pasquier F, Leys D, Vermersch P, Petit H: Severe hypoglycorrhachia after subarachnoid hemorrhage: Two cases with spontaneous recovery in adults. **Acta Neurol Belg** 87:76–79, 1987.
27. Poon WS, Ng S, Wai S: CSF antibiotic prophylaxis for neurosurgical patients with ventriculostomy: A randomised study. **Acta Neurochir Suppl** 71:146–148, 1998.
28. Rosner MJ, Becker DP: ICP monitoring: Complications and associated factors. **Clin Neurosurg** 23:494–519, 1976.
29. Rossi S, Buzzi F, Paparella A, Mainini P, Stocchetti N: Complications and safety associated with ICP monitoring: A study of 542 patients. **Acta Neurochir Suppl** 71:91–93, 1998.
30. Schultz M, Moore K, Foote AW: Bacterial ventriculitis and duration of ventriculostomy catheter insertion. **J Neurosci Nurs** 25:158–164, 1993.
31. Smith RW, Alksne JF: Infections complicating the use of external ventriculostomy. **J Neurosurg** 44:567–570, 1976.
32. Stenager E, Gerner-Smidt P, Kock-Jensen C: Ventriculostomy-related infections: An epidemiological study. **Acta Neurochir (Wien)** 83:20–23, 1986.
33. Sundbarg G, Kjallquest A, Lundberg N, Ponten U: Complications due to prolonged ventricular fluid pressure recording in clinical practice, in Brock M, Dietz H (eds): *Intracranial Pressure I: Experimental and Clinical Aspects—International Symposium on Intracranial Pressure, Hannover, 1972*. Berlin, Springer-Verlag, 1972, pp 348–351.
34. Sundbarg G, Nordstrom CH, Soderstrom S: Complications due to prolonged ventricular fluid pressure recording. **Br J Neurosurg** 2:485–495, 1988.
35. Troost BT, Walker JE, Cherington M: Hypoglycorrhachia associated with subarachnoid hemorrhage. **Arch Neurol** 19:438–442, 1968.
36. Vincent FM: Hypoglycorrhachia after subarachnoid hemorrhage. **Neurosurgery** 8:7–14, 1981.
37. Winfield JA, Rosenthal P, Kanter RK, Casella G: Duration of intracranial pressure monitoring does not predict daily risk of infectious complications. **Neurosurgery** 33:424–431, 1993.
38. Wyler AR, Kelly WA: Use of antibiotics with external ventriculostomies. **J Neurosurg** 37:185–187, 1972.

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COMMENTS

Until a better way is found to either reduce cerebrospinal fluid (CSF) formation or provide for its diversion, the ventriculostomy will remain a necessity in the neurosurgical armamentarium. Assessment for the continued need for ventriculostomy should be made on a daily basis to minimize the time that the ventriculostomy is in place and thus to minimize the length of time and the degree to which the patient is at risk for infection. In their review of the literature, the authors found that irrigation of the ventriculostomy was associated with a higher incidence of infection, but they did not find this problem in conjunction with site leaks, disconnections, or component changes, which is somewhat surprising, because all have in common the opening of a closed system. One wonders whether a multicenter, prospective, randomized study might show a higher incidence of infection any time the system is opened. Because prophylactic ventricular catheter change is associated with iatrogenic risk, the recommendation that this procedure not be performed unless a subsequent

prospective, randomized study definitely is shown to have a significant advantage is appropriate.

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Lozier et al. provide a succinct and thought-provoking analysis of the exhaustive, often conflicting literature on risk factors for ventriculostomy-related infections (VRIs). The most interesting of their conclusions, to my mind, is that prophylactic catheter exchange does not seem to modify the risk of VRI. Much of the way in which patients are managed at individual institutions is based on dogma rather than on data. The time seems to be ripe for a prospective, randomized trial of prophylactic catheter exchange to determine whether this maneuver really has any bearing on subsequent VRIs. I think that the authors have performed an important service in bringing this issue to the attention of neurosurgeons.

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The authors have performed a tedious but nevertheless thorough review of the literature using a search technique that, although not exhaustive, probably includes all of the relevant literature. The predominantly retrospective nature of the literature review certainly limits one's ability to derive clearly usable recommendations for the management of ventriculostomy, but this article does render some issues quite clear. Multicenter trials addressing several of the specific questions that the authors discuss are needed, and without these trials, neurosurgeons will continue to rely on Class III information, which ultimately is little more than opinion that lacks a scientific foundation (1). Agreed-on definitions of the various levels of VRI is an excellent and necessary place to start. Given the prevalence of this clinical problem in general neurosurgical practice, national organizations will undoubtedly stand behind a coordinated effort to implement the authors' recommendations. I add one comment on the basis of my own experience: although the authors state that patients with intraventricular hemorrhage are poor candidates for long-tunnel ventriculostomy because of the significant chance of blockage from thrombus degradation products, my colleagues and I have not observed this complication after performing more than 100 procedures at our institution. Alas, another practice option!

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1. Eddy DM: Clinical decision making: From theory to practice—Designing a practice policy: Standards, guidelines, and options. **JAMA** 263:3077, 3081, 3084, 1990.