Comparison of Hospital Cost and Resource Use Associated With Antibiotic-Impregnated Versus Standard Shunt Catheters

Scott L. Parker, BS, S. Harrison Farber, Owoicho Adogwa, BS, Daniele Rigamonti, MD, and Matthew J. McGirt, MD

Since their introduction in the 1950s, cerebrospinal fluid (CSF) shunts have been the mainstay of hydrocephalus treatment.[1-5] Despite improvements in preoperative and perioperative antibiotic therapy, 5% to 15% of all shunts placed in North America become infected.[1,6,7] The clinical consequence of shunt infections in both pediatric and adult high-risk populations has been described extensively and includes reduced intelligence quotient, psychomotor retardation, and seizures.[1,8-13] Several independent risk factors have been identified, including patient age, cause of hydrocephalus, duration of surgery, revision surgery, surgeon experience, preceding shunt infection, postoperative CSF leakage, and conversion from external ventricular drain to shunt.[14] The direct medical cost of shunt infection has been reported to be $17 300 to $48 454, with an estimated total annual cost of $100 million.[11,15-17]

Antibiotic-impregnated shunts (AISs) were recently introduced with the aim of reducing the incidence rate of shunt-related infections. The AIS catheters release antibiotics over the course of several weeks to prevent the colonization of shunt systems by Gram-positive bacteria, which accounts for the preponderance of shunt infections.[7,14,18,19] To date, the majority of published studies on this subject have demonstrated a statistically significant reduction in shunt-associated infections when AIS catheters were used; however, there has been some reluctance to adopt these systems because of their increased cost compared with conventional catheters.[6,10,20-23] Furthermore, the efficacy of AIS catheters in these studies was confined to the pediatric population. Less evidence exists supporting their utility in adult hydrocephalus.[24]

We recently reported a significant reduction in the incidence of shunt infection in adult hydrocephalus after the categorical conversion to AIS catheters at our institution.[24] In the present study, we performed a retrospective cohort study and economic analysis to determine whether the use of AIS catheters in adult hydrocephalus at our institution has been cost-effective.

0148-396X

METHODS

All adult patients undergoing CSF shunt insertion by a single surgeon (D.R.) over a 7-year period at the Johns Hopkins Hospital were retrospectively reviewed (2004-2009). In 2006, a categorical switch to AIS catheters (Bactiseal, Codman) was made. Before 2006, standard nonimpregnated shunt catheters were used. In 2006 and thereafter, AIS catheters were used in all cases regardless of patient characteristics. Once the 250th consecutive AIS shunt system was implanted in February 2009, this retrospective cohort study was initiated to determine the incidence of infection in our experience with AIS catheters. As a comparison group, the 250 consecutive patients receiving standard non-AIS CSF shunts immediately before the AIS conversion were reviewed (2004-2006). Patient demographics, CSF shunt surgery history, clinical presentation, radiological studies, operative variables, shunt type and configuration, and CSF, blood, and hardware culture data were reviewed. Only adult patients (> 21 years of age) were included.

The majority of patients undergoing CSF shunting for adult hydrocephalus in our practice were treated for normal-pressure hydrocephalus (NPH) or idiopathic intracranial hypertension (pseudotumor cerebri). As previously described in detail,[25,26] NPH patients were shunted if they demonstrated cognitive decline, gait abnormalities, or urinary incontinence with significant improvement after trial CSF drainage. As also previously described by our group, pseudotumor cerebri patients were shunted if they had medically refractory headache or visual decline and persistently elevated opening pressures on serial lumbar punctures.[27] Throughout the reviewed period of time (2004-2009), no modifications were made to the shunt surgery technique or procedure other than the use of AIS catheters in 2006. All procedures were done in the same surgical suites by the senior author. Moreover, the treatment of shunt infection remained standardized throughout the reviewed period.

Shunt infection was defined as a clinical suspicion of shunt infection (fever, increased white blood cell count, and/or wound breakdown involving the shunt) with positive cultures

from CSF and/or hardware. All cases of shunt infection were treated with intravenous antibiotics and either shunt externalization or shunt removal.

Resource Use and Hospital Cost Data

Resources used in the treatment of shunt infection during the reviewed time period were recorded. These data included duration of hospital stay, days of intensive care unit stay, duration of shunt externalization, duration of intravenous antibiotics, number of shunt surgeries, number and type of imaging modalities used, use of peripherally inserted central catheter lines, and number of subspecialty consults. Resources used to treat morbidities that resulted directly from shunt infection were also recorded and included multiorganism infections, hospital-acquired pneumonia, and dermatological and renal complications to antibiotic therapy.

The billing and accounting records of all patients treated for CSF shunt infection during this time period were reviewed in detail. The hospital billing records consisted of an itemized list of all costs incurred during the hospital stay for shunt infection. Any billing costs related to procedures, tests, or other general resources not directly related to CSF shunt infection were excluded. The total billing costs for the treatment of CSF shunt infection were calculated for each patient. Parametric data was expressed as mean ± SD and compared via the Student *t* test. Nonparametric data were expressed as median (interquartile range [IQR]) and compared via the Mann-Whitney test. Percentages were compared by use of 2-tailed χ^2 tests.

RESULTS

Patient Population

A total of 500 CSF shunt procedures were performed for adult hydrocephalus during the reviewed period. Of these operations, 240 (48%) were performed in men and 260 (52%) were performed in women; patients ranged from 21 to 93 years of age (mean, 60 ± 18 years). Underlying pathology included NPH hydrocephalus in 378 patients (76%) and pseudotumor cerebri in 83 patients (17%). Forty patients (8%) underwent shunting for various obstructive and communicating hydrocephalus types. Cerebrospinal fluid shunting was performed for initial implantation in 376 patients (75%) and for shunt catheter revision in 124 patients (25%). The types of shunts that were placed included 314 (63%) ventriculoperitoneal shunts, 170 (34%) ventriculoatrial shunts, and 15 (3%) ventriculopleural shunts. There were no significant differences in patient age (60 ± 19 vs 61 ± 18 years), type of hydrocephalus (NPH, 183 [73%] vs 195 [78%]; pseudotumor cerebri, 47 [19%] vs 36 [14%]), or proportion of shunt revisions (54 [22%] vs 70 [28%]) between AIS and non-AIS cohorts. However, ventriculopleural shunts were used more frequently in the AIS (13 [5%]) than in the non-AIS (2 [1%]) cohort ($P < .01$).

Shunt Infection, Resource Use, and Cost

By 12 months after surgery, 13 patients (2.6%) experienced a CSF shunt infection a mean of 2 ± 2 months postoperatively. The incidence of shunt infection was decreased in the AIS (n = 3, 1.2%) compared with the non-AIS (n = 10, 4.0%) cohort ($P = .05$). For AIS vs non-AIS patients, mean length of stay was 20.3 vs 11.5 days; shunt surgeries per infection was 2.3 vs 1.9; number of computed tomography scans per infection was 6.3 vs 2.7; number of x-rays per infection was 2.0 vs 1.8; and number of magnetic resonance images per infection was 3 vs 1. Overall, the median cost per shunt infection was $28 686 (IQR, $25 729-$48 732). For AIS catheters, the median cost per shunt infection was $56 452 (IQR, $49 515-$71 272; range, $42 577-$86 091). For non-AIS catheters, the median cost per shunt infection was $28 224 (IQR, $24 902-$34 350; range, $14 234-$62 481).

Per 250 shunts placed, the total cost associated with shunt infection was reduced from $321 407 to $203 424 after the conversion to AIS catheters. AIS catheters were associated with an infection-associated direct cost-savings of $47 193 per 100 shunt surgeries performed.

DISCUSSION

In a retrospective analysis of our categorical conversion to AIS catheters in the treatment of adult hydrocephalus at a tertiary medical center, we observed a 3.3-fold reduction in the incidence of shunt infection. This reduction in infection was associated with a significant reduction in infection-related resource use and direct medical costs. Although the 3 patients with AIS infection had more prolonged hospital courses and a greater mean infection-related cost per patient, the large reduction in infection incidence resulted in a cost savings of $47 193 per 100 shunt surgeries performed. Our experience suggests that AIS catheters are cost-effective when used in the treatment of adult hydrocephalus.

Of the approximately 40 000 shunt surgeries performed annually to treat hydrocephalus, shunt failure rates as one of the most common causes of shunt-related complications.[4,8,22,28-30] Risk factors associated with shunt infections in high-risk adult patients include inadequate surgical technique, length of surgery, number of prior revisions, experience of the surgeon, type of hydrocephalus, patient age, immune status, and postoperative CSF leakage. Despite significant improvement in surgical technique, perioperative antibiotic therapy, adherence to sterilization techniques, and appreciation of the aforementioned risk factors, low infection rates are not consistently achieved.[20] Shunt-associated infections prolong in-hospital stays and lead to significant morbidity and mortality, with 33% of shunt-related deaths occurring as a result of shunt infection.[10,17,28,31,32]

Numerous studies have demonstrated a reduction in shunt infection with AIS systems. Pattavilakom et al[23] showed

in a prospective cohort study of 243 AIS procedures a significant reduction in the infection incidence rate with antibiotic-impregnated compared with nonimpregnated catheters (1.2% vs 6.5%, respectively). Similarly, Eymann et al,[10] in a retrospective study, reported an 85% reduction in shunt infection rate with AIS systems in adults and a 72% rate reduction in children. In a prospective randomized trial, Govender et al[33] also demonstrated a statistically significant reduction in shunt infections with AIS (6%) vs non-AIS (17%) systems. Furthermore, Sciubba et al[7,11] reported a 2.4-fold reduction in shunt-associated infections $<$ 6 months after surgery with antibiotic-impregnated catheters.

To date, 2 studies have failed to show a reduction in shunt infection with AIS catheters. In a retrospective cohort study of 258 patients, Ritz et al[6] reported a similar incidence of shunt infection when AIS (6.94%) or non-AIS (7.14%) catheters were used. In a retrospective cohort study of 214 AIS and 77 non-AIS shunt catheters, Hayhurst et al[34] also demonstrated comparable infection rates between AIS (9.8%) and non-AIS (10.4%) systems. However, $>$ 25% of their shunts were revisions of previous infections, were placed after external ventricular drain–associated ventriculitis, or were conversions from external ventricular drain to shunt.

The reluctance of providers and healthcare systems to adopt AIS catheters into practice has been due largely to the direct initial cost of these systems. Each AIS catheter costs approximately $400 more than conventional systems, which, when aggregated, represents a significant upfront cost in high-volume centers.[10,28] However, when considering the significant cost savings associated with the reduction in infection reported here, we see that AISs may be extremely cost-effective. Shunt infections occur as the principal diagnosis in 7.2% of pediatric hydrocephalus admissions and cost an additional $17 300 to $48 454 per infection.[10,17,22,28,32] Our overall median cost of shunt infection ($28 686) was consistent with these estimates.

Several potential weaknesses of this retrospective study should be noted. Although treatment bias was limited by the categorical switch from non-AIS to AIS systems, unmeasured factors related to time of care or evolution of the associated health services may have contributed in part to the results observed here. Because costs were calculated and compared only for patients experiencing a shunt infection, the increased cost of the AIS vs conventional catheter in noninfected patients was not factored into our analysis. This increased upfront cost should be considered when interpreting the infection-related cost savings reported in this study. In addition, costs were calculated from billing records and not collections. Collections will vary between institutions, insurance providers, and geographic regions and are always less than total charges. Hence, collections-based cost estimates will be less than reported here. However, indirect costs such as missed work and lost productivity were not assessed in this study and may far exceed the direct medical cost savings associated with reduced shunt infection. Nevertheless, the treatment strategy and algorithm of care for shunt infections remained constant throughout the reviewed period, suggesting that the AIS-associated cost savings were due directly to the rate reduction in infection rather than confounding factors.

CONCLUSION

In a retrospective cohort study of 500 CSF shunt surgeries performed for adult hydrocephalus, our categorical conversion to AIS catheters was associated with a significant reduction in infection-related medical costs within the first year after surgery. Although prospective, randomized cost-utility studies are needed to confirm our observations, our results suggest that AIS catheters are cost-effective in the treatment of adult hydrocephalus.

Disclosures

Dr Rigamonti is supported by the Swenson family foundation. Dr McGirt is a consultant for Codman & Shurtleff. The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

1. Ammirati M, Raimondi AJ. Cerebrospinal fluid shunt infections in children: a study on the relationship between the etiology of hydrocephalus, age at the time of shunt placement, and infection rate. *Childs Nerv Syst*. 1987;3(2):106-109.
2. Aryan HE, Meltzer HS, Park MS, Bennett RL, Jandial R, Levy ML. Initial experience with antibiotic-impregnated silicone catheters for shunting of cerebrospinal fluid in children. *Childs Nerv Syst*. 2005;21(1):56-61.
3. Bondurant CP, Jimenez DF. Epidemiology of cerebrospinal fluid shunting. *Pediatr Neurosurg*. 1995;23(5):254-258.
4. Chapman PH, Borges LF. Shunt infections: prevention and treatment. *Clin Neurosurg*. 1985;32:652-664.
5. Cochrane DD, Kestle J. Ventricular shunting for hydrocephalus in children: patients, procedures, surgeons and institutions in English Canada, 1989-2001. *Eur J Pediatr Surg*. 2002;12(Suppl 1):S6-S11.
6. Ritz R, Roser F, Morgalla M, Dietz K, Tatagiba M, Will BE. Do antibiotic-impregnated shunts in hydrocephalus therapy reduce the risk of infection? An observational study in 258 patients. *BMC Infect Dis*. 2007; 7:38.
7. Sciubba DM, Noggle JC, Carson BS, Jallo GI. Antibiotic-impregnated shunt catheters for the treatment of infantile hydrocephalus. *Pediatr Neurosurg*. 2008;44(2):91-96.
8. Blount JP, Campbell JA, Haines SJ. Complications in ventricular cerebrospinal fluid shunting. *Neurosurg Clin N Am*. 1993;4(4):633-656.
9. Darouiche RO. Treatment of infections associated with surgical implants. *N Engl J Med*. 2004;350(14):1422-1429.
10. Eymann R, Chehab S, Strowitzki M, Steudel WI, Kiefer M. Clinical and economic consequences of antibiotic-impregnated cerebrospinal fluid shunt catheters. *J Neurosurg Pediatr*. 2008;1(6):444-450.
11. Sciubba DM, Stuart RM, McGirt MJ, et al. Effect of antibiotic-impregnated shunt catheters in decreasing the incidence of shunt infection in the treatment of hydrocephalus. *J Neurosurg*. 2005;103(2)(Suppl):131-136.
12. Walters BC, Hoffman HJ, Hendrick EB, Humphreys RP. Cerebrospinal fluid shunt infection. Influences on initial management and subsequent outcome. *J Neurosurg*. 1984;60(5):1014-1021.

13. Whitehead WE, Kestle JR. The treatment of cerebrospinal fluid shunt infections: results from a practice survey of the American Society of Pediatric Neurosurgeons. *Pediatr Neurosurg*. 2001;35(4):205-210.
14. McGirt MJ, Zaas A, Fuchs HE, George TM, Kaye K, Sexton DJ. Risk factors for pediatric ventriculoperitoneal shunt infection and predictors of infectious pathogens. *Clin Infect Dis*. 2003;36(7):858-862.
15. Attenello FJ, Garces-Ambrossi GL, Zaidi HA, Sciubba DM, Jallo GI. Hospital costs associated with shunt infections in patients receiving antibiotic-impregnated shunt catheters versus standard shunt catheters. *Neurosurgery*. 2010;66(2):284-289.
16. Eymann R, Steudel WI, Kiefer M. Infection rate with application of an antibiotic-impregnated catheter for shunt implantation in children: a retrospective analysis. *Klin Padiatr*. 2009;221(2):69-73.
17. Sciubba DM, Lin LM, Woodworth GF, McGirt MJ, Carson B, Jallo GI. Factors contributing to the medical costs of cerebrospinal fluid shunt infection treatment in pediatric patients with standard shunt components compared with those in patients with antibiotic impregnated components. *Neurosurg Focus*. 2007;22(4):E9.
18. Borges LF. Cerebrospinal fluid shunts interfere with host defenses. *Neurosurgery*. 1982;10(1):55-60.
19. Pople IK, Bayston R, Hayward RD. Infection of cerebrospinal fluid shunts in infants: a study of etiological factors. *J Neurosurg*. Jul 1992;77(1):29-36.
20. Choux M, Genitori L, Lang D, Lena G. Shunt implantation: reducing the incidence of shunt infection. *J Neurosurg*. 1992;77(6):875-880.
21. Gardner P, Leipzig T, Phillips P. Infections of central nervous system shunts. *Med Clin North Am*. 1985;69(2):297-314.
22. Kestle JR, Hoffman HJ, Soloniuk D, Humphreys RP, Drake JM, Hendrick EB. A concerted effort to prevent shunt infection. *Childs Nerv Syst*. 1993; 9(3):163-165.
23. Pattavilakom A, Xenos C, Bradfield O, Danks RA. Reduction in shunt infection using antibiotic impregnated CSF shunt catheters: an Australian prospective study. *J Clin Neurosci*. 2007;14(6):526-531.
24. Farber SH, Parker SL, Adogwa O, McGirt MJ, Rigamonti D. Effect of antibiotic impregnated shunts on infection rate in adult hydrocephalus: a single institution's experience [published online ahead of print April 14, 2011]. *Neurosurgery*. doi: 10.1227/NEU.0b013e31821bc435.
25. McGirt MJ, Woodworth G, Coon AL, Thomas G, Williams MA, Rigamonti D. Diagnosis, treatment, and analysis of long-term outcomes in idiopathic normal-pressure hydrocephalus. *Neurosurgery*. 2005;57(4): 699-705.
26. Woodworth GF, McGirt MJ, Williams MA, Rigamonti D. Cerebrospinal fluid drainage and dynamics in the diagnosis of normal pressure hydrocephalus. *Neurosurgery*. 2009;64(5):919-925.
27. McGirt MJ, Woodworth G, Thomas G, Miller N, Williams M, Rigamonti D. Cerebrospinal fluid shunt placement for pseudotumor cerebri-associated intractable headache: predictors of treatment response and an analysis of long-term outcomes. *J Neurosurg*. 2004;101(4):627-632.
28. Patwardhan RV, Nanda A. Implanted ventricular shunts in the United States: the billion-dollar-a-year cost of hydrocephalus treatment. *Neurosurgery*. 2005;56(1):139-144.
29. Spanu G, Karussos G, Adinolfi D, Bonfanti N. An analysis of cerebrospinal fluid shunt infections in adults. A clinical experience of twelve years. *Acta Neurochir (Wien)*. 1986;80(3-4):79-82.
30. Vinchon M, Dhellemmes P. Cerebrospinal fluid shunt infection: risk factors and long-term follow-up. *Childs Nerv Syst*. 2006;22(7):692-697.
31. Richards HK, Seeley HM, Pickard JD. Efficacy of antibiotic-impregnated shunt catheters in reducing shunt infection: data from the United Kingdom Shunt Registry. *J Neurosurg Pediatr*. 2009;4(4):389-393.
32. Williams MA, Sharkey P, van Doren D, Thomas G, Rigamonti D. Influence of shunt surgery on healthcare expenditures of elderly fee-for-service Medicare beneficiaries with hydrocephalus. *J Neurosurg*. 2007; 107(1):21-28.
33. Govender ST, Nathoo N, van Dellen JR. Evaluation of an antibiotic-impregnated shunt system for the treatment of hydrocephalus. *J Neurosurg*. 2003;99(5):831-839.
34. Hayhurst C, Cooke R, Williams D, Kandasamy J, O'Brien DF, Mallucci CL. The impact of antibiotic-impregnated catheters on shunt infection in children and neonates. *Childs Nerv Syst*. 2008;24(5):557-562.

