INCE the early days of shunt insertion, shunt failure has been considered a serious problem. There are many possible causes for shunt malfunction. These include over- and underdrainage, mechanical mismatch, occlusion, valve failure, growth effects in children, infection, catheter migration, and other less common complications.

Attempts to address these problems include finding alternative drainage locations, ventricular catheter placements, and new valve designs. The latter include a variety of drainage pressures, antisiphon devices, programmable and flow-regulated valves, and catheter and shunt assembly designs.

We have made progress in certain aspects of shunt function. For example, the proportion of shunt failures attributable to infection has probably decreased over the years. Several investigators have suggested that surgical skill, technological advances, or specific operative techniques can lower shunt failure rates. Nevertheless, not all studies have shown a difference, and there is no convincing evidence that overall shunt failure rates are falling. The purpose of this study was to perform a critical review of the literature on the subject, to analyze failure rates mathematically, and to seek temporal trends.

Currently, the Medline search using the key words “hydrocephalus” and “shunt” in the subject heading, title, or text fields. The search produced 3153 abstracts. After excluding case reports, non-English language publications, reviews without original data, reports listing only 1 cause of shunt failure, republication of previously reported data, letters, and animal studies, we were left with 142 articles. Pooled data from 33,000 cases in these reports were used to create evidence tables, from which we calculated the incidence of shunt failures.

We separated the studies into 3 groups as follows: those dealing with children, with adults, and series reporting patients of all ages. We proceeded to analyze the incidence rates of shunt failure in each study. We defined shunt failure as a shunt complication requiring revision or replacement. This included malfunction or infection but not elective lengthening of ventriculoatrial shunts. Kaplan–Meier survival curves were reinterpreted to yield the number of patients at risk and the number of shunt failures during each year of follow-up. We calculated the rate of shunt failures in the 1st year and annual failure rates for subsequent years, where available. In studies not listing delayed complication rates explicitly, we estimated them from the number of delayed shunt failures and the mean number of patient-years > 1 on...
follow-up (for each study, the former number divided by the latter equals the mean annual failure rate). In reports in which Kaplan–Meier survival curves were used, this usually involved manually calculating the number of patients at risk and the number of shunt failures at each step in the published curves. We did not separate data by valve or catheter type, method of insertion, or cause of hydrocephalus. Following convention in the literature, we used the age of 17 years as the separation between children and adults.

We use metaregression to analyze data collected from several sources. We use a mixed-effects logistic regression model by including the random study effect, which takes into account that the patients are clustered with a study. The number of failures from each study is assumed to follow a binomial distribution with the study-specific failure rate and the number of patients at risk. After a logistic transformation, the study-specific failure rate, standardized by the duration of the study, is modeled as a fixed-effect linear trend in time plus a study-specific random intercept that accounts for the clustering effect of each study. This model assumes that, whereas the overall study population has a common temporal trend, each study’s mean failure rate can have a slight deviation from the population-average rate, characterized by the random study effect. The final estimated population-average temporal trend and the average failure rates are weighted averages across the studies, taking into account the study clustering effects, and the numbers of patients in and durations of the studies. A model with a study-specific random temporal trend was also fit to the data, but the random temporal trend was not significant, and therefore the results reported are based on the random intercept model. All statistical procedures were performed using the SAS PROC NLINMIXED software program (SAS, Inc.). We considered differences for which the probability was < 0.05 to be significant.

Results

The series used to determine shunt failure rates for each group are shown in Table 1. The table lists the studies and total patients used to calculate each value. Table 2 summarizes the results of the metaregressions. The slopes are indicators of the degree of change, or trends, in the failure rates over time. The farther they are from 0, the greater this positive or negative relationship. The significance of these trends is also reported in Table 2, as are pooled mean failure rates for shunts inserted during the year 2000 (the midpoint of the last 10-year time period for which failure rates were reported). First-year failure rates are notably higher in children than in adults. After the 1st year, the annual shunt failure rate diminishes in both groups.

Figure 1 upper illustrates 1st-year failure rates for shunts placed in pediatric patients as a function of year of insertion. This bubble diagram, in which bubble size is proportional to the number of patients in the corresponding series, fails to suggest a change over time. Figure 1 lower represents late ( > 1 year) shunt failure rates for the pediatric patients. Although our initial analysis suggested a significant decreasing trend in late failures of shunts in pediatric patients (slope −0.02, p = 0.02), we elected to remove series reporting ventriculocisternal shunts inserted before 1960 for reasons detailed in the Discussion section. After these cases were removed, there was no evidence of a temporal trend in late failure rates. Higher failure rates in the earlier studies (excluded from analysis but included in the figure) are clearly seen.

First-year failure rates for shunts inserted in adults fell at a rate of just over 0.02% per year, a barely significant trend (Table 2). Also shown in Table 2, late failure rates in adults have actually risen over the years at a significant rate of 0.05% per year. Figure 2 illustrates the trends for shunts in adult patients. Clinical case series with mixed-age patient populations reported shunt failure rates intermediate between those of children and adults.

Discussion

We have not reduced pediatric shunt failure rates. These sobering results come as no surprise to the experienced shunt surgeon. Nevertheless, they serve to suggest that we redirect our efforts. Early, rosier predictions that technical improvements and operative skill would be sufficient to prevent shunt failure led to considerable efforts to improve shunt design and to optimize operative technique. Our analysis suggests that the effect of these efforts has been mini-
Only 1 temporal change is evident. Some early case series had unusually high failure rates after the 1st year.\textsuperscript{12,32,58,59} It must be recalled that all of the shunts in these series had distal catheters that emptied into the heart. As the children treated with shunts grew, the catheter tips migrated out of the right atrium. When the resulting distal occlusions were discovered to be inevitable, and elective shunt lengthening was introduced,\textsuperscript{161} failures became much less common. Hence we felt justified in eliminating series involving shunts inserted before 1960 from our analysis of late shunt failures.

The case of shunt insertion in adults appears to be somewhat more complex. The modest tendency toward fewer 1st-year failures may be the result of improving shunt technology. However, the increasing trend toward late failures makes this unlikely. Perhaps there is a physiological tendency for failures to occur at later times in adults than in children, and increasing survival times in adults with hydrocephalus are reflected in the growing rates of late failures.
Another possibility is the difficulty in recognizing shunt failure in normal-pressure hydrocephalus, a condition much more prevalent in adults than in children. Shunt failure may go unrecognized for months or years in this group, thus delaying diagnosis of malfunctioning shunts. As an example, Williams and colleagues evaluated 28 patients with normal-pressure hydrocephalus whose response to shunt insertion was absent or temporary. Twenty-two of them (~80%) exhibited partial or complete shunt obstruction.

This model is limited by the inconsistent follow-up statistics in the various series. Wherever possible, we used numbers of shunts surviving the 1st year and mean patient-years of follow-up in each series to calculate late failure rates. Nevertheless, this cannot account for all of the differences. One series, for example, had an especially low failure incidence. In this series, follow-up was primarily by questionnaire, and complications may have been underreported. Eighteen sudden deaths were attributed to the underlying diseases rather than to blocked shunts. A similar reporting problem may be responsible for the lower reported incidence of shunt failure in adults. Nonfunctioning shunts in patients with normal intracranial pressure may be relatively asymptomatic, and malfunction may be missed.

Other more subtle biases may also be at play. Although most case series we cite simply reported the patients’ clinical courses following shunt insertion, some studies were done to test particular hypotheses. These series may have omitted some patients whose shunt results did not address the hypotheses but might have been relevant to our goals. Trends in the origin of hydrocephalus over time may confound our results, because the incidence of shunt complications tends to vary with the underlying disease. For example, the incidence of hydrocephalus associated with myelomeningocele has fallen over the years, whereas that associated with nonfatal intraventricular hemorrhage has increased. Although most reports made a distinction between newly inserted and revised shunts, this was not always explicit. Where the data permitted us to separate fresh shunts from shunt revisions, we used only the former. Because several authors reported that the 2 shunt categories have the same failure rates in children, adults, and in mixed populations, we did not exclude reports in which some reinserted shunts were included.

The possibility that other factors play prominent roles in shunt malfunction must also be considered. Biological factors, such as changes in cerebrospinal fluid pulsatility, ventricular geometry, alteration of the ventricular lining, shedding of cells, cumulative host responses to silicone, choroid plexus growth, and hydrodynamic properties should be investigated more thoroughly. Possible fluctuations of intraventricular pressure, absorption capacity, and cellular response have as yet unknown influences on shunt function. Factors we have yet to consider may someday prove to be vital.

Conclusions

We have been advised to exercise caution when being offered new shunt hardware, while continuing to study the basic physiology of hydrocephalus and searching for alternate treatment modalities. Our data support that caution.

Acknowledgment

We thank Ms. Neisha Sundaram, of NeuroDiagnostic Devices, for her assistance in the literature search.

References

Preventing shunt failure

Preventing shunt failure


This study was funded in part by NeuroDiagnostic Devices, Inc.
Address correspondence to: Sherman C. Stein, M.D., Department of Neurosurgery, University of Pennsylvania School of Medicine, 310 Spruce Street, Philadelphia, Pennsylvania 19106. email: sherman.stein@uphs.upenn.edu.