The Preventable Shunt Revision Rate: a potential quality metric for pediatric shunt surgery

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OBJECTIVE Shunt surgery consumes a large amount of pediatric neurosurgical health care resources. Although many studies have sought to identify risk factors for shunt failure, there is no consensus within the literature on variables that are predictive or protective. In this era of “quality outcome measures,” some authors have proposed various metrics to assess quality outcomes for shunt surgery. In this paper, the Preventable Shunt Revision Rate (PSRR) is proposed as a novel quality metric.

METHODS An institutional shunt database was queried to identify all shunt surgeries performed from January 1, 2010, to December 31, 2014, at Le Bonheur Children's Hospital. Patients' records were reviewed for 90 days following each “index” shunt surgery to identify those patients who required a return to the operating room. Clinical, demographic, and radiological factors were reviewed for each index operation, and each failure was analyzed for potentially preventable causes.

RESULTS During the study period, there were 927 de novo or revision shunt operations in 525 patients. A return to the operating room occurred 202 times within 90 days of shunt surgery in 927 index surgeries (21.8%). In 67 cases (33% of failures), the revision surgery was due to potentially preventable causes, defined as inaccurate proximal or distal catheter placement, infection, or inadequately secured or assembled shunt apparatus. Comparing cases in which failure was due to preventable causes and those in which it was due to nonpreventable causes showed that in cases in which failure was due to preventable causes, the patients were significantly younger (median 3.1 vs 6.7 years, $p = 0.01$) and the failure was more likely to occur within 30 days of the index surgery (80.6% vs 64.4% of cases, $p = 0.02$). The most common causes of preventable shunt failure were inaccurate proximal catheter placement (33 [49.3%] of 67 cases) and infection (28 [41.8%] of 67 cases). No variables were found to be predictive of preventable shunt failure with multivariate logistic regression.

CONCLUSIONS With economic and governmental pressures to identify and implement “quality measures” for shunt surgery, pediatric neurosurgeons and hospital administrators must be careful to avoid linking all shunt revisions with “poor” or less-than-optimal quality care. To date, many of the purported risk factors for shunt failure and causes of shunt revision surgery are beyond the influence and control of the surgeon. We propose the PSRR as a specific, meaningful, measurable, and—hopefully—modifiable quality metric for shunt surgery in children.

<http://thejns.org/doi/abs/10.3171/2015.12.PEDS15388>

KEY WORDS ventriculoperitoneal shunt; shunt malfunction; neurosurgery; hydrocephalus; pediatrics

HYDROCEPHALUS is characterized by impaired CSF flow or absorption occurring within or outside the ventricular system, which leads to an expansion of the ventricles.³⁸ There are many causes and predisposing risk factors, such as congenital brain malformations,

cyst formation, genetic mutations, hemorrhage, infection, neoplasms, and neural tube defects.⁴⁹ Shunt surgery is currently the procedure most commonly performed by pediatric neurosurgeons, and although there is hope that the combination of endoscopic third ventriculostomy with

ABBREVIATIONS EMR = electronic medical records; HCRN = Hydrocephalus Clinical Research Network; IQR = interquartile range; KID = Kids' Inpatient Database; LBCH = Le Bonheur Children's Hospital; LOS = length of hospital stay; NSQIP-P = National Surgical Quality Improvement Program–Pediatrics; PHHP = posthemorrhagic hydrocephalus of prematurity; PSRR = Preventable Shunt Revision Rate; RQ = Revision Quotient; SAR = Surgical Activity Rate; UTHSC = University of Tennessee Health Science Center.

SUBMITTED June 24, 2015. **ACCEPTED** December 28, 2015.

INCLUDE WHEN CITING Published online March 11, 2016; DOI: 10.3171/2015.12.PEDS15388.

choroid plexus cauterization will result in fewer shunts being placed, the procedure will likely remain frequent for the foreseeable future.²

Shunt failure continues to exasperate providers and families. In a recent study by Al-Tamimi et al., 1615 patients from an international cohort were evaluated for shunt survival at 30 days and 1 year. The overall failure rates were 13.3% and 28.8%, respectively, and the rates for previously revised shunts were worse (21.2% and 40.4%, respectively).¹ Berry et al. reported on a group of 1307 patients from 32 US hospitals over a 5-year period. The 5-year risk of shunt revision was 37%, with 69% of first-time shunt revisions occurring within 1 year of shunt placement.⁴ Long-term follow-up data from the Shunt Design Trial demonstrated shunt survival to be 62% at 1 year, 52% at 2 years, 46% at 3 years, and 41% at 4 years; survival was independent of valve type.²²

Shunt surgery represents a substantial financial burden on the pediatric US health care system. A study conducted by the Hydrocephalus Clinical Research Network (HCRN) found that shunts account for nearly 40,000 admissions per year, approximately 400,000 hospital days, and a total cost of \$1.4–\$2 billion annually.⁴⁶ In comparison, a mid-1990s study estimated the annual number of shunt-related procedures performed in the US as 36,000, at a cost of \$100 million.⁷ Using an administrative database (the Nationwide Inpatient Sample), Patwardhan and Nanda estimated that for the year 2000, there were 28,000 admissions for ventricular shunts in the US, with an average total cost of \$35,816 and average length of hospital stay (LOS) of 8.4 days.³⁴ A recent study by Lam et al. suggests that costs are rising, with average charges for initial shunt placement for the year 2009 being \$49,317 (SD \$74,483) and an average LOS of 18.2 days (SD 28.5 days).²⁶

Many studies have sought to identify risk factors for shunt failure.^{5,10,13,15,27,29,37,48} To date, there is no consensus within the literature on any clinical, demographic, or procedural variable as being predictive of shunt failure. We recently conducted our own institutional review of 739 shunt operations performed over a 4-year period and found no predictive risk factors for shunt failure within 90 and 180 days of surgery (de novo or revision).³⁹ Surgical strategies or techniques thought to improve shunt survival have also been investigated, such as laparoscopic placement of the peritoneal catheter,^{32,44} use of image guidance (i.e., ultrasonography or neuronavigation) or endoscopy to place the ventricular catheter,^{14,16,21,28,50,51} location of the shunt,^{11,19} and use of antibiotic-impregnated catheters.^{17,18,24,47}

In this era of quality, outcomes, and pay-for-performance, hospital administrations and physicians are searching for clinically useful outcome measures or quality metrics. Barton et al. proposed the Surgical Activity Rate (SAR) and the Revision Quotient (RQ).³ The SAR is defined as the number of definitive operations for the treatment of hydrocephalus performed in a neurosurgical practice over the course of a year, divided by the number of patients with hydrocephalus seen in follow-up during that year. The RQ is calculated by dividing the number of definitive revision operations performed in a neurosurgical practice in the course of a year by the number of definitive initial operations during that year for patients with newly

diagnosed hydrocephalus. This same group, as well as Dr. Goumnerova and colleagues at Boston Children's Hospital (<http://www.qualityforum.org/QPS/0713>), have advocated the use of the 30-day shunt malfunction rate.³⁵

The purpose of this study was to analyze in detail the etiologies of early shunt failure (within the first 90 days) in our population of pediatric patients with hydrocephalus and to determine the proportion of shunt failures that potentially could have been prevented. We believe that such detailed analysis is a requisite for the creation of any so-called quality metric within neurosurgery.

Methods

Database Creation and Outcome

The institutional review boards of University of Tennessee Health Science Center (UTHSC) and Le Bonheur Children's Hospital (LBCH) approved this study. An institutional operative database, prospectively maintained by the Neuroscience Institute at LBCH, was queried to identify all shunt surgeries from January 1, 2010, to December 31, 2014. All endoscopic surgeries (i.e., endoscopic third ventriculostomy and septum pellucidotomy) were excluded, as were nondefinitive procedures (i.e., shunt taps, external ventricular drain placement, externalization, or complete removal of existing shunt system). An "index surgery" was defined as implantation of a new shunt or revision or augmentation (i.e., addition of another proximal catheter) of an existing shunt system. Placement of a new shunt or revision or augmentation of an existing shunt marked a new index surgery. Each patient in our series may, therefore, have had multiple index shunt surgeries. Many of the patients and procedures included in this study were also included in our recent shunt revision analysis paper.³⁹

The primary outcome was need for further shunt surgery within 90 days of the index procedure. This outcome can be, for the most part, considered equivalent to shunt failure, although it should be noted that not all instances of revisions were due to failure of the existing shunt (e.g., additional proximal catheter placed for loculated hydrocephalus or switching to a programmable valve for symptomatic overdrainage). The patients' records were reviewed for the 90-day period following each index procedure in order to identify a return visit for shunt surgery; therefore, the study period for revision procedures was extended to March 31, 2015.

Study Question

With this retrospective observational study, we sought answers to the following questions: What is the 90-day shunt revision rate? What was the etiology of each failure and was it potentially preventable? And are there any demographic, clinical, or procedural variables that are associated with preventable shunt failures?

Variables and Definitions

Table 1 lists all the variables that were collected, with brief explanations. Each variable was recorded per procedure. Preventable failure was defined as a failure subsequent to infection, malposition of the proximal or distal catheter, or an improperly assembled or inadequately se-

cured shunt that resulted in postoperative disconnection, migration, kinking, or obstruction. This definition was agreed upon by the 3 primary authors (G.T.V., N.B.R., P.K.) after thorough deliberation of what were felt to be were unequivocal or near-unequivocal and potentially preventable reasons for revision surgery, which could be ascertained in the setting of a retrospective study design. We debated whether “infection” should be included in our definition because some infections will occur despite all efforts, but ultimately felt that it should be included, as most shunt infections occur at the time of surgery and are theoretically preventable.

An example of an improperly assembled shunt system would be one in which the shunt tubing was not properly secured to the valve (e.g., silk ties were not applied or loosely applied) and subsequently became disconnected (Rickham reservoirs are not routinely used in our practice), leading to shunt malfunction and return to the operating room. An example of an inadequately secured shunt would be a case in which the valve was not tacked down to the underlying pericranium and migrated within its subgaleal pocket beyond its original site along with the attached proximal catheter, thus causing the hole-bearing region of the catheter tip to slide out of the ventricle.

An “accurate” proximal catheter placement was defined as one in which the entirety or a portion of the hole-bearing region of the catheter (first 15 mm) was inside the targeted ventricle or loculated CSF space based on preoperative CT or MRI. Conversely, an “inaccurate” proximal catheter placement was defined as one in which the entire hole-bearing region was within the brain parenchyma, in a cistern, or—for example, in the case of loculated hydrocephalus—in the unintended CSF compartment or ventricle, and this placement was confirmed by intraoperative description of poor or absent CSF flow from the catheter, thus requiring repositioning.

An “inaccurate” distal catheter placement was placement by the neurosurgeon (without the assistance of a general surgeon) in an unintended terminus compartment (e.g., preperitoneal rather than the peritoneal cavity; superior vena cava rather than the cardiac atrium) based on preoperative imaging (e.g., plain radiographs or CT), thus requiring revision. A shunt infection was defined by highly suspicious signs and symptoms of a shunt infection (e.g., fever, CSF pleocytosis, or cellulitis of shunt wounds or along the shunt tract) with or without an organism cultured from the CSF, shunt apparatus, abdominal pseudocyst, or shunt wound(s).

Etiology of hydrocephalus was based upon a review of clinical and radiographic information available at the time of the initial index procedure. The category “other” included patients for whom the etiology was unclear or diagnoses low in number, such as posttraumatic or postinfectious hydrocephalus. Proximal catheter location was defined as frontal, occipital (which included parietal or posterior fossa catheters), or both. The number of proximal catheters described the number of connected catheters that the patient relied upon prior to their shunt revision. In other words, old proximal catheters that were tied off but still in place were not counted. We designated a patient as having “slit ventricles” if that term or a similar

TABLE 1. Data points collected and explanation of variables within the shunt surgery database

Variable	Details
Demographic	
Age	Continuous variable
Sex	Male or female
Race	Caucasian, African American, Latino, other
Insurance status	Private, government, none
Clinical	
Etiology of hydrocephalus	PHHP, neoplastic, spinal dysraphism, congenital, or other
Ventricular shunt type	Ventriculoperitoneal, -atrial, or -pleural
Proximal catheter	Frontal, occipital, or both
Number of proximal catheters	Number
Slit ventricles at index surgery	Yes or no
Prior shunt surgeries	Number performed at LBCH or other institutions
History of shunt or ventricular infection	Yes or no
Index surgery due to recent infection	Yes or no
Procedural	
Type of index surgery	New placement, revision (proximal, distal, complete), or other
Intraventricular hemorrhage at index surgery	Yes or no
Image guidance	Ultrasound, stereotactic, or none
Primary surgeon	1–5
Operative time	Continuous variable
Use of endoscopy	Yes or no
Use of laparoscopy	Yes or no
Failure classification	
Potentially preventable	Yes or no
Time to failure	Continuous variable, 0–30 days, 31–90 days
Type of failure	Infection, proximal, valve, distal, wound revision, loculated hydrocephalus
Proximal catheter etiology	Catheter obstruction, malposition, migration or kinking, other unidentifiable
Valve dysfunction	Direct damage, obstruction, under- or overdrainage, inadequately secured, other unidentifiable
Distal catheter etiology	Malposition (preperitoneal), kinking, malabsorption, adhesions, other unidentifiable

description was used in the operative note or history and physical examination findings at the time of the patient’s index surgery. The number of prior ventricular shunt operations and history of shunt infection were obtained from

the electronic medical records (EMR); we recognize that some operations may have been missed if they were performed at institutions other than LBCH or in the period of time before EMR. "Index surgery due to recently treated shunt infection" was positive if the current procedure was a direct result of a recent infection (e.g., the shunt had been externalized or removed because of infection and was now being replaced).

Three authors (G.T.V., P.K., N.B.R.) reviewed each case independently for potential preventability. Any questions or disagreements were resolved through discussion among the authors; the senior author (P.K.) made the final decision. Table 1 also lists the failure etiology categories.

Statistical Analysis

Data for all shunt revisions were pooled to calculate descriptive statistics for the entire sample. All continuous data were found to be nonparametric and are presented as median values with interquartile range (IQR). We also planned a priori to conduct a subgroup analysis of non-preventable versus preventable shunt revisions. In this analysis, all data were also found to be nonparametric and were analyzed using the Mann-Whitney test, which was followed by multivariable logistic regression. Surgeons were compared as individuals versus the group, and additional Kruskal-Wallis testing was used to compare the group as a whole. All nominal data were analyzed using either the chi-square test or Fisher's exact test. Two-tailed statistical tests were used, and $p < 0.05$ was considered to represent statistical significance in the univariate and multivariable analysis. All data were analyzed using SPSS software (IBM SPSS Statistics for Windows, version 21.0).

Results

From January 1, 2010, to December 31, 2014, there were 927 de novo or revision shunt operations performed at LBCH in 525 patients (Table 2). The patients' median age at the time of index shunt operation was 5.6 years (IQR 0.83–11.53 years, overall range 0–36 years), and the vast majority of patients (92.3%) were younger than 18 years. There was a slight male predominance (53.5%).

Early Shunt Failures

There were 202 shunt failures (21.8%) within 90 days of the index shunt operation in 117 patients; 141 failures (69.8%) presented within 30 days of the index surgery (Table 2). In 54.5% of the 202 shunt failures, the patients were male; the patients' median age at surgery was 5.6 years (IQR 0.87–12.75 years), and the vast majority (92%) were less than 18 years of age. The most common index surgery was proximal revision (42.1%). New shunt placement, distal revision, valve revision, and complete revision represented 23.3%, 8.9%, 5%, and 9.4% of the index surgeries, respectively.

Need for further shunt surgery within 90 days of the index procedure was classified as follows: proximal catheter failure (84 cases [41.6%]), valve dysfunction (35 cases [17.3%]), distal catheter malfunction (27 cases [13.4%]), shunt infection (28 cases [13.9%]), loculated/compartimentalized hydrocephalus (12 cases [5.9%]), combination of

proximal catheter and valve failure (10 cases [5%]), superficial wound breakdown without infection (5 cases [2.5%]), and combination of valve and distal catheter failure (1 case [0.5%]).

Of the 94 proximal failures (i.e., 84 in isolation and 10 with associated valve dysfunction), 51 (54.3%) were due to catheter obstruction with blood, protein/debris, or choroid plexus, 33 (35.1%) were due to malposition, 9 (9.6%) had no identifiable cause, and in 1 case (0.5%), the catheter was kinked. Among the 46 valve failures (i.e., 35 in isolation and 11 in combination with proximal or distal catheter), 19 (40.4%) were due to obstruction with blood or protein/debris, 12 (25.5%) were due to low-pressure hydrocephalus, 7 (14.9%) were due to intolerance of the antisiphon device, 5 (10.6%) were due to overdrainage, 2 (4.3%) were caused by migration of a poorly secured valve, and 1 (2.2%) was due to a direct blow damaging the valve. Of the 28 distal failures (i.e., 27 in isolation and 1 in combination with valve dysfunction), 16 (57.1%) were due to malabsorption secondary to intraperitoneal adhesions (with or without associated pseudocyst), 4 (14.3%) were due to malposition (preperitoneal catheter), 4 (14.3%) were due to kinking within the peritoneum, 3 (10.7%) had no identifiable etiology, and 1 (3.6%) was due to fracture of the catheter leading to a CSF-cutaneous fistula.

Preventable Shunt Revision

Sixty-seven shunt operations (33.2% of failures, 7.2% of the 927 procedures) failed due to a preventable cause within 90 days of the index shunt surgery. Table 2 details the differences between the preventable and nonpreventable shunt failures. The group of preventable shunt failures did not show the male patient predominance that was found in the nonpreventable shunt failure group (49.3% vs 57% of procedures involving male patients), and the patients were younger (median 3.1 vs 6.7 years, $p = 0.01$); the preventable failures were also more likely to occur within the first 30 days after the index surgery (80.6% vs 64.4%, $p = 0.02$). The most common preventable causes of failure were inaccurate proximal catheter placement (33 cases, 49.3%) and infection (28 cases, 41.8% of preventable failures, 3% overall [28/927]) (Table 3). A multivariable logistic regression analysis identified no statistically significant variables that were predictive or protective of preventable shunt failure. Additional subgroup analysis of the failures caused by infection identified no significant association with remote history of infection ($p = 0.59$) or reinfection when the index shunt operation was performed for a recently treated shunt infection ($p = 0.09$).

Discussion

Our Results

Of the 927 operations performed in 525 children, 202 (22%) resulted in the need for repeat operations within 90 days of the preceding or "index" shunt operation, with the majority (141, 70%) occurring within 30 days. Sixty-seven (33%) of the 202 ninety-day failures were due to potentially preventable causes. Therefore, at our institution, the 2010–2014 90-day Preventable Shunt Revision Rate (PSRR) was 33%. Compared with the patients who under-

TABLE 2. Characteristics of patients and procedures in 927 shunt operations and results of univariate analysis

Variable	All Shunt Operations (n = 927)	All Shunt Failures (n = 202)	Nonpreventable Shunt Failures (n = 135 [66.8%])	Preventable Shunt Failures (n = 67 [33.2%])	p Value
Sex					
Male	501 (54%)	110 (55%)	77 (57%)	33 (49.3%)	0.30
Female	425 (46%)	92 (45%)	58 (43%)	34 (50.7%)	—
Race					
Caucasian	449 (48.4%)	109 (54%)	70 (51.9%)	39 (58.2%)	0.39
African American	413 (44.6%)	83 (41.1%)	55 (40.7%)	28 (41.8%)	0.89
Latino	22 (2.4%)	5 (2.5%)	5 (3.7%)	—	—
Other	43 (4.6%)	5 (2.5%)	5 (3.7%)	—	—
Insurance status					
None	2 (0.2%)	—	—	—	—
Private	319 (34.4%)	66 (32.7%)	47 (34.8%)	19 (28.4%)	0.36
Government	606 (65.4%)	136 (67.3%)	88 (65.2%)	48 (71.6%)	0.36
Age in yrs at index op					
Median	5.1	5.6	6.7	3.1	0.01
IQR	0.83–11.53	0.87–12.75	1.2–13.9	0.5–8.74	
Etiology					
Congenital	165 (17.8%)	41 (20.3%)	27 (20%)	14 (20.9%)	0.88
Dysraphism	108 (11.7%)	22 (10.9%)	16 (11.9%)	6 (9%)	0.53
Other	168 (18.1%)	45 (22.3%)	32 (23.7%)	13 (19.4%)	0.49
Neoplastic	195 (21%)	31 (15.3%)	22 (16.3%)	9 (13.4%)	0.60
PHHP	286 (30.9%)	63 (31.2%)	38 (28.1%)	25 (37.3%)	0.19
Shunt type					
Peritoneal	889 (95.9%)	197 (97.5%)	130 (96.3%)	67 (100%)	0.30
Atrial	35 (3.8%)	4 (2%)	4 (3%)	—	—
Pleural	3 (0.3%)	1 (0.5%)	1 (0.7%)	—	—
Shunt location					
Frontal	347 (37.4%)	91 (45%)	63 (46.7%)	28 (41.8%)	0.51
Occipital	547 (59%)	101 (50%)	63 (46.7%)	38 (56.7%)	0.18
Both	33 (3.6%)	10 (5%)	9 (6.7%)	1 (1.5%)	0.11
No. of catheters					
Median	1	1	1	1	0.70
IQR	1–1	1–1	1–1	1–1	
No. of previous shunt ops					
Median	1	2	2	1	0.64
IQR	0–3	1–4	1–4	1–4	
History of shunt infection	102 (11%)	31 (15.3%)	23 (17%)	8 (11.9%)	0.34
Index op due to prior infection	62 (6.7%)	21 (10.4%)	12 (8.9%)	9 (13.4%)	0.32
Slit ventricles at index surgery	57 (6.1%)	16 (7.9%)	14 (10.4%)	2 (3%)	.07
IVH at index op	43 (4.6%)	11 (5.4%)	9 (6.7%)	2 (3%)	0.34
Type of index op					
New shunt	288 (31.1%)	47 (23.2%)	29 (21.5%)	18 (26.9%)	0.40
Proximal revision	298 (32.1%)	85 (42.1%)	59 (43.7%)	26 (38.8%)	0.51
Distal revision	125 (13.5%)	18 (8.9%)	13 (9.6%)	5 (7.5%)	0.61
Valve change	46 (5%)	10 (5%)	7 (5.2%)	3 (4.5%)	1.00
Complete revision	68 (7.3%)	19 (9.4%)	13 (9.6%)	6 (9%)	0.88
Other	101 (11%)	23 (11.4%)	14 (10.4%)	9 (13.4%)	0.52
Intraoperative use					
Stereotactic navigation	92 (9.9%)	16 (7.9%)	12 (8.9%)	4 (6%)	0.47
Ultrasonography	6 (0.6%)	6 (3%)	5 (3.7%)	1 (1.5%)	0.67
Endoscopy	11 (1.2%)	6 (3%)	4 (3%)	2 (3%)	1.00
Laparoscopy	9 (0.9%)	3 (1.5%)	2 (1.5%)	1 (1.5%)	1.00
Operative time in minutes					
Median	43	44	45	42	0.40
IQR	32–62	31–63	33–66	30–62	

TABLE 3. Reasons for preventable shunt revisions (n = 67)

Description	No. of Revisions (%)
Inaccurate proximal catheter placement	33 (49.3%)
Infection	28 (41.8%)
Inaccurate distal catheter placement	4 (5.9%)
Unsecured shunt	2 (2.9%)

went repeat surgery for nonpreventable failures, those who had preventable failures were younger and their reoperations occurred sooner. Procedures in the preventable failure group were more likely to have involved patients with posthemorrhagic hydrocephalus of prematurity (PHHP). Shunt revision surgery after completion of antibiotic therapy for a shunt infection and inaccurate proximal catheter placement accounted for over 90% of preventable revisions. There were few preperitoneal distal catheters (n = 4) and unsecured valves that led to catheter migration out of the ventricle (n = 2). Revision surgery following treatment for a shunt infection (i.e., internalization of an externalized shunt or complete revision) may predispose the patient to reinfection, an observation similar to that of Simon et al.,⁴⁵ who reported an overall reinfection rate of 15%. However, remote history of shunt infection did not seem to affect the risk of infection. Multivariate analysis did not identify any variable that was predictive of preventable shunt failure.

The UCLA (University of California, Los Angeles) group demonstrated that the most common reason for 30-day readmission among patients with neurosurgical complications was CSF shunt-related problems.⁸ They then went on to show that the most common indication for early (i.e., within 7 days) unplanned reoperation was shunt failure (63 [34.4%] of 183 cases).³⁰ As a result of this, the department has set-up process-improvement ideas to reduce reoperation rates, such as defining the use of intraoperative navigation for proximal catheter placement, endoscopy for distal catheter placement, intraoperative confirmation of shunt position, and standardizing the use of intrathecal antibiotics.

The pediatric group in Atlanta has looked at 30-day readmission rates and causes following shunt surgery and other operations.^{9,42,52} They analyzed 1755 shunt operations over a 4-year period; there were 290 readmissions after the index surgery (16.5%).⁹ Of these 290 readmissions, 184 were for 1 or more operations, and 157 were for additional shunt surgery, yielding a 30-day shunt revision rate of 8.9%. The authors stopped short of determining which reoperations were potentially preventable and which were not, but they do state that while lower revision rates are obviously desirable, they may not currently be possible without “significant technological advances.”

Quality Metrics in Pediatric Shunt Surgery

As in other areas of neurosurgery, there has been recent interest in the identification of so-called outcomes and quality metrics in pediatric shunt surgery. Dr. Piatt and his group have led the charge.^{3,35,36} In 2013, they introduced the SAR and RQ.³ Using 2009 data from the Kids' Inpatient Database (KID), they found the weighted mean RQ for the

117 participating hospitals was 1.79 ± 0.69 . They followed this with a more detailed analysis, using nonconsecutive 5-year data from the KID.³⁶ The median RQ was 2.53 (range 0.06–10.92) from 334 annual RQs for 152 different hospitals. Finally, using 1-year data from the National Surgical Quality Improvement Program-Pediatrics (NSQIP-P) database, Piatt found that the overall all-cause 30-day shunt failure rate was 13.5% (95% CI 11.9%–15.2%).

Sarda et al. and the authors of this paper have raised questions about the metrics that Piatt et al. have proposed and the underlying methodology.⁴³ The SAR takes into consideration the surgical and clinical volume of a pediatric hydrocephalus practice, so we fail to see how the SAR directly or indirectly measures quality. Similarly, their RQ and 30-day reoperation rate associates all revision surgery with poor or less than optimal quality of care, a dangerous supposition. In fact, Piatt and Friebott themselves admitted that, with regard to the statistical model of RQ, it is almost entirely dependent on “health care system phenomena rather than clinical phenomena” and to have a quality metric that “categorizes neurosurgical performance to such a substantial yet uncertain degree on the basis of practice setting is not optimal.”³⁶

The generation of quality metrics based on data obtained from non-neurosurgery-specific databases, such as KID and NSQIP-P, deserves scrutiny. There has been an exponential increase in the use of such databases for neurosurgical research, but questions have been raised.^{6,12,20,31,40,41,43} For example, Kestle²⁰ identified a number of major limitations, such as the data source, coding issues, linkages, data validation, confounders, and definitions. While these large administrative databases can dazzle the reader with the large number of patients and statistics, they were not created by neurosurgeons or for neurosurgery, and personnel who have little pediatric neurosurgical knowledge or direct patient contact maintain them. It is our opinion that such databases are ideal for surveying the landscape in health care utilization and costs but do not contain the resolution needed to appropriately generate and evaluate outcomes for neurosurgery.

The Preventable Shunt Revision Rate

We have previously proposed that for a metric to be designated “quality,” it must satisfy 3 core criteria, which we term the “3 Ms”: Make sense, be Measureable, and be Modifiable. Furthermore, the clinical benchmark should be subspecialty specific and be applicable to not only the provider's institution but to others. The Preventable Shunt Revision Rate (PSRR) satisfies the first “M” by identifying causes of shunt failure, unlike demographic risk factors, that are directly under the surgeon's control, but the ability of one to measure a certain outcome (i.e., the second “M”) is entirely dependent on its definition. We feel that our definition is clear and easily applied. What cannot be readily measured with the PSRR is the surgeon's judgment—i.e., performing the right operation on the right patient at the right time. Determining an error in judgment is inherently more subjective and would require more deliberation, similar to what is done for monthly morbidity-and-mortality conferences. The last “M” is theoretically possible, but will require the development and implementation of

strategies as well as time and further analysis to determine whether such strategies were successful.

Aspects of shunt surgery that are directly under the control of the attending surgeon are technique and technology. Although we have recently shown that intraoperative image guidance has not, as yet, led to improved shunt survival,³³ it is possible that the application of such technology in certain cases, such as in patients with small or dysmorphic ventricles or compartmentalized hydrocephalus, would be beneficial in optimally placing the hole-bearing region of the catheter and preventing early failures. Similarly, having a general surgeon consulted a priori or intraoperatively to assist in placement of the distal catheter in certain cases, such as those involving infants with prior necrotizing enterocolitis or other intraperitoneal pathology that is preventing the easy placement of the catheter into the peritoneum, may prevent misplacement or intra-abdominal kinking.

Limitations

Our study sample is relatively small compared with other series, particularly given the large number of variables we collected per procedure. Prospective multi-institution collaborative efforts, such as the HCRN, could provide a greater sample size and an enhanced ability to detect differences between subsets of patients.

The definition of preventable shunt failure that we used in this study was developed with the intention of providing a clear definition that could be applied with minimal subjectivity, in a retrospective manner, and potentially by others. While all 90-day failure cases were independently reviewed and adjudicated by the senior author, having blinded reviewers, which was not really possible, might have eliminated a small amount of potential bias. We recognize that there may be more “preventable” cases in our series, but no additional cases that met our criteria for preventability were readily apparent based on review of the EMR and imaging. For example, if a neurosurgeon correctly placed a new ventriculoperitoneal shunt in an infant with PHHP and a history of necrotizing enterocolitis, and the child returned with CSF ascites, one could argue that there was an error in judgment in choosing to place the distal catheter into the abdomen. On the other hand, it is also reasonable to prove that the abdomen is hostile before considering another terminus for the shunt. For the purpose of this study, this case would not be deemed a preventable revision. As previously mentioned, it is challenging to critically evaluate surgical judgment, but the challenge is not insurmountable if the evaluation is done prospectively and by committee consensus. Such analysis of surgical decision making is an area for future research.

Shunt infection could arguably be removed from the PSRR and kept as a separate quality metric. Shunt infection prevention strategies bundled in the form of a checklist, as we have implemented several years ago, have been shown to be beneficial, but once an institution's shunt infection rate falls below approximately 5%, further attempts to lower the infection risk are unlikely to have a statistically significant impact unless a very large number of patients are evaluated.^{23,25} While our metric is far from perfect and adds to the discussion on “quality metrics” for CSF diversion, we hope our work will stimulate others to

debate, critique, modify, or use our metric. We look forward to seeing this and other prospective quality measures in pediatric neurosurgery evolve with time.

Conclusions

As demonstrated by Chern et al.,⁹ return visits to the emergency room and readmissions after shunt surgery are common, but only a fraction are related to the patient's hydrocephalus. With this study, we have demonstrated that a significant proportion of 90-day shunt failures at our institution—at least 33%—were preventable. We propose the PSRR as a meaningful, measurable, and hopefully modifiable metric of quality outcome for CSF shunting in children.

Acknowledgments

We wish to thank Andrew J. Gienapp (Department of Neurosurgery, UTHSC, and Department of Medical Education, Methodist University Hospital, Memphis, TN) for technical and copy editing, preparation of the manuscript for publishing, and publication assistance with this manuscript.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Klimo. Acquisition of data: Venable, Rossi, Khan, Smalley, Roberts. Analysis and interpretation of data: Klimo, Venable. Drafting the article: Klimo, Venable. Critically revising the article: all authors. Reviewed submitted version of manuscript: Klimo, Venable. Approved the final version of the manuscript on behalf of all authors: Klimo. Statistical analysis: Klimo, Venable, Jones. Study supervision: Klimo.

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