Risk of failure in pediatric ventriculoperitoneal shunts placed after abdominal surgery

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OBJECTIVE Experience has led us to suspect an association between shunt malfunction and recent abdominal surgery, yet information about this potential relationship has not been explored in the literature. The authors compared shunt survival in patients who underwent abdominal surgery to shunt survival in our general pediatric shunt population to determine whether such a relationship exists.

METHODS The authors performed a retrospective review of all cases in which pediatric patients underwent ventriculoperitoneal shunt operations at their institution during a 7-year period. Survival time in shunt operations that followed abdominal surgery was compared with survival time of shunt operations in patients with no history of abdominal surgery. Univariate and multivariate analyses were used to identify factors associated with failure.

RESULTS A total of 141 patients who underwent 468 shunt operations during the period of study were included; 107 of these 141 patients had no history of abdominal surgery and 34 had undergone a shunt operation after abdominal surgery. Shunt surgery performed more than 2 weeks after abdominal surgery was not associated with time to shunt failure ($p = 0.86$). Shunt surgery performed within 2 weeks after abdominal surgery was associated with time to failure (adjusted HR 3.6, 95% CI 1.3–9.6).

CONCLUSIONS Undergoing shunt surgery shortly after abdominal surgery appears to be associated with shorter shunt survival. When possible, some patients may benefit from shunt placement utilizing alternative termini.

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KEY WORDS ventriculoperitoneal; shunt; malfunction; failure; surgery; abdominal; pediatric; percutaneous endoscopic gastrostomy; hydrocephalus

VENTRICULOPERITONEAL (VP) shunts in pediatric patients often present a challenge for neurosurgeons given the need for reoperation. Despite its shortcomings, VP shunting remains the mainstay of treatment for most children with hydrocephalus. Many studies in recent years have sought to identify modifiable risk factors for shunt malfunction. Shunt malfunctions are frequent and costly, and recent studies have shown that between 25% and 60% of pediatric shunt patients will experience shunt failure within 1 year of shunt placement.^{1,10,13,20,35}

Abdominal surgery is common in shunt-treated pediatric patients. For instance, myelomeningocele patients often require operations to augment bowel and/or bladder function.¹⁶ At our institution, experience led us to suspect that VP shunt malfunction occurs more frequently when

the shunt is placed after an abdominal procedure. There is little information in the literature regarding this subject, and it is unclear whether these patients are actually at additional risk.

Considering the relationship between abdominal surgery and shunt failure may serve to optimize surgical decision-making. To better our understanding, we compared survival time in shunt operations that followed abdominal surgery to survival time in shunt operations in patients with no history of abdominal surgery.

Methods

Patient Selection and Treatment

We retrospectively reviewed data on all cases involving

ABBREVIATIONS PEG = percutaneous endoscopic gastrostomy; VP = ventriculoperitoneal.

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pediatric patients undergoing VP shunt placement or revision at our institution between January 2008 and December 2015. Complete records were gathered with respect to all operations on each patient during the period of study. Patients without continuity (those who received operations at other institutions between visits to our institution) were excluded from the study. Patients with alternative distal catheter termination sites were also excluded. This review was completed with approval from our institutional review board.

VP shunts were placed by 1 of 9 neurosurgeons via the occipital or frontal approach. Neuroendoscopy, image guidance, and antibiotic-impregnated catheters were used for ventricular placement according to attending preference. After tunneling, conventional open placement was performed for the peritoneal portion of the catheter. If the position of the distal catheter remained in question following insertion, a general surgeon verified its placement with laparoscopy. Patients were seen in clinic at 3 and 6 months postoperatively, then at 12-month intervals.

Studied Variables

Abdominal surgery was defined as any procedure requiring entry into the abdominal cavity. This included, but was not limited to, inguinal herniorrhaphy, appendectomy, cholecystectomy, lysis of adhesions, and fundoplication. Emergent operations involving viscous perforation were not included, as the likelihood of bacterial seeding would have precluded placement of a distal catheter acutely. Urological procedures not requiring entry into the abdomen (circumcision, hypospadias repair, etc.) were not recorded as abdominal surgeries. Any patient who underwent abdominal surgery with a shunt in place was also excluded from the study. Abdominal surgery was noted to be either open (laparotomy) or laparoscopic. Data on other variables, including age, sex, and etiology of hydrocephalus, were collected for every patient to allow for identification of any confounding factors in our analysis.

Any shunt surgery was recorded as a first-time placement or a revision of an existing shunt. In patients with existing shunts, distal catheters were often externalized prior to planned abdominal procedures, and then replaced in the abdomen at a later date. Replacement into the abdomen of an externalized shunt was considered a replacement of an existing shunt. Malfunction/revision was further characterized as either proximal catheter or distal catheter, or involving multiple components. Flow of CSF was assessed through the valve and through proximal and distal catheters after disconnection from the valve in all revision surgeries. Isolated valve failure was uncommon and was analyzed together with combined (catheter tubing + valve) and complete revisions of the shunt system.

Outcome Assessment

Many patients underwent multiple shunt surgeries, and in some cases, multiple abdominal surgeries. Out of concern for overrepresentation by variables affecting patients undergoing multiple surgeries, only the first shunt observation for each patient was included in our final analysis. Using one observation per patient enabled a random

distribution of additional risks for short-term failure. An observation was defined as the time from shunt placement or revision to shunt revision or removal.

Shunt malfunction was recorded as infection in the presence of positive cultures and/or clinical diagnosis. All cultures were incubated for 7 days to include sensitivity for propionibacteria.³ Clinical diagnosis was made in the presence of symptoms (fever, nausea, vomiting, lethargy, shunt malfunction, etc.) and the absence of another identifiable infectious source. Wound erosion was by definition categorized as infection, whereas abdominal pseudocyst was only considered infection if the given criteria were met.

Statistical Analysis

Continuous variables were reported as means with standard deviations unless otherwise specified. Categorical variables were reported using frequencies and percentages. Each variable was analyzed with the primary outcome of first VP shunt failure in univariate analysis. Between-group differences were analyzed using the Wilcoxon rank-sum test. Time to shunt failure was censored in cases of patient relocation, shunt removal not related to malfunction, or death unrelated to shunt malfunction.

Cox proportional hazards analysis was performed to model shunt failure hazard. A variable was excluded from the model if its removal resulted in no significant difference in interpretation of other variables. We decided a priori to include the following 2 variables independent of univariate analysis results: 1) age at the time of shunt placement/revision (because of the association of age with shunt failure given in the literature^{8,14,27,45}) and 2) etiology of hydrocephalus (given the relationship between myelomeningocele and early revision²⁹). The final multivariate analysis results are presented as hazard ratios with 95% confidence intervals. The proportional hazards model assumption was tested for all variables by plotting Schoenfeld residuals, and no time-dependent cofactors were identified.

A p value ≤ 0.05 was considered statistically significant. All data analysis was conducted using SAS (version 9.4, SAS Institute).

Results

Patient Population

A total of 468 shunt operations were performed on 141 patients included in this study. Of these patients, 107 (76%) had no history of abdominal surgery, and 34 (24%) had undergone abdominal surgery prior to their shunt operation. The patients' mean age was 3.7 ± 4.8 years (range 2 days–17 years). Diagnosis of infection was made in 16 (11%) of 141 cases. The mean follow-up time for the entire group of 141 patients was 55.9 ± 37.3 months. A summary of demographic and clinical characteristics, including types of abdominal surgeries performed and prevalent etiologies of hydrocephalus, is presented in Table 1.

Shunt operations performed more than 2 weeks after abdominal surgery were not associated with significantly different shunt survival times when compared with shunt operations in patients with no history of abdominal surgery ($p = 0.86$), as shown in Table 2. Consequently, all

TABLE 1. Characteristics of patients who underwent shunt operations

Characteristic	Value
Total shunt procedures	468
Total no. of pts/1st observations	141
No abdominal op	107 (76%)
Abdominal op	34 (24%)
Open	22 (65%)
Laparoscopic	12 (35%)
Types of abdominal op	
Ex-lap	6 (18%)
Herniorrhaphy	10 (29%)
Fundoplication	3 (9%)
Cystoplasty	3 (9%)
Appendectomy	1 (3%)
Cholecystectomy	2 (6%)
PEG tube placement	7 (20%)
Other	2 (6%)
Sex	
Male	82 (58%)
Female	59 (42%)
Age	
Mean $\pm$ SD (yrs)	3.7 $\pm$ 4.8
Range (yrs)	0.0–17.9
Etiology of HC	
Spinal dysraphism	42 (30%)
Tumor	10 (7%)
IVH	31 (22%)
Other	57 (40%)
Unknown	1 (1%)
Follow-up (mos), mean $\pm$ SD	55.9 $\pm$ 37.3
Shunt infection, no. of observations	16/141 (11%)

Ex-lap = exploratory laparotomy; HC = hydrocephalus; IVH = intraventricular hemorrhage; pt = patient.

remaining analyses were performed including only patients undergoing abdominal surgery within the 2 weeks immediately preceding their shunt surgery and those with no history of abdominal surgery (Fig. 1).

Analysis of Risk Factors

In Table 3, the proportion of failed shunts relative to VP shunt operations for each variable is given for direct comparison, and survival analyses were used to generate corresponding p values. Failure occurred following 6 (86%) of 7 shunt operations performed within 2 weeks after abdominal surgery, compared with 80 (75%) of 107 shunt operations not related to abdominal surgery ($p = 0.02$). Failure occurred in 56 (93%) of 60 patients aged 0–6 months, compared with 6 (54%) of 11 patients aged 6 months to 2 years and 24 of (56%) 43 patients aged 2 years to 18 years ($p < 0.01$); and in 31 (82%) of 38 patients who were treated with CSF shunting for hydrocephalus associated with spinal dysraphism compared with 55 (67%)

TABLE 2. Shunt survival with remote history of abdominal surgery

Time Since Abdominal Op at Placement/Revision	Failures	p Value
2 wks–6 mos	6/11 (55%)	0.86
6 mos–2 yrs	9/16 (71%)	
Control group	80/107 (75%)

FIG. 1. Kaplan-Meier survival analysis comparing shunt survival in patients who had shunt operations within 2 weeks after abdominal surgery to shunt survival in patients who never underwent abdominal surgery.

of 76 patients who were being treated for hydrocephalus of other etiologies ($p = 0.14$). Failure also occurred in 66 (92%) of 72 first-placement shunts, compared with 6 (38%) of 16 proximally revised shunts, 4 (40%) of 10 distally revised shunts, and 10 (62%) of 16 completely revised shunts ($p \leq 0.01$).

Multivariate Analysis

All variables found to have a significant association with time to shunt failure in univariate analysis, as well as those decided upon a priori, were included in the proportional hazards model. Three risk factors were found to have an independent association with time to shunt failure: abdominal surgery within 2 weeks before shunt operation (adjusted HR 3.6, 95% CI 1.3–9.6); shunting secondary to spinal dysraphism (adjusted HR 1.6, 95% CI 1.1–2.6); and first-time shunt placements (adjusted HR 5.8, 95% CI 2.3–14.5). These are given in Table 4.

Patients Who Underwent Shunt Surgery Within 2 Weeks After Abdominal Surgery

Additional details of the 7 patients who underwent a shunt operation within 2 weeks after abdominal surgery are given in Table 5. Two patients experienced shunt survival beyond 1 year. The remaining 5 patients experienced failure within 6 weeks, and all had failure of the distal catheter. Of these 5 patients, 1 (20%) had failure due to

TABLE 3. Association between variables and time to shunt malfunction

Covariate	Failures	p Value
Previous abdominal op		0.02
≤2 wks earlier	6/7 (86%)	
Control group	80/107 (75%)	
Age		<0.01
0–6 mos	56/60 (93%)	
6 mos–2 yrs	6/11 (54%)	
2 yrs–18 yrs	24/43 (56%)	
Sex		0.26
Female	35/50 (70%)	
Male	51/64 (80%)	
Etiology of HC		0.14
Spinal dysraphism	31/38 (82%)	
Other	55/76 (67%)	
Shunt op		<0.01
New placement	66/72 (92%)	
Complete/combined revision	10/16 (62%)	
Proximal revision	6/16 (38%)	
Distal revision	4/10 (40%)	

shunt infection. Other known reasons for early distal catheter failure included abdominal pseudocyst and intraabdominal adhesions.

Discussion

Some evidence exists to support delaying abdominal surgery after shunt placement in adults,²⁸ but most discussion has centered on case reports^{5,12,15,41,44} and small case series^{9,38,47} not limited to pediatric patients. To address the lack of information regarding the treatment of patients requiring abdominal and shunt operations in succession, we endeavored to identify whether abdominal surgery before shunt placement was related to shunt survival time. Our analysis revealed that patients undergoing shunt operations within 2 weeks after abdominal surgery were at increased risk for shunt failure when compared with those who had not had abdominal surgery.

The reason for shunt failure in the setting of recent abdominal surgery is unclear, but there did not appear to be a relationship between abdominal surgery and infection in our cohort. Of the 5 patients to experience shunt failure after a shunt operation following abdominal surgery, only 1 was suspected to have shunt infection. The overall infection rate for this cohort was slightly higher than expected⁴⁸ but was within ranges given in previous studies.^{2,49} As patients with frequent complications are more likely to receive follow-up care, excluding patients without sufficient records may have eliminated some of the patients who fared better from our analysis. Past studies have consistently reported infection and obstruction as the most common causes of shunt failure overall in pediatric patients.^{30,40}

Intraabdominal processes known to occur following surgery may account for the relationship between recent

TABLE 4. Analysis of variables associated with shunt malfunction

Study Variable	Adjusted HR (95% CI)	p Value
Abdominal op		
No previous abdominal op	Ref	—
Abdominal op <2 wks before shunt	3.5 (1.3–9.6)	0.01
Age (per yr of age)	1.0 (0.9–1.1)	0.84
Etiology		
Spinal dysraphism	1.6 (1.1–2.6)	0.05
Other causes	Ref	—
Shunt op		
New placement	5.8 (2.3–15.6)	<0.01
Complete/combined revision	2.3 (0.8–6.4)	0.11
Proximal revision	Ref	—
Distal revision	1.4 (0.4–5.0)	0.63

Ref = referent.

abdominal surgery and shunt failure. Residual inflammation from abdominal surgery has been documented in children²³ and may lead to more adhesions and impairment of CSF absorption. Distal shunt failure has been linked to chronic inflammation and foreign body reaction,^{4,6,34} and recent abdominal surgery may consequently leave patients more susceptible to shunt obstruction.

Another possibility is that manipulation of bowel could lead to the introduction of enteric microorganisms into the peritoneum, where they remain for a limited period of time. Authors of an earlier study similarly proposed ascending infection as a mechanism of shunt failure, relating to observations in pediatric brain tumor patients after percutaneous endoscopic gastrostomy (PEG) tube placement.¹⁸ Some types of anaerobic bacteria point toward intraperitoneal infection, and could offer insight into infectious source.⁷ Efforts have been made in recent years to improve culturing protocols and improve culture sensitivity,³ but the microorganisms involved still cannot always be reliably identified. As such, patients are sometimes treated for shunt infection based on clinical suspicion in the absence of positive cultures.

Overall survival rates of shunts in this study are comparable to those in the existing literature.^{1,39,43} Shunt survival in children continues to improve, and recent advances in operative protocols have been an important factor in reducing infection and failure rates.^{19,21,22,36,42} In other studies, various hydrocephalus etiologies have been shown to influence the risk of shunt failure within the first year,^{8,24,27,35,45} although etiology has not been a universally significant risk factor.^{33,43} In this study there was an association between shunt placement for hydrocephalus due to spinal dysraphism and shunt failure, with other etiologies not appearing to confer increased risk.

Interestingly, in our multivariate model, no significant individual association was evident between patient age at shunt placement/revision and time to shunt failure, despite seemingly significant differences in the univariate analysis. Previous studies have suggested patient age at

TABLE 5. Clinical characteristics of 7 patients who underwent shunt operation ≤ 2 weeks after abdominal surgery

Case No.	Etiology of HC	Type of Abdominal Op	Shunt Survival Time (days)	Time From Abdominal Op to Shunt Op (days)	Type of Failure	CSF WCC (per mm ³)	CSF Culture	Comments
1	IVH	Fundoplication	40	13	Distal catheter	7	No growth	Shunt was externalized for poor distal flow. Distal catheter was found to be adherent w/ in the abdomen
2	IVH	Inguinal herniorrhaphy	1456	2	Proximal catheter & valve	0	No growth	Has not required revision in past 3 yrs
3	Trauma	PEG tube placement	2	10	Valve & distal catheter	7	No growth	Poor distal flow improved after valve change & proximal catheter flushing
4	Tumor	Inguinal herniorrhaphy	—	5	—	—	—	Shunt remained functioning 4 yrs postop
5	Tumor	Ex-lap	25	0	Distal catheter	234	No growth	Shunt was externalized for presumed infection
6	IVH	Ex-lap	13	14	Distal catheter	4	No growth	Pt was leukopenic from receiving chemo for primary renal tumor*
7	Congenital	Cholecystectomy	9	0	Distal catheter	2	No growth	Pt developed abdominal pseudocyst

chemo = chemotherapy; IVH = intraventricular hemorrhage; WCC = white cell count.

* Abdominal tumor was located remotely from shunt catheter and not found to be the cause of distal obstruction intraoperatively. Notably, removal of this case would not affect the reported statistical significance of shunt surgery ≤ 2 weeks after abdominal surgery ($p = 0.01$ vs $p = 0.04$).

first placement as an independent risk factor for shunt failure.^{8,14,25–27,31,32,45} One potential reason for this difference is that our cohort does not exclusively contain first-time placements as do cohorts of some other studies.^{10,17,24,37}

Our multivariate analysis suggested that first-time placement was associated with risk of failure, independent of age. This was not an expected finding. A number of past studies have noted no relationship between first-time placement and shunt failure;^{11,25,46} in contrast, another found first-time placement to confer lower risk of failure.¹ One possible explanation for our result is the duration of our study. Stone and colleagues⁴³ previously noted that a small, but significant percentage of first-placement shunts survive beyond 10 years. As the mean follow-up for our study was about 5 years, our first-placement survival times may not fairly represent some shunts that survived much longer. Nevertheless, first-placement status and recent abdominal surgery (≤ 2 weeks prior to shunt surgery) appear to be independently related to shunt failure.

The mechanism behind shunt failure in the setting of abdominal surgery may remain difficult to elucidate without more accessible, sensitive testing for pathogens. Other limitations of this study are those inherent to retrospective analysis, and larger studies may uncover additional relationships not addressed here. Indeed, a larger study may be necessary to fully elucidate the relationship between abdominal surgery and shunt malfunction. Our study spanned 7 years and included review of over 500 pediatric shunt cases, yet after necessary exclusions were made, only 7 patients were identified as having had shunts placed shortly after abdominal surgery. However, given that short-term shunt failure in pediatric patients remains a major challenge within pediatric neurosurgery and can strongly impact patient outcomes, we believe our initial exploration of the relationship between shunt failure and recent abdominal surgery warrants further investigation.

Our data suggest that patients could benefit from avoidance of peritoneal catheter placement for up to 2 weeks following abdominal surgery when possible, but the small size of the study calls for a cautious interpretation.

Conclusions

Ventriculoperitoneal shunt surgery shortly after abdominal surgery appears to be associated with shorter shunt survival. When feasible, some patients who require shunt surgery within the first 2 weeks after abdominal surgery might benefit from the use of atrial or pleural termini.

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Disclosures

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Author Contributions

Conception and design: Mapstone. Acquisition of data: Burks, Conner, Briggs, Bonney. Analysis and interpretation of data: Burks. Drafting the article: Burks. Critically revising the article: Mapstone, Conner, Briggs, Glenn, Bonney, Cheema, Gross. Reviewed submitted version of manuscript: Mapstone, Burks. Approved the final version of the manuscript on behalf of all authors: Mapstone. Statistical analysis: Burks, Chen.

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