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Risk, timing and causes of shunt revision in adults: a single-centre cohort study of 1,102 patients over ten years

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Abstract

Background

Adult data on shunt revision are heterogeneous and rarely reported at both patient and procedure level. We assessed the frequency, timing, causes and risk factors of revision.

Methods

We retrospectively studied all consecutive adults undergoing cerebrospinal fluid (CSF) shunt surgery, including primary implantations and revisions, between 2016 and 2025. Analyses were performed at patient and procedure level. Time to first revision was analysed with Kaplan–Meier and multivariable Cox regression, with logistic regression as a secondary analysis.

Results

Of 1,102 patients undergoing 1,424 procedures, 197 (17.9%) required revision; revisions accounted for 21.6% of all operations. Of 308 revisions, 64.3% were mechanical, and infection was the most frequent single cause (35.7%). Revisions occurred within one month in 32.8% and beyond two years in 26.0%. Revision-free survival was 81.7% at 1 and 75.2% at 5 years. In the Cox model, revision was associated with ventriculoatrial shunts (HR 3.08) and siphon-resistive devices (HR 1.68). Diagnosis was associated with first revision but not with the number of further revisions. In logistic regression only, younger age was associated with more revisions (OR 0.98 per year), and a worse modified Rankin Scale score at discharge after haemorrhage or brain injury with fewer revisions (OR 0.76 per point); the former disappeared when follow-up was considered, and the latter probably reflects competing events.

Conclusion

Shunt revision is an integral part of CSF diversion in adults rather than an occasional complication. Ventriculoatrial shunts and siphon-resistive devices should be reserved for patients with a clear indication, and follow-up should extend beyond the first year.

Introduction

Permanent cerebrospinal fluid (CSF) diversion by shunting is the most widely used treatment for hydrocephalus in adult neurosurgical practice [16, 18, 20]. Endoscopic third ventriculostomy is an option in obstructive hydrocephalus [25, 26] but has a limited role in communicating and post-haemorrhagic forms. Adults requiring shunt surgery are not a homogeneous group. Adult hydrocephalus is the shared endpoint of conditions as diverse as idiopathic normal pressure hydrocephalus (iNPH), long-standing overt ventriculomegaly in adults (LOVA), subarachnoid and intracerebral haemorrhage, traumatic brain

injury (TBI), intracranial tumours, intracranial infection, and hydrocephalus persisting from childhood into adult life [8, 27]. Shunting is furthermore an option in idiopathic intracranial hypertension (IIH) when medical treatment fails [10, 17]. All these entities differ in their disturbances of CSF dynamics, clinical presentation and associated comorbidities.

The principal limitation of shunt treatment lies not in the initial implantation but in the durability of the implant. Despite decades of technical development, malfunction remains common [18, 19], and adult series have reported overall complication or failure rates of approximately 17% to 33% [11, 12, 14, 19–22, 24, 28]. Failure is not a single event: obstruction or malfunction of the proximal or distal catheter, disconnection, valve malfunction, over- and under-drainage, abdominal complications and infection each contribute, and each can lead to a further operation, so that the number of revision procedures exceeds the number of patients revised. The cost of shunt treatment is correspondingly dominated by revision rather than by implantation [13, 18]. Shunt failure has been investigated far more thoroughly in children, in whom it is also reported more frequently [8, 21, 28]. As populations age, however, the number of adults exposed to the risk of revision is likely to increase, particularly among patients with iNPH [4, 9].

Reported revision rates vary considerably, partly because of differences in patient selection, aetiologies, follow-up duration and definitions of failure, and partly because outcomes are reported per patient in some series and per procedure in others [2, 8]. Adult cohorts are furthermore often restricted to a single underlying cause or comprise small numbers, so that it remains difficult to determine how the risk, timing and causes of revision vary with the underlying aetiology. We therefore analysed a consecutive single-centre cohort of adults who underwent CSF shunt surgery over a ten-year period. The aims were to determine the frequency and timing of revisions at both the patient and the procedure level, to characterise the indications for revision and their distribution across the underlying diagnoses, and to identify factors associated with revision.

Materials and methods

Study design and eligibility

This single-centre retrospective cohort study included all consecutive adults (≥ 18 years) who underwent CSF shunt surgery for hydrocephalus or IIH at our tertiary centre between January 2016 and December 2025. Patients with an initial shunt implanted externally or before the age of 18 years, or with surgery solely for unrelated abdominal pathology, were excluded (Fig. 1).

Group definitions and unit of analysis

A shunt revision was defined as any operation on the shunt for a shunt-related complication. In shunt infection, explantation with insertion of an external ventricular drain counted as a revision. A new shunt implanted after explantation counted as a further index procedure, with follow-up reset. Analyses were performed at two levels (Fig. 1). At the patient level, each of the 1,102 patients contributed one

observation and was assigned to the Revision group (≥ 1 revision; n = 197) or the No Revision group (n = 905). At the procedure level, the unit was the individual operation: 1,424 procedures, comprising 1,116 index implantations (905 in non-revised and 211 in revised patients, including 14 new shunts after explantation) and 308 revisions. Because patients could contribute more than one procedure, procedure-level p values were not adjusted for clustering and are exploratory. Group comparisons were made at the patient level; the time-to-event analysis was based on index implantations

Data collection and variables

Data were extracted retrospectively from the electronic medical records: demographics, diagnosis, shunt and valve characteristics (shunt type, valve model, siphon-resistive device, antibiotic-impregnated shunt), CSF cell count, protein and lactate, the modified Rankin Scale (mRS) at discharge and, for revised patients, revision history and causes. CSF values were available for a subset, obtained before revision for valve dysfunction (Revision group) or before implantation (No Revision group). The mRS was analysed only in the intracerebral or intraventricular haemorrhage, aneurysmal or non-aneurysmal subarachnoid haemorrhage and TBI subgroups, in which it is clinically interpretable.

Two types of siphon-resistive device (SRD) were used: the SiphonGuard (Integra LifeSciences, Princeton, NJ, USA) with the Codman Hakim, MicroValve or Certas valve, and the ShuntAssistant (Christoph Miethke GmbH & Co. KG, Potsdam, Germany) with the proGAV 2.0 valve [6, 23].

Diagnoses were grouped into seven categories: intracerebral or intraventricular haemorrhage (ICH/IVH); aneurysmal or non-aneurysmal subarachnoid haemorrhage (aSAH/naSAH); TBI; infection; iNPH, LOVA or IIH (iNPH/LOVA/IIH); tumour-associated; and other. Non-aneurysmal SAH denoted subarachnoid bleeding without a demonstrable source that fitted no other category. The iNPH/LOVA/IIH category combined three chronic, communicating disorders of CSF dynamics without a preceding acute intracranial event, shunted electively with CSF of normal composition.

Causes of revision were grouped into five categories: proximal catheter malfunction, valve dysfunction, distal catheter malfunction, infection, and unclear or other cause. Infection comprised shunt infection (meningitis, ventriculitis or peritonitis), wound healing disorder and open skin lesion. The five categories were collapsed into two groups: mechanical dysfunction, comprising all categories other than infection, and infection.

In the Revision group, the interval from implantation to each revision was recorded, and follow-up ran from the last revision to the last documented contact; in the No Revision group, it ran from implantation to the last outpatient or emergency department visit. Because these endpoints differ, descriptive follow-up is reported separately for each group and was not compared statistically. For the time-to-event analysis, time was measured uniformly in both groups from implantation to first revision or, in patients without revision, to the last documented contact, whereas the logistic regression did not account for follow-up duration.

Statistical analysis

Data are given as mean (standard deviation, SD), median (interquartile range, IQR) or n (%); analyses used complete cases. Proportions were compared with the chi-squared or Fisher's exact test, or, for larger tables with expected counts below 5, the Fisher–Freeman–Halton test with Monte Carlo p values. Continuous variables were compared with Student's t-test or, if non-normal (Kolmogorov–Smirnov test), the Mann–Whitney U test, and across more than two groups with the Kruskal–Wallis test with Bonferroni correction. Spearman's rho assessed mRS versus number of revisions.

Time to first revision was analysed with the Kaplan–Meier method, censoring non-revised patients at last contact, and compared between diagnoses with the log-rank test; revision-free survival is reported at 1, 2 and 5 years with 95% confidence intervals (CI). Factors associated with revision were analysed with multivariable Cox regression including age at implantation, sex, diagnosis, initial shunt type, valve model and SRD, reported as hazard ratios (HR) with 95% CI. Proportional hazards were checked with Schoenfeld residuals. The time-to-event analysis was restricted to implantations within the study period; a sensitivity analysis included the 37 revised patients with primary implantation before 2016.

As a secondary analysis, patient-level multivariable logistic regression with the same covariates, which does not account for follow-up duration, was reported as adjusted odds ratios (OR) with 95% CI, the area under the receiver operating characteristic curve (AUC), the Hosmer–Lemeshow test and Nagelkerke R^2. An additional model in the haemorrhage and TBI subgroups, excluding in-hospital deaths, included mRS at discharge.

All p values are two-tailed, with significance at $p < 0.05$. Analyses used SPSS version 27.0.

Ethics

The study was approved by the local Ethics Committee of the Technische Universität Dresden (approval number: BO ff (Mono)-EK-296062025).

Results

Revision group

The Revision group comprised 197 patients with 308 revisions (mean age at implantation 56.2 years, SD 17.2; 50.8% female; initial ventriculoperitoneal shunt 89.8%). The most frequent diagnoses were aSAH/naSAH (30.5%) and ICH/IVH (20.8%). Patients underwent one to seven revisions (mean 1.56, SD 1.02; median 1, IQR 1–2): 130 (66.0%) one and 67 (34.0%) more than one. Neither multiple revisions nor their number differed across diagnoses ($p = 0.789$ and $p = 0.669$) (Table 1).

Mean mRS at discharge was 4.7 (SD 1.0) in TBI, 4.2 (SD 1.3) in ICH/IVH and 3.7 (SD 1.7) in aSAH/naSAH ($p = 0.017$), and 4.0 (SD 1.5) for the three combined, unchanged after excluding in-hospital deaths. The

number of revisions did not correlate with the mRS (p = 0.333) (Table 1).

The median interval from implantation to the last revision was 3.2 months (IQR 0.7–23.8; mean 31.3, SD 63.9), and 2.0 months (IQR 0.4–7.4; mean 7.9, SD 14.9) in the 160 patients implanted within the study period. Median follow-up after the last revision was 18.1 months (IQR 9.8–45.2; mean 29.4, SD 27.9) in the 113 patients with a documented last contact. Thirty-two patients (16.2%) died during follow-up, five from shunt-related causes (ventriculitis in four, dysfunction in one).

Table 1
Patient, shunt and revision characteristics of the Revision group (n = 197).

Variable	n (%) or mean (SD)	Median (IQR)	p
Sex			
Female	100 (50.8)		
Male	97 (49.2)		
Age, years			
At initial implantation	56.2 (17.2)	56.7 (45.6–69.4)	
At first revision	58.4 (16.4)	59.6 (47.8–72.0)	
At last revision	58.8 (16.3)	60.0 (48.1–72.0)	
Initial shunt type			
VP	177 (89.8)		
VA	11 (5.6)		
Subduroperitoneal	5 (2.5)		
Other	4 (2.0)		
Diagnosis			
aSAH/naSAH	60 (30.5)		
ICH/IVH	41 (20.8)		
iNPH/LOVA/IIH	31 (15.7)		
Tumour-associated	27 (13.7)		
TBI	18 (9.1)		
Other	13 (6.6)		
Infection	7 (3.6)		
Number of revisions per patient[a]	1.56 (1.02)	1 (1–2)	0.669
1	130 (66.0)		
2	43 (21.8)		
3	12 (6.1)		
4	8 (4.1)		
5	1 (0.5)		

Variable	n (%) or mean (SD)	Median (IQR)	p
Sex			
6	2 (1.0)		
7	1 (0.5)		
More than one revision[a]	67 (34.0)		0.789
mRS at discharge[b, c]			**0.017**
TBI	4.8 (1.0)	5 (5–5)	
ICH/IVH	4.2 (1.3)	5 (3–5)	
aSAH/naSAH	3.7 (1.7)	5 (2–5)	
All three subgroups combined	4.0 (1.5)	5 (3–5)	
Time from implantation to last revision, months			
All patients	31.3 (63.9)	3.2 (0.7–23.8)	
Implanted within the study period	7.9 (14.9)	2.0 (0.4–7.4)	
Follow-up after the last revision, months	29.4 (27.9)	18.1 (9.8–45.2)	
Death during follow-up	32 (16.2)		

a Compared across all seven diagnoses: Kruskal–Wallis test for the number of revisions, Fisher–Freeman–Halton test for the occurrence of more than one revision.

b Compared across the three diagnostic subgroups in which the mRS is clinically interpretable — TBI, ICH/IVH and aSAH/naSAH (combined n = 119) — using the Kruskal–Wallis test.

c In these 119 patients, the number of revisions was not correlated with the mRS at discharge (Spearman rho = 0.08; p = 0.333).

d 160 patients whose index implantation took place between January 2016 and December 2025.

e 113 patients with a documented last contact after the last revision.

aSAH/naSAH, aneurysmal/non-aneurysmal subarachnoid haemorrhage; ICH/IVH, intracerebral/intraventricular haemorrhage; IIH, idiopathic intracranial hypertension; iNPH, idiopathic normal pressure hydrocephalus; IQR, interquartile range; LOVA, long-standing overt ventriculomegaly in adults; mRS, modified Rankin Scale; SD, standard deviation; TBI, traumatic brain injury; VA, ventriculoatrial; VP, ventriculoperitoneal.

Revision characteristics at patient level

Indications for revision were mechanical dysfunction in 138 patients (70.1%) and infection in 96 (48.7%), both in 37 (18.8%); 101 (51.3%) had mechanical dysfunction alone and 59 (29.9%) infection alone. Infection comprised shunt infection (meningitis, ventriculitis or peritonitis) in 62 (64.6%), wound healing disorder in 27 (28.1%) and open skin lesion in 13 (13.5%). Before revision, an SRD was in place in 108 patients (54.8%), and the Codman Hakim was the predominant valve (87.8%). The valve was exchanged in 60 patients (30.5%), in 35 (58.3%) for documented or suspected dysfunction, independently of SRD ($p = 0.290$) or valve model ($p = 0.066$). Shunts were converted in 38 patients (19.3%), mostly from ventriculoperitoneal (VP) to ventriculoatrial (VA) (78.9%), without significant difference across diagnoses ($p = 0.050$). After infection, 20 of 60 reimplanted patients (33.3%) received an antibiotic-impregnated shunt. In 43 patients (21.8%), the shunt was explanted without reimplantation because diversion was no longer required, most often in patients with other diagnoses (46.2%), TBI (33.3%) or ICH/IVH (26.8%; $p = 0.060$). The same cause of revision recurred during follow-up in 30 patients (15.2%) (Table 2).

Table 2
Operative, laboratory and microbiological characteristics of shunt revisions (197 patients, 308 revisions).

Variable[a]	**n (%) or mean (SD)**	**Median (IQR)**	**p**
Patient level (n = 197)			
Cause of revision[b]			
Mechanical dysfunction	138 (70.1)		
Infection	96 (48.7)		
Mechanical dysfunction only	101 (51.3)		
Infection only	59 (29.9)		
Both	37 (18.8)		
Valve and device characteristics			
SRD before revision	108 (54.8)		
Valve model at first revision			
Codman Hakim	173 (87.8)		
Certas	11 (5.6)		
proGAV 2	8 (4.1)		
Other	5 (2.5)		
Valve model at last revision (n = 124)[c]			
Codman Hakim	114 (91.9)		
Certas	4 (3.2)		
proGAV 2	2 (1.6)		
Other	4 (3.2)		
Valve change			
Valve changed	60 (30.5)		
Same model reimplanted (n = 59)	47 (79.7)		
Different model implanted (n = 59)	12 (20.3)		
Documented or suspected valve dysfunction (n = 60)	35 (58.3)		
Programming impossible owing to defect (n = 40)	14 (35.0)		

Variable[a]	n (%) or mean (SD)	Median (IQR)	p
Patient level (n = 197)			
Cause of revision[b]			
Valve change by SRD before revision[d]			0.290
Valve change by valve model at first revision[d]			0.066
Operative details			
Shunt conversion[e]	38 (19.3)		0.050
VP to VA	30 (78.9)		
VA to VP	3 (7.9)		
Other conversion	5 (13.2)		
Antibiotic-impregnated shunt after infection (n = 60)[f]	20 (33.3)		
Shunt explantation[e]	43 (21.8)		0.060
Type of infection (n = 96)[g]			
Shunt infection	62 (64.6)		
Wound healing disorder	27 (28.1)		
Open skin lesion	13 (13.5)		
Site of wound healing disorder (n = 27)			
Retroauricular	12 (44.4)		
Frontal	11 (40.7)		
Abdominal	2 (7.4)		
More than one site	2 (7.4)		
Same cause recurring across revisions[h]			
Any recurring cause	30 (15.2)		
Infection	11 (5.6)		
Malfunction of unclear aetiology or other cause	8 (4.1)		
Proximal catheter malfunction	6 (3.0)		

Variable[a]	n (%) or mean (SD)	Median (IQR)	p
Patient level (n = 197)			
Cause of revision[b]			
Distal catheter malfunction	6 (3.0)		
Valve dysfunction	2 (1.0)		
Procedure level (n = 308 revisions)			
Cause of revision[e]			**0.032**
Infection	110 (35.7)		
Proximal catheter malfunction	59 (19.2)		
Malfunction of unclear aetiology or other cause	58 (18.8)		
Valve dysfunction	42 (13.6)		
Distal catheter malfunction	39 (12.7)		
Type of infection (n = 110)			
Shunt infection	68 (61.8)		
Wound healing disorder	29 (26.4)		
Open skin lesion	13 (11.8)		
CSF parameters in valve dysfunction (n = 9)[i]			
Cell count, cells/µL	28.0 (41.1)	7 (2–29)	
Protein, mg/L	1211.4 (1262.8)	496 (296–2635)	
Lactate, mmol/L	3.4 (2.4)	3.0 (1.9–4.0)	
Microbiology in patients with infection (n = 96)[j]			
Culture-positive	89 (92.7)		
Culture-negative	4 (4.2)		
Not available	3 (3.1)		
Isolated organisms (n = 149)			
Coagulase-negative staphylococci	48 (32.2)		
S. epidermidis	31 (20.8)		

Variable[a]	n (%) or mean (SD)	Median (IQR)	p
Patient level (n = 197)			
Cause of revision[b]			
S. capitis	6 (4.0)		
S. hominis	4 (2.7)		
S. haemolyticus	3 (2.0)		
S. caprae	2 (1.3)		
S. lugdunensis	2 (1.3)		
S. aureus	27 (18.1)		
Cutibacterium acnes	16 (10.7)		
Klebsiella species	11 (7.4)		
Pseudomonas aeruginosa	9 (6.0)		
Escherichia coli	6 (4.0)		
Enterococcus faecalis	5 (3.4)		
Enterobacter cloacae	4 (2.7)		
Candida albicans	1 (0.7)		
Other isolates[j]	22 (14.8)		
Site of isolation (n = 114 specimens)			
CSF	47 (41.2)		
Shunt	27 (23.7)		
CSF and shunt	26 (22.8)		
Wound	9 (7.9)		
CSF and wound	4 (3.5)		
Wound and catheter	1 (0.9)		
Microbial pattern			
Shunt infection, polymicrobial (n = 72)	27 (37.5)		
Wound healing disorder, polymicrobial (n = 10)	2 (20.0)		

a Denominators are given in parentheses where they differ from the level total.

b The first two rows are not mutually exclusive, since a patient could have both a mechanical and an infectious indication across successive revisions; the three rows that follow are mutually exclusive and sum to 197. Mechanical dysfunction comprises proximal catheter malfunction (comprises malposition, dislocation, and occlusion), valve dysfunction, distal catheter malfunction, and malfunction of unclear aetiology or other cause; infection comprises shunt infection, wound healing disorder, and open skin lesion.

c Valve model at last revision was recorded for 124 patients. In the remaining 73, the shunt had been explanted (n = 30), the valve had not been exchanged at any revision (n = 36), or the valve model was not documented (n = 7).

d Valve change was associated neither with the presence of an SRD before revision (p = 0.290, Pearson's chi-squared test) nor with the valve model at first revision (p = 0.066, Pearson's chi-squared test).

e Compared across the seven diagnostic categories: shunt conversion p = 0.050 and shunt explantation p = 0.060, cause of revision p = 0.032 (Fisher–Freeman–Halton test, Monte Carlo estimate).

f Patients with an infectious indication in whom the shunt type at reimplantation was documented; of the remaining 36, 31 had undergone explantation without reimplantation.

g Not mutually exclusive: five patients had more than one type of infection.

h Two patients had more than one recurring cause.

i CSF values obtained before shunt revision for valve dysfunction.

j Restricted to the 96 patients with an infectious indication; isolates and specimens refer to these patients. Other isolates comprise Serratia marcescens (n = 3), Enterococcus avium (n = 2), Citrobacter koseri (n = 2) and 15 single isolates.

CSF, cerebrospinal fluid; IQR, interquartile range; SD, standard deviation; SRD, siphon-resistive device; VA, ventriculoatrial; VP, ventriculoperitoneal.

Revision characteristics at procedure level

Of 308 revisions, 64.3% were mechanical; infection was the most frequent single cause (35.7%). Proximal catheter malfunction (19.2%) was the leading mechanical cause, due to malposition in 47 of 59 (79.7%). Causes differed across diagnoses (p = 0.032) (Table 2, Supplementary Table 3). Revisions peaked within one month (32.8%) and beyond 24 months (26.0%). Timing differed by cause (p = 0.002): proximal catheter malfunction was mostly early (61.0% within one month), valve and distal catheter dysfunction mostly late (35.7% and 30.8% beyond two years), and infection biphasic (27.3% and 26.4%). Timing also differed by diagnosis (p = 0.007): revisions after intracranial infection were mostly early

(70.6%; none beyond two years), those in tumour-associated and other diagnoses mostly late (40.0% and 60.0%) (Table 3).

CSF before revision for valve dysfunction (n = 9) showed a median cell count of 7/µL (IQR 2–29), protein 496 mg/L (IQR 296–2635) and lactate 3.0 mmol/L (IQR 1.9–4.0). Cultures were positive in 89 of 96 patients with infection (149 isolates from 114 specimens). Gram-positive skin flora accounted for 61.1% of isolates, mainly coagulase-negative staphylococci (32.2%), Staphylococcus aureus (18.1%) and Cutibacterium acnes (10.7%); 37.5% of infections were polymicrobial (Table 2).

Table 3
Timing of shunt revision at patient (n = 197) and procedure (n = 308) level, overall and according to cause of revision and underlying diagnosis.

Variable	Time from initial implantation, n (%)							
	< 1 month	**1 to < 3**	**3 to < 6**	**6 to < 12**	**12 to < 24**	**≥ 24 months**	**Total**	**p**
Patient level (n = 197)								
Interval to last revision[a]	57 (28.9)	37 (18.8)	19 (9.6)	19 (9.6)	15 (7.6)	50 (25.4)	197	
Procedure level (n = 308)								
All revisions[a]	101 (32.8)	48 (15.6)	28 (9.1)	25 (8.1)	26 (8.4)	80 (26.0)	308	
By cause of revision[b]								**0.002**
Proximal catheter malfunction[c]	36 (61.0)	9 (15.3)	2 (3.4)	1 (1.7)	3 (5.1)	8 (13.6)	59	
Valve dysfunction	10 (23.8)	3 (7.1)	7 (16.7)	4 (9.5)	3 (7.1)	15 (35.7)	42	
Distal catheter malfunction[c]	10 (25.6)	3 (7.7)	4 (10.3)	5 (12.8)	5 (12.8)	12 (30.8)	39	
Infection	30 (27.3)	21 (19.1)	8 (7.3)	9 (8.2)	13 (11.8)	29 (26.4)	110	
Unclear aetiology or other cause	15 (25.9)	12 (20.7)	7 (12.1)	6 (10.3)	2 (3.4)	16 (27.6)	58	
By diagnosis[b]								**0.007**
ICH/IVH	23 (37.7)	12 (19.7)	4 (6.6)	5 (8.2)	7 (11.5)	10 (16.4)	61	
aSAH/naSAH	29 (33.0)	16 (18.2)	11 (12.5)	8 (9.1)	7 (8.0)	17 (19.3)	88	
TBI	10 (33.3)	4 (13.3)	3 (10.0)	2 (6.7)	4 (13.3)	7 (23.3)	30	
Infection	12 (70.6)	3 (17.6)	0 (0)	1 (5.9)	1 (5.9)	0 (0)	17	

Variable	Time from initial implantation, n (%)							
	< 1 month	1 to < 3	3 to < 6	6 to < 12	12 to < 24	≥ 24 months	Total	p
Patient level (n = 197)								
iNPH/LOVA/IIH	12 (28.6)	5 (11.9)	2 (4.8)	5 (11.9)	5 (11.9)	13 (31.0)	42	
Tumour-associated	11 (24.4)	8 (17.8)	4 (8.9)	3 (6.7)	1 (2.2)	18 (40.0)	45	
Other	4 (16.0)	0 (0)	4 (16.0)	1 (4.0)	1 (4.0)	15 (60.0)	25	

a At patient level the interval is measured from shunt implantation to the last revision, each patient contributing one observation; at procedure level it is measured from shunt implantation to each individual revision.

b Fisher–Freeman–Halton test; p values estimated by Monte Carlo simulation.

c Catheter malfunction comprises malposition, dislocation, and occlusion; infection as a cause of revision comprises shunt infection, wound healing disorder, and open skin lesion.

aSAH/naSAH, aneurysmal/non-aneurysmal subarachnoid haemorrhage; ICH/IVH, intracerebral/intraventricular haemorrhage; IIH, idiopathic intracranial hypertension; iNPH, idiopathic normal pressure hydrocephalus; LOVA, long-standing overt ventriculomegaly in adults; TBI, traumatic brain injury.

No Revision group

The No Revision group comprised 905 patients (mean age at implantation 63.2 years, SD 15.3; 47.5% female; VP shunt 96.7%). The most frequent diagnoses were ICH/IVH (24.4%), iNPH/LOVA/IIH (21.8%) and aSAH/naSAH (20.9%). An SRD was present in 439 of 900 patients (48.8%), the Codman Hakim valve in 89.5% and an antibiotic-impregnated shunt in 63 of 902 (7.0%). Mean mRS at discharge was 4.6 (SD 1.0) for the three interpretable subgroups combined, falling to 4.5 after exclusion of patients who died in hospital (Supplementary Table 1). Mean follow-up was 17.5 months (SD 24.9; median 5.1, IQR 0.4–24.3); in 14 patients without a valid date of last contact it was set to the postoperative control on day 2.

Comparison between the Revision and No Revision groups

All comparisons are at patient level (Revision versus No Revision group). Revised patients were younger at implantation (56.2 versus 63.2 years; $p < 0.001$); sex did not differ ($p = 0.408$). Initial shunt type ($p < 0.001$) and diagnosis ($p = 0.015$) differed: VA shunts (5.6% versus 1.1%) and aSAH/naSAH (30.5% versus 20.9%) were more frequent and iNPH/LOVA/IIH (15.7% versus 21.8%) less frequent among revised

patients. Valve model (p = 0.120), SRD (p = 0.124) and CSF parameters (all p > 0.13) did not differ. Mean mRS at discharge was lower in revised patients with ICH/IVH (4.2 versus 4.7; p = 0.010) and aSAH/naSAH (3.7 versus 4.3; p = 0.011), but not with TBI (p = 0.958); combined, it was 4.0 versus 4.6, and 4.0 versus 4.5 after excluding in-hospital deaths (both p < 0.001) (Supplementary Table 1).

Time to first revision

The time-to-event analysis comprised 1,065 index implantations in 1,062 patients (2016–2025), 160 of them followed by a first revision; median follow-up (reverse Kaplan–Meier) was 6.2 months. Only first revisions were analysed; repeat revisions (67 patients, 34.0%) are described in Tables 1 and 3. Revision-free survival was 81.7% (95% CI 78.7–84.3) at 1 year, 79.3% (76.0–82.3) at 2 years and 75.2% (70.7–79.1) at 5 years (Fig. 2A, Supplementary Table 2a); three quarters of 5-year revisions thus occurred within the first year. Revision-free survival differed across diagnoses (log-rank p = 0.006): at 5 years, it was highest in other diagnoses (88.2%) and iNPH/LOVA/IIH (82.5%) and lowest in TBI (56.8%), tumour-associated hydrocephalus (66.0%) and ICH/IVH (66.8%) (Supplementary Table 2a). In the multivariable Cox model, revision was associated with a VA shunt (HR 3.08, 95% CI 1.39–6.83; p = 0.005), a valve model outside routine use (HR 5.37, 1.91–15.08; p = 0.001) and an SRD (HR 1.68, 1.19–2.37; p = 0.003); iNPH/LOVA/IIH (HR 0.42, 0.24–0.72; p = 0.002) and other diagnoses (HR 0.36, 0.16–0.80; p = 0.012) carried a lower hazard than aSAH/naSAH (Fig. 2B, Supplementary Table 2b). Age (HR 0.99 per year, 0.98–1.01) and sex (HR 1.02, 0.74–1.40) were not associated with revision. The excess hazard of VA shunts was confined to the first three months (HR 4.03 versus 1.23 thereafter, Supplementary Table 2b). Including the 37 revised patients implanted before 2016 yielded similar revision-free survival (82.2%, 79.1% and 74.2% at 1, 2 and 5 years); associations with SRD, iNPH/LOVA/IIH and other diagnoses persisted, whereas those with VA shunts and other valve models lost significance (Supplementary Table 2c).

Patients without revision were censored at their last documented contact; in 14 patients without a valid date of last contact, follow-up was set to the postoperative control on day 2.

The 37 revised patients with primary implantation before 2016 were excluded; including them (sensitivity analysis, Supplementary Table 2c) gave revision-free survival of 82.2%, 79.1% and 74.2% at 1, 2 and 5 years.

aSAH/naSAH, aneurysmal/non-aneurysmal subarachnoid haemorrhage; CI, confidence interval; HR, hazard ratio; ICH/IVH, intracerebral/intraventricular haemorrhage; IIH, idiopathic intracranial hypertension; iNPH, idiopathic normal pressure hydrocephalus; LOVA, long-standing overt ventriculomegaly in adults; SRD, siphon-resistive device; TBI, traumatic brain injury; VA, ventriculoatrial; VP, ventriculoperitoneal.

Secondary analysis: logistic regression

Logistic regression of revision at any time, which does not account for follow-up duration, largely confirmed the Cox model: higher odds of revision were associated with a VA shunt (OR 4.70, 95% CI

1.87–11.83; p = 0.001), other shunt configurations (OR 2.92, 1.22–7.02; p = 0.017), a valve model outside routine use (OR 4.22, 1.20–14.89; p = 0.025) and an SRD (OR 1.42, 1.01–2.00; p = 0.044), and lower odds with iNPH/LOVA/IIH (OR 0.54, 0.31–0.94; p = 0.029) and other diagnoses (OR 0.35, 0.18–0.69; p = 0.002) versus aSAH/naSAH (Table 4). Unlike in the Cox model, younger age was also associated with revision (OR 0.98 per year, 0.97–0.99; p < 0.001). Model performance was modest (AUC 0.671; Nagelkerke R^2 0.093). In the additional model restricted to ICH/IVH, aSAH/naSAH and TBI and excluding in-hospital deaths, each one-point increase in the mRS at discharge was associated with lower odds of revision (OR 0.76, 0.64–0.90; p = 0.002).

Table 4
Multivariable logistic regression for shunt revision (secondary analysis, patient level).

Variable	Primary model OR (95% CI)	p	Secondary model OR (95% CI)	p
Age, per year	0.98 (0.97–0.99)	**< 0.001**	0.98 (0.97–1.00)	**0.008**
Female vs male	1.11 (0.80–1.53)	0.539	1.08 (0.70–1.65)	0.728
Initial shunt type (ref. VP)				
VA	4.70 (1.87–11.83)	**0.001**	4.40 (1.17–16.49)	**0.028**
Other configuration	2.92 (1.22–7.02)	**0.017**	0.83 (0.09–7.80)	0.871
Valve model (ref. Codman Hakim)				
Certas	1.12 (0.53–2.33)	0.770	1.07 (0.37–3.13)	0.904
proGAV 2	1.12 (0.47–2.68)	0.794		
Other	4.22 (1.20–14.89)	**0.025**	6.32 (0.84–47.68)	0.074
SRD	1.42 (1.01–2.00)	**0.044**	1.29 (0.83–2.00)	0.253
Diagnosis (ref. aSAH/naSAH)				
ICH/IVH	0.64 (0.41–1.02)	0.058	0.74 (0.46–1.19)	0.212
TBI	0.56 (0.30–1.03)	0.062	0.72 (0.38–1.37)	0.316
Infection	0.71 (0.28–1.81)	0.476		
iNPH/LOVA/IIH	0.54 (0.31–0.94)	**0.029**		
Tumour-associated	0.69 (0.39–1.20)	0.187		
Other	0.35 (0.18–0.69)	**0.002**		
mRS at discharge, per point			0.76 (0.64–0.90)	**0.002**
Model performance				
Patients / revised	1,097 / 197		612 / 119	
AUC	0.671		0.662	
Hosmer–Lemeshow	$\chi^2 = 15.96$; p = 0.043		$\chi^2 = 9.47$; p = 0.304	
Nagelkerke R^2	0.093		0.097	

All covariates were entered simultaneously. Patients with missing covariates were excluded.

a All 1,102 patients (197 Revision, 905 No Revision); 5 without valve model or SRD information excluded.

b Restricted to ICH/IVH, aSAH/naSAH and TBI, excluding patients who died in hospital (mRS 6) and those without documented mRS.

c Not estimable: no revised patient with a proGAV 2 valve in these subgroups.

aSAH/naSAH, aneurysmal/non-aneurysmal subarachnoid haemorrhage; AUC, area under the receiver operating characteristic curve; CI, confidence interval; ICH/IVH, intracerebral/intraventricular haemorrhage; IIH, idiopathic intracranial hypertension; iNPH, idiopathic normal pressure hydrocephalus; LOVA, long-standing overt ventriculomegaly in adults; mRS, modified Rankin Scale; OR, odds ratio; SRD, siphon-resistive device; TBI, traumatic brain injury; VA, ventriculoatrial; VP, ventriculoperitoneal.

Discussion

In this consecutive ten-year cohort of 1,102 adults undergoing 1,424 shunt procedures, 17.9% of patients required at least one revision, and revisions accounted for 21.6% of all operations. A third of revised patients (34.0%) underwent more than one revision. Revisions clustered early, with 32.8% performed within one month of implantation, but 26.0% occurred beyond two years (Tables 1–3). The revision rate of 17.9% lies within the range of 17% to 33% reported for adults [11, 12, 14, 19, 20, 22, 24, 28]. Pooling 38,095 adult shunt insertions published between 1990 and 2021, Isaacs et al. found failure rates ranging from 10% with less than one year of follow-up to 32% beyond two years, with a pooled rate of 17% [8]. Merkler et al. reported revision in 22.0% of VP shunts over a mean of 3.9 years [16], and Stewart et al. a failure rate of 28.7% with a mean time to failure of 62 days [24]. Such comparisons require caution for two reasons. First, reported rates rise with the duration of follow-up [8]. Second, revision is expressed per patient in some series and per procedure in others [2, 8]. We therefore report both levels separately: the patient-level comparisons and the time-to-event analysis form the main analysis, whereas procedure-level results are exploratory.

Mechanical dysfunction was the predominant cause of revision at both levels: it was the indication in 70.1% of revised patients, compared with 48.7% for infection, the two overlapping in 18.8%, and it accounted for 64.3% of all revision procedures (Table 2). Considered individually, however, the mechanical categories were each smaller than infection, which was the most frequent single cause (35.7%), ahead of proximal catheter malfunction (19.2%), itself attributable to malposition in 47 of 59 cases.

The distribution of causes also differed by diagnosis ($p = 0.032$; exploratory, procedure level; Table 2, Supplementary Table 3), owing to two diagnostic categories. After intracranial infection, proximal catheter malfunction was more frequent and infection less frequent; in iNPH/LOVA/IIH, distal catheter malfunction was more frequent and proximal catheter malfunction less frequent. Given the small numbers, this finding remains exploratory.

The timing of revision depended on its cause (p = 0.002; exploratory, procedure level; Table 3), mainly because of proximal catheter malfunction: 61.0% of these revisions occurred within the first month, consistent with malposition at implantation. This factor may be modifiable, as most of our ventricular catheters were placed freehand, whereas neuronavigation-guided placement reduced proximal failure in the study by Isaacs et al. [7]. Timing also differed by diagnosis (p = 0.007; exploratory, procedure level; Table 3). Revisions after intracranial infection occurred mostly early, whereas those in tumour-associated and other diagnoses occurred mostly late. As these differences are based mainly on the two smallest diagnostic categories (17 and 25 revisions), they should be interpreted with caution.

Valve dysfunction and distal catheter malfunction were most frequent beyond two years (35.7% and 30.8%), and infection showed an early and a late peak (27.3% and 26.4%) (exploratory, procedure level; Table 3). The early peak matches the median time to infection of four weeks reported by Isaacs et al. [8], and the predominance of Gram-positive skin flora (61.1%) suggests that most organisms are introduced at operation. The late peak shows that infection can still arise years later. At first sight, infection was frequent, accounting for 35.7% of revisions. Our definition, however, was broad and included wound healing disorders and open skin lesions in addition to shunt infection in the strict sense (meningitis, ventriculitis or peritonitis). Shunt infection in the strict sense occurred in 62 patients (5.6%), who underwent 68 revisions (4.8% of all shunt procedures). This is at the lower end of the 5.6% to 12.9% per patient reported in adults by Conen et al. [3] and below the 10.5% per patient and 7.2% per procedure reported by Reddy et al. [21]. These 68 revisions accounted for 22.1% of all revisions, almost identical to the 22.5% of shunt failures attributed to infection in the pooled data of Isaacs et al. [8]. Despite this favourable comparison with the literature, the infection rate may still be reducible, as antibiotic-impregnated catheters reduced shunt infection compared with standard catheters in the BASICS trial [15], whereas they were used in only 7.1% of our index implantations, too few to assess their effect in our cohort.

Although most revisions occurred early, the risk persisted over time. The median interval from implantation to the last revision was 3.2 months, yet 25.4% of revised patients underwent their last revision more than two years after implantation (Table 3). In the time-to-event analysis, the cumulative incidence of revision rose from 18.3% at 1 year to 24.8% at 5 years (Fig. 2A). In other words, one in four revisions within the first five years occurred after the first year. Follow-up limited to the first postoperative year would therefore miss a substantial share of failures.

In the time-to-event analysis, two device-related factors were independently associated with revision: a VA rather than a VP shunt (HR 3.08, 95% CI 1.39–6.83), with the excess risk confined to the first three postoperative months, and an SRD (HR 1.68, 1.19–2.37) (Fig. 2B, Supplementary Table 2b). Both were confirmed in the logistic regression (Table 4). Younger age was associated with revision only in the logistic model (Table 4), not once follow-up duration was taken into account (Fig. 2B, Supplementary Tables 2b and 2c), suggesting that it reflected the longer observation of younger patients rather than a higher risk of failure. Korinek et al. likewise identified atrial shunting as a risk factor [12], whereas a

recent meta-analysis found no difference in revision between VA and VP shunts [1]. As VA shunts are placed when the peritoneum is unsuitable, our estimate is partly confounded by indication.

The association with an SRD persisted when the 37 patients with primary implantation before 2016 were included (Supplementary Table 2c). Unadjusted comparisons, however, showed no difference in SRD use between the Revision and No Revision groups (Supplementary Table 1) and no effect on valve exchange among revised patients (Table 2), and Desai et al. found no difference in complication rates between adult shunt systems with and without siphon control [5]. Moreover, each SRD was combined with particular valve models, and one valve model (Codman Hakim) accounted for nearly nine of ten implantations in our cohort, so the effects of SRD and valve cannot be fully separated. The association is thus consistent across the adjusted analyses but does not prove a causal effect. We therefore consider that an SRD may increase the risk of revision and recommend it only for patients at realistic risk of overdrainage who require protection against it, rather than for all patients.

Valve models outside routine use were also associated with revision, both in the Cox model (HR 5.37, 95% CI 1.91–15.08; Fig. 2B) and in the logistic model (OR 4.22, 1.20–14.89; Table 4). However, these valves were implanted in only a few patients, the confidence intervals were wide, and the association lost significance in the sensitivity analysis (Supplementary Table 2c), so this finding should not be overinterpreted.

Diagnosis was associated with the risk of a first revision. Compared with aSAH/naSAH, every other diagnostic category had lower adjusted odds, significantly so for iNPH/LOVA/IIH (OR 0.54; $p = 0.029$) and other diagnoses (OR 0.35; $p = 0.002$) (Table 4), and the Cox model confirmed the lower hazard in both categories ($p = 0.002$ and $p = 0.012$; Fig. 2B), whereas ICH/IVH, TBI, infection and tumour-associated hydrocephalus carried a risk similar to aSAH/naSAH. Once a first revision had occurred, however, diagnosis was no longer associated with the further course: neither repeat revision ($p = 0.789$) nor the number of revisions ($p = 0.669$) differed across diagnoses (Table 1).

Functional outcome was harder to interpret. Never-revised patients had a worse mRS at discharge (4.6 versus 4.0; $p < 0.001$; Supplementary Table 1), and each one-point increase in the mRS was associated with 24% lower odds of revision (OR 0.76, 95% CI 0.64–0.90; $p = 0.002$; Table 4), whereas the mRS was not correlated with the number of revisions (rho = 0.08; $p = 0.333$; Table 1). Poor neurological status is unlikely to protect against shunt failure. More likely, severely disabled patients die before a shunt failure becomes apparent, attend follow-up less often and are less often offered further surgery, and a shunt that is never investigated is never revised. Death therefore acts as a competing event, and loss to follow-up as informative censoring. A competing-risk analysis could address this formally but was not possible because dates of death were missing.

Finally, in 43 patients (21.8%), the shunt was explanted without reimplantation, most often in patients with TBI, ICH/IVH or other diagnoses (Table 2). A revision may therefore also be an opportunity to test whether continued diversion is still required.

Limitations

This study has several limitations. As a retrospective single-centre analysis of routinely collected data, its generalisability is limited, although indications, implant selection and perioperative management followed consistent institutional standards throughout.

Patients lost to follow-up and revisions performed at other hospitals could not be captured. The time-to-event analysis accounts for unequal follow-up, but the long-term estimates are based on only a few patients followed beyond 2 years. In addition, dates of death were unavailable for most of the 124 patients who died, so death could not be analysed as a competing risk. Since patients who have died can no longer be revised, the Kaplan–Meier estimates may slightly overstate the cumulative incidence of revision.

Some categories were heterogeneous. The iNPH/LOVA/IIH category combined conditions that differ in age and in the direction of the pressure disturbance, but LOVA and IIH were too rare to be analysed separately.

CSF was sampled at different time points in the two groups, before implantation and, in a small subset, before revision for valve dysfunction, which limits the comparability of these values.

Finally, potentially relevant factors such as the American Society of Anesthesiologists physical status (ASA grade), urgency of surgery, operative duration and previous external ventricular drainage were not analysed, and the threshold for revision may have varied between surgeons. Accordingly, the variables in the multivariable logistic regression explained only a small part of the revision risk (AUC 0.67; Nagelkerke R^2 0.09; Table 4).

Conclusion

Shunt revision is not an occasional complication of CSF diversion in adults but an integral part of its long-term management. About one in five shunts required revision within the first year and one in four within five years. VA shunts, with an excess risk confined to the first postoperative months, and SRDs were associated with revision. The apparent association of younger age with revision disappeared once follow-up was taken into account. VA shunts and SRDs should therefore be reserved for patients with a clear indication, and follow-up should extend well beyond the first postoperative year.

Abbreviations

aSAH aneurysmal subarachnoid haemorrhage

AUC area under the receiver operating characteristic curve

CI confidence interval

CSF cerebrospinal fluid

HR hazard ratio

ICH intracerebral haemorrhage

IIH idiopathic intracranial hypertension

iNPH idiopathic normal pressure hydrocephalus

IQR interquartile range

IVH intraventricular haemorrhage

LOVA long-standing overt ventriculomegaly in adults

mRS modified Rankin Scale

naSAH non-aneurysmal subarachnoid haemorrhage

OR odds ratio

SAH subarachnoid haemorrhage

SD standard deviation

SRD siphon-resistive device

TBI traumatic brain injury

VA ventriculoatrial

VP ventriculoperitoneal

Declarations

Funding

This research received no external funding.

Conflict of interest

The authors declare that they have no conflict of interest.

Research involving human participants

All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The study was approved by the local Ethics Committee of the Technische Universität Dresden, Faculty of Medicine Carl Gustav Carus, University Hospital Carl Gustav Carus, Dresden, Germany (approval number: BO ff (Mono)-EK-296062025). This article does not contain any studies with animals performed by any of the authors.

Informed consent

The requirement for informed consent was waived by the local ethics committee due to the retrospective nature of the study.

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29. Supplementary Table 1 Patient-level comparison of the Revision and No Revision groups (n = 1,102)

Figures

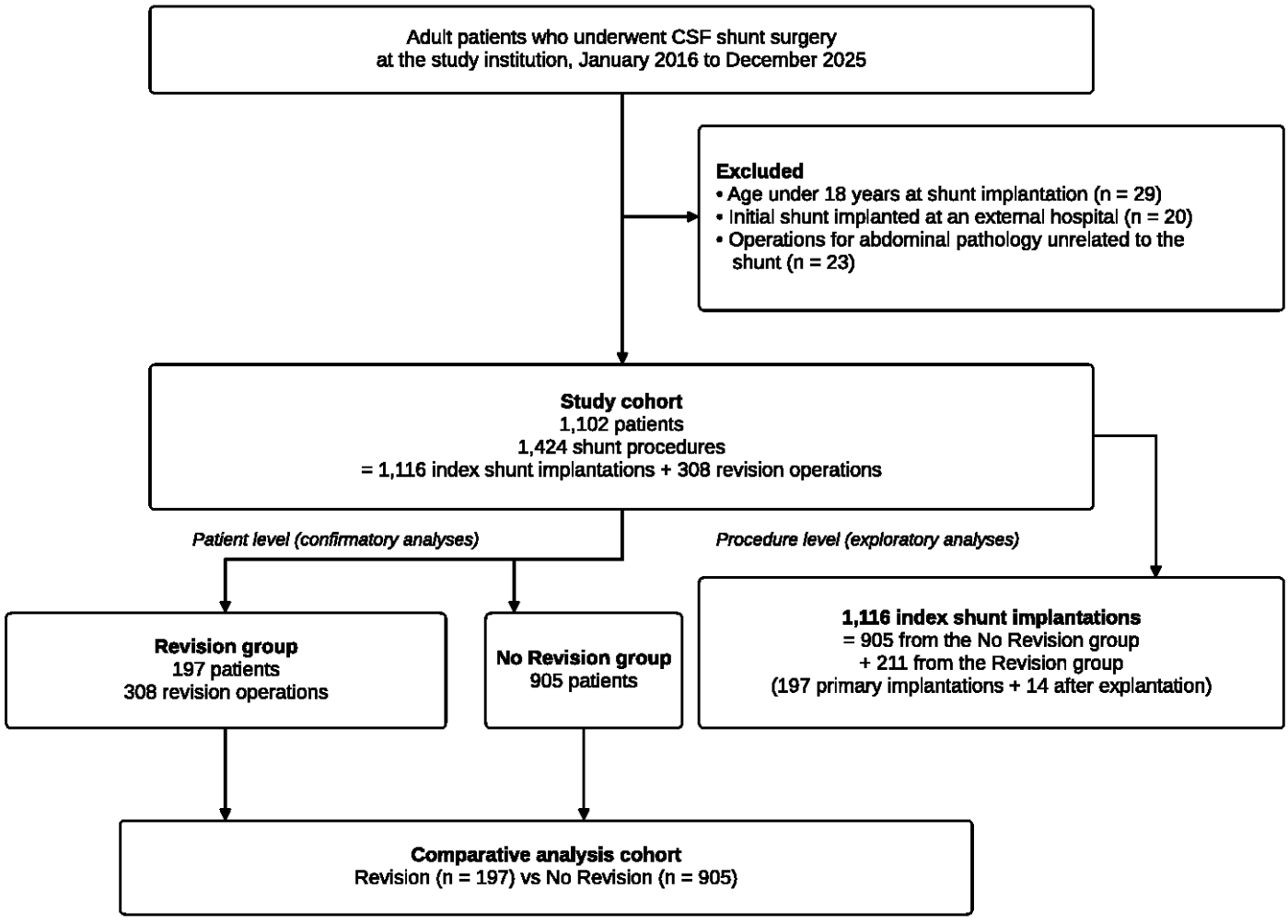

Figure 1

Study flow diagram.

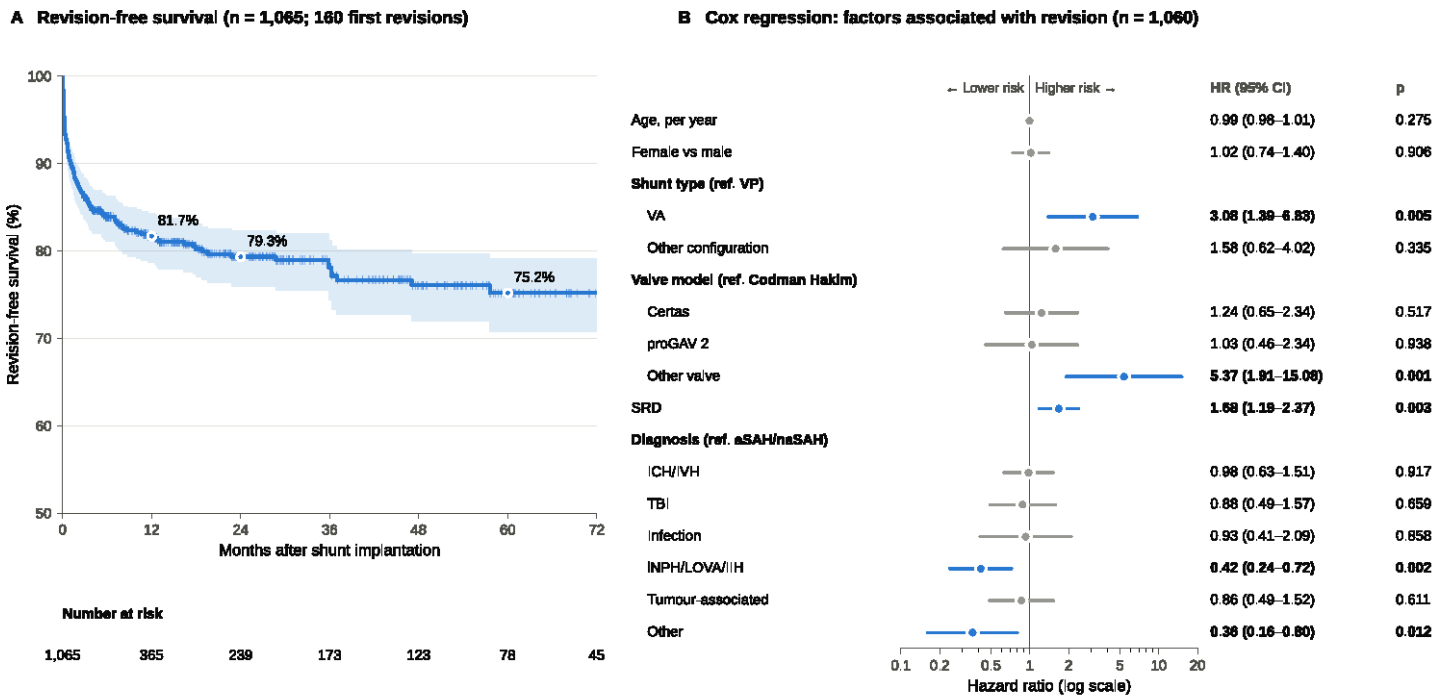

Figure 2

Time to first revision: Kaplan–Meier estimates and Cox proportional hazards regression (n = 1,065 implantations 2016–2025; 160 first revisions). (A) Kaplan–Meier estimate of revision-free survival with 95% CI (shaded). (B) Cox proportional hazards regression (n = 1,060 with complete covariates); HR with 95% CI on a logarithmic scale; filled blue markers, $p < 0.05$.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryTables.docx