Shunt-Dependent Hydrocephalus After Aneurysmal Subarachnoid Hemorrhage: Predictors and Long-Term Functional Outcomes

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BACKGROUND: Although chronic hydrocephalus requiring shunt placement is a known sequela of aneurysmal subarachnoid hemorrhage (aSAH), its effect on long-term functional outcomes is incompletely understood.

OBJECTIVE: To identify predictors of shunt-dependent hydrocephalus and shunt complications after aSAH and determine the effect of shunt dependence on functional outcomes in aSAH patients.

METHODS: We evaluated a database of patients treated for aSAH at a single center from 2000 to 2015. Favorable and unfavorable outcomes were defined as modified Rankin Scale grades 0 to 2 and 3 to 6, respectively. We performed statistical analyses to identify variables associated with shunt-dependent hydrocephalus, unfavorable outcome, and shunt complication.

RESULTS: Of the 888 aSAH patients, 116 had shunt-dependent hydrocephalus (13%). Older age ($P = .001$), intraventricular hemorrhage (IVH) ($P = .004$), higher World Federation of Neurological Surgeons (WFNS) grade ($P < .001$), surgical aneurysm treatment ($P = .002$), and angiographic vasospasm ($P = .005$) were independent predictors of shunt-dependent hydrocephalus in multivariable analysis. Functional outcome was evaluable in 527 aSAH patients (mean follow-up 18.6 mo), with an unfavorable outcome rate of 17%. Shunt placement ($P < .001$), shunt infection ($P = .041$), older age ($P < .001$), and higher WFNS grade ($P = .043$) were independently associated with an unfavorable outcome in multivariable analysis. Of the shunt-dependent patients, 18% had a shunt-related complication. Higher WFNS grade ($P = .011$), posterior circulation aneurysm ($P = .018$), and angiographic vasospasm ($P = .008$) were independent predictors of shunt complications in multivariable analysis.

CONCLUSION: aSAH patients with shunt-dependent hydrocephalus have significantly poorer long-term functional outcomes. Patients with risk factors for post-aSAH shunt dependence may benefit from increased surveillance, although the effect of such measures is not defined in this study.

KEY WORDS: Hydrocephalus, Intracranial aneurysm, Intracranial hemorrhages, Shunt, Stroke, Subarachnoid hemorrhage

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Despite improvements in the management of ruptured intracranial aneurysms, aneurysmal subarachnoid hemorrhage (aSAH) remains a devastating event. The mortality rate of aSAH is approximately 45%, and the majority of survivors suffer functional morbidity and neurocognitive deficits.[1-4] A known sequela of aSAH is chronic hydrocephalus requiring permanent cerebrospinal fluid (CSF) diversion, which has been estimated to occur in 9% to 36% of aSAH patients.[5-9] A number of factors, including acute hydrocephalus, intraventricular hemorrhage (IVH),

ABBREVIATIONS: aSAH, aneurysmal subarachnoid hemorrhage; **CSF,** cerebrospinal fluid; **EVD,** external ventricular drain; **GCS,** Glasgow Coma Scale; **IVH,** intraventricular hemorrhage; **mRS,** modified Rankin Scale; **OR,** odds ratio; **WFNS,** World Federation of Neurological Surgeons and poor neurological condition at presentation, have been found to predict post-aSAH chronic hydrocephalus.[10,11] However, the effect of shunt dependence on long-term functional outcomes is incompletely understood. Therefore, the aims of this study are to (1) define the predictors of shunt-dependent hydrocephalus after aSAH, (2) identify factors associated with shunt-related complications in aSAH patients, and (3) determine the effect of post-aSAH shunt dependence on functional outcomes.

METHODS

Study Design

We performed a retrospective evaluation of an institutional database comprising all SAH patients who were treated at a single center from 2000 to 2015. We obtained institutional review board approval, data were obtained from directed chart review, and patient information was de-identified. The inclusion factors for this study were (1) spontaneous SAH from a ruptured intracranial aneurysm; (2) sufficient data regarding baseline patient, aneurysm, and treatment characteristics; and (3) available outcomes data, specifically with respect to the necessity of a shunt, or lack thereof. Shunt-dependent hydrocephalus was defined as persistent, symptomatic hydrocephalus presenting after aSAH that required permanent CSF diversion. Patients without available outcomes data or who died during the initial hospitalization were excluded from the analysis of long-term functional outcomes.

Data and Variables

The following patient, aneurysm, treatment, and hospitalization variables were determined for all aSAH cases included in the study cohort: patient age, gender, acute hydrocephalus at presentation, presence of IVH, placement of external ventricular drain (EVD), Glasgow Coma Scale (GCS) at presentation, Fisher's grade, Hunt and Hess grade, World Federation of Neurological Surgeons (WFNS) grade, aneurysm location (stratified as anterior vs posterior circulation), aneurysm size (maximum diameter), aneurysm treatment modality (classified as surgical, endovascular, or no treatment), occurrence of angiographic cerebral vasospasm, and survival of initial hospitalization.[12-14]

The following shunt-specific variables were ascertained for each aSAH patient who developed shunt-dependent hydrocephalus: shunt type (classified as ventriculoperitoneal, ventriculopleural, or lumboperitoneal) and valve type (stratified as programmable vs nonprogrammable valve).

Follow-up

After excluding patients who died during the initial hospitalization, those with available follow-up were assessed for functional outcomes based on a combination of hospital records or clinic notes from the study center, referring institutions, and local primary care physicians. Each patient's functional outcome was evaluated using the modified Rankin Scale (mRS) at last follow-up.[15] A favorable functional outcome was defined as an mRS grade of 0 to 2 (ie, functional independence) at last follow-up, whereas an unfavorable functional outcome was defined as an mRS grade of 3 to 6 (ie, functionally dependent or dead).

Shunted aSAH patients were assessed for shunt revisions and complications. A shunt complication was defined as a shunt infection, injury to nearby thoracic or peritoneal structures, inadequate placement of ventricular or distal catheters requiring revision, IVH or hemorrhage along the shunt tract, development of pseudomeningocele or CSF pseudocyst, wound breakdown, exposed hardware, or inadequate shunting from valve malfunction.

Statistical Analysis

Data were presented as mean and standard deviation for continuous variables and as frequency for categorical variables. Continuous variables were compared using Student's *t*-test. Categorical variables were compared using Pearson's χ^2 and Fisher's exact tests, as appropriate. Univariable logistic regression analyses were performed to identify factors significantly associated with shunt-dependent hydrocephalus (population: all aSAH patients in the study cohort), unfavorable functional outcome (population: all aSAH patients with available follow-up), and shunt complications (population: all aSAH patients in the study cohort). Factors with a $P < .20$ were entered into a multivariable logistic regression analysis to determine independent predictors of each of the aforementioned clinical endpoints. Statistical significance was defined as $P < .05$. All statistical analyses were carried out using Stata 14.0 (StataCorp LLC, College Station, Texas).

RESULTS

Study Participants

Of the 1249 patients who presented with spontaneous SAH between 2000 and 2015, 888 patients had aSAH and were included in the study cohort (Figure). After excluding 121 patients who died during initial hospitalization (13.7%) and 240 with incomplete follow-up data, 527 patients were found to be evaluable for long-term functional outcomes.

Shunt-Dependent Hydrocephalus after aSAH

Of the 888 aSAH patients, 116 developed shunt-dependent hydrocephalus (13.1%). The shunt type was ventriculoperitoneal in 109 (94.0%), ventriculopleural in 2 (1.7%), and lumboperitoneal in 5 (4.3%). Table 1 summarizes the comparison of characteristics between aSAH patients with and without shunt-dependent hydrocephalus. Patients with shunt-dependent hydrocephalus were older (mean age 58.2 vs 54.9 yr; $P = .015$); were more likely to have acute hydrocephalus (97.4% vs 60.8%; $P < .001$) and IVH (94.0% vs 73.7%; $P < .001$); were more likely to undergo EVD placement (73.3% vs 26.0%; $P < .001$); had lower GCS scores (mean 10.5 vs 12.5; $P < .001$) and higher Fisher's (mean 3.9 vs 3.6; $P < .001$), Hunt and Hess (mean 3.3 vs 2.7; $P < .001$), and WFNS (mean 3.0 vs 2.1; $P < .001$) grades; were more likely to have posterior circulation aneurysms (51.7% vs 38.7%; $P = .008$); had higher rates of angiographic vasospasm (64.7% vs 40.0%; $P < .001$); and were more likely to survive the initial hospitalization (97.4% vs 84.7%; $P < .001$).

Table 2 details the logistic regression analyses for predictors of shunt-dependent hydrocephalus after aSAH. In the multivariable analysis, older age ($P = .001$), IVH ($P = .004$), higher WFNS grade ($P < .001$), surgical aneurysm treatment ($P = .002$), and angiographic vasospasm ($P = .005$) were independent predictors of shunt-dependent hydrocephalus, whereas posterior circulation aneurysm location trended toward significance ($P = .051$).

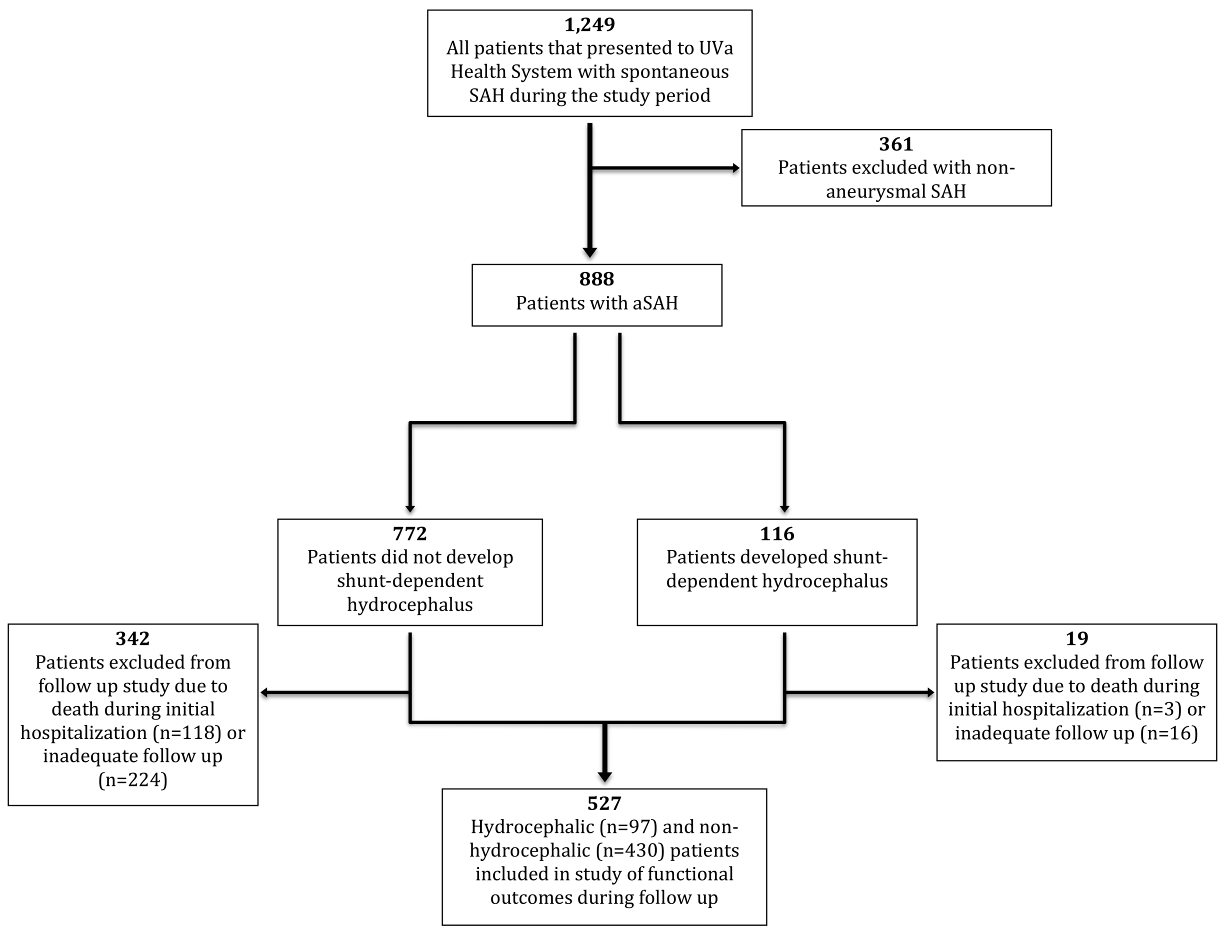

FIGURE. *Flow diagram depicting the study cohort composition.*

The presence of IVH (odds ratio [OR] 5.0) was the strongest independent predictor of shunt dependence, followed by surgical aneurysm treatment (OR 2.3) and angiographic vasospasm (OR 2.2).

Table 3 summarizes the comparison of characteristics between shunt-dependent aSAH patients with and without EVD placement during initial hospitalization. An EVD was placed during the initial hospitalization in 85 aSAH patients who eventually underwent shunt placement (73.3%). Shunt-dependent patients who underwent EVD placement during the initial hospitalization had a lower GCS score at presentation (mean 9.7 vs 12.9; $P = .002$), higher Hunt and Hess grade (mean 3.5 vs 2.8; $P < .001$), and higher WFNS grade (mean 3.3 vs 2.0; $P < .001$); were less likely to undergo surgical aneurysm treatment (48.2% vs 74.2%; $P = .013$); and were more likely to have angiographic vasospasm (74.1% vs 38.7%; $P < .001$).

Table 4 summarizes the comparison of characteristics between shunt-dependent aSAH patients who underwent shunt placement before vs after discharge from the hospital. Of the 115 shunt-dependent aSAH patients with available data regarding the time of shunt placement, 59 underwent shunt placement prior to discharge (51.3%), whereas 56 underwent shunt placement after discharge (48.7%). The mean time to shunt placement for all shunt-dependent patients was 2.7 ± 3.9 mo after aSAH. There were no significant differences in patient, aneurysm, or treatment factors between the 2 subgroups.

Functional Outcomes After aSAH

Follow-up after hospital discharge was available for 527 aSAH patients at a mean duration of 18.6 mo (range: 1-184 mo). The mRS was 0 in 135 (25.6%), 1 in 195 (37.0%), 2 in 105 (19.9%), 3 in 31 (5.9%), 4 in 22 (4.2%), 5 in 31 (5.9%), and 6 in 8 (1.5%). Favorable (mRS 0-2) and unfavorable (mRS 3-6) outcomes were noted in 435 (82.5%) and 92 (17.5%) patients, respectively.

Table 5 summarizes the comparison of characteristics between aSAH patients with favorable and unfavorable outcomes. Patients with unfavorable outcomes had significantly higher rates of shunt placement (46.7% vs 12.4%; $P < .001$), revision (8.7% vs 2.8%;

TABLE 1. Comparison of Characteristics between aSAH Patients with and Without Shunt-Dependent Hydrocephalus

Factor	Shunt ($n = 116$)	No shunt ($n = 772$)	P-value
Age (mean ± SD yr)	58.2 ± 13.1	54.9 ± 13.6	.015*
Female gender	78 (67.2%)	543 (70.3%)	.498
Acute hydrocephalus at presentation	113 (97.4%)	469 (60.8%)	<.001*
Presence of IVH	109 (94.0%)	569 (73.7%)	<.001*
EVD placement	85 (73.3%)	201 (26.0%)	<.001*
GCS at presentation (mean ± SD)	10.5 ± 1.6	12.5 ± 4.6	<.001*
Fisher's grade (mean ± SD)	3.9 ± 0.5	3.6 ± 0.9	<.001*
Hunt and Hess Grade (mean ± SD)	3.3 ± 1.3	2.7 ± 1.2	<.001*
WFNS Grade (mean ± SD)	3.0 ± 1.7	2.1 ± 1.6	<.001*
Posterior circulation aneurysm location	60 (51.7%)	299 (38.7%)	.008*
Aneurysm size (mean ± SD mm)	6.8 ± 4.4	6.7 ± 4.2	.812
Surgical aneurysm treatment	64 (55.2%)	386 (50.0%)	.299
Endovascular aneurysm treatment	49 (42.2%)	353 (45.7%)	.482
No aneurysm treatment	3 (2.6%)	33 (4.3%)	.390
Angiographic vasospasm	75 (64.7%)	309 (40.0%)	<.001*
Survival of initial hospitalization	113 (97.4%)	654 (84.7%)	<.001*

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.
*Statistically significant ($P < .05$).

TABLE 2. Univariable and Multivariable Logistic Regression Analyses for Factors Associated with Shunt-Dependent Hydrocephalus After aSAH. Only Factors With $P < .20$ in the Univariable Analysis were Listed

	Univariable			Multivariable		
Factor	Odds ratio	95% CI	P-value	Odds ratio	95% CI	P-value
Older age	1.02	1.01–1.03	.017*	**1.04**	**1.02–1.06**	**.001***
Acute hydrocephalus at presentation	24.33	7.66–77.28	<.001*	–	–	NS
Presence of IVH	5.34	2.44–11.66	<.001*	**5.02**	**1.70–14.83**	**.004***
EVD placement	7.79	5.01–12.11	<.001*	–	–	NS
Lower GCS at presentation	1.11	1.06–1.16	<.001*	–	–	NS
Higher Fisher's Grade	2.32	1.50–3.59	<.001*	–	–	NS
Higher Hunt and Hess Grade	1.47	1.25–1.73	<.001*	–	–	NS
Higher WFNS Grade	1.38	1.22–1.56	<.001*	**1.46**	**1.24–1.72**	**<.001***
Posterior circulation aneurysm location	1.45	0.92–2.29	.111	1.86	1.00–3.47	.051
Surgical aneurysm treatment	1.31	0.89–1.95	.175	**2.34**	**1.35–4.07**	**.002***
Angiographic vasospasm	2.74	1.82–4.12	<.001*	**2.16**	**1.27–3.69**	**.005***
Survival of initial hospitalization	6.86	2.15–21.96	.001*	–	–	NS

EVD = external ventricular drain, IVH = intraventricular hemorrhage, WFNS = World Federation of Neurological Surgeons, NS = not significant ($P \geq .05$) in the multivariable analysis.
*Statistically significant ($P < .05$).

$P = .007$), infection (7.6% vs 0.2%; $P < .001$), and complication (12.0% vs 1.8%; $P < .001$); were older (mean age 59.8 vs 52.0 yr; $P < .001$); were more likely to have acute hydrocephalus (75.0% vs 60.5%; $P = .009$) and IVH (82.6% vs 70.6%; $P = .019$); were more likely to undergo EVD placement (47.8% vs 23.9%; $P < .001$); had lower GCS (mean 11.4 vs 13.1; $P = .002$) and higher Fisher's (mean 3.7 vs 3.5; $P = .048$) and WFNS grades (2.7 vs 2.0; $P < .001$); and were more likely to undergo surgical (56.5% vs 45.1%; $P = .045$) and less likely to undergo endovascular (37.0% vs 53.1%; $P = .005$) aneurysm treatment.

Table 6 details the logistic regression analyses for factors associated with unfavorable outcome after aSAH. In the multivariable analysis, shunt placement ($P < .001$), shunt infection ($P = .041$), older age ($P < .001$), and higher WFNS grade ($P = .043$) were found to be independent variables associated with unfavorable outcome. Shunt infection was the strongest independent variable associated with unfavorable outcome (OR

TABLE 3. **Comparison of Characteristics between Shunt-Dependent aSAH Patients with and Without EVD Placement During Initial Hospitalization**

Factor	EVD (n = 85)	No EVD (n = 31)	*P*-value
Age (mean ± SD yr)	57.4 ± 13.0	60.1 ± 13.5	.329
Female gender	57 (67.1%)	21 (67.7%)	.945
Acute hydrocephalus at presentation	84 (98.8%)	29 (93.5%)	.065
Presence of IVH	82 (96.4%)	27 (87.1%)	.061
GCS at presentation (mean ± SD)	9.7 ± 4.5	12.9 ± 5.6	.002*
Fisher's Grade (mean ± SD)	3.9 ± 1.0	3.7 ± 0.4	.282
Hunt and Hess Grade (mean ± SD)	3.5 ± 1.2	2.8 ± 1.3	<.001*
WFNS Grade (mean ± SD)	3.3 ± 1.6	2.0 ± 1.5	<.001*
Posterior circulation aneurysm location	42 (49.4%)	18 (58.1%)	.409
Aneurysm size (mean ± SD mm)	6.4 ± 4.3	7.9 ± 4.5	.103
Surgical aneurysm treatment	41 (48.2%)	23 (74.2%)	.013*
Endovascular aneurysm treatment	41 (48.2%)	8 (25.8%)	.051
No aneurysm treatment	3 (3.5%)	0 (0.0%)	.167
Angiographic vasospasm	63 (74.1%)	12 (38.7%)	<.001*
Survival of initial hospitalization	82 (96.5%)	31 (100.0%)	.289

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.
*Statistically significant ($P < .05$).

TABLE 4. **Comparison of Characteristics between Shunt-Dependent aSAH Patients Who Underwent Shunt Placement Before vs After Discharge**

Factor	Shunt placed before discharge (n = 59)	Shunt placed after discharge (n = 56)	*P*-value
Age (mean ± SD yr)	59.9 ± 12.7	56.6 ± 13.5	.167
Female gender	37 (61.0%)	41 (73.2%)	.165
Acute hydrocephalus at presentation	56 (94.9%)	56 (100.0%)	.058
Presence of IVH	56 (94.9%)	52 (92.9%)	.645
EVD placement	44 (74.6%)	41 (73.2%)	.868
GCS at presentation	10.8 ± 5.1	10.1 ± 4.6	.442
Fisher's Grade (mean ± SD)	3.9 ± 0.4	3.9 ± 0.5	1.000
Hunt and Hess Grade (mean ± SD)	3.2 ± 1.3	3.4 ± 1.3	.411
WFNS Grade (mean ± SD)	2.9 ± 1.8	3.1 ± 1.6	.531
Posterior circulation aneurysm location	31 (52.5%)	28 (50.0%)	.785
Aneurysm size (mean ± SD mm)	6.9 ± 4.5	6.5 ± 4.4	.631
Surgical aneurysm treatment	28 (47.5%)	35 (62.5%)	.105
Endovascular aneurysm treatment	29 (49.2%)	20 (35.7%)	.145
No aneurysm treatment	2 (3.4%)	1 (1.8%)	.590
Angiographic vasospasm	37 (62.7%)	37 (66.1%)	.707
Survival of initial hospitalization	58 (98.3%)	54 (96.4%)	.528

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.
*Statistically significant ($P < .05$).

10.2), followed by shunt placement (OR 5.3), and higher WFNS grade (OR 1.2).

Shunt Complications in aSAH Patients

Of the 116 aSAH patients with shunt-dependent hydrocephalus, 21 experienced at least 1 shunt-related complication (18.1%). Shunt related complications included injury to peritoneal or thoracic structures ($n = 2$, 1.7%), exposed hardware ($n = 3$, 2.6%), inadequate shunting due to valve malfunction ($n = 11$, 9.5%), shunt infection ($n = 8$, 6.9%), wound breakdown ($n = 3$, 2.6%), IVH or hemorrhage along the shunt tract (n = 4, 3.5%), pseudomeningocele ($n = 2$, 1.7%), CSF pseudocyst ($n = 1$, 0.9%), and inadequate placement of ventricular or distal catheters requiring revision ($n = 6$, 5.2%). Table 7 summarizes the comparison of characteristics between shunt-dependent aSAH patients with and without shunt

TABLE 5. Comparison of Characteristics between aSAH Patients with Favorable (mRS 0-2) vs Unfavorable (mRS 3-6) Outcome

Factor	mRS 0-2 ($n = 435$)	mRS 3-6 ($n = 92$)	*P*-value
Shunt placement	54 (12.4%)	43 (46.7%)	<.001*
Shunt revision	12 (2.8%)	8 (8.7%)	.007*
Shunt infection	1 (0.2%)	7 (7.6%)	<.001*
Age (mean ± SD yr)	52.0 ± 13.3	59.8 ± 14.7	<.001*
Female gender	310 (71.3%)	58 (63.0%)	.119
Acute hydrocephalus at presentation	263 (60.5%)	69 (75.0%)	.009*
Presence of IVH	307 (70.6%)	76 (82.6%)	.019*
EVD placement	104 (23.9%)	44 (47.8%)	<.001*
GCS at presentation	13.1 ± 4.6	11.4 ± 5.2	.002*
Fisher's Grade (mean ± SD)	3.5 ± 0.9	3.7 ± 0.8	.048*
Hunt and Hess Grade (mean ± SD)	2.6 ± 1.2	3.1 ± 1.3	.520
WFNS Grade (mean ± SD)	2.0 ± 1.6	2.7 ± 1.7	<.001*
Posterior circulation aneurysm location	239 (54.9%)	50 (54.3%)	.917
Aneurysm size (mean ± SD mm)	6.6 ± 4.4	6.8 ± 4.7	.737
Surgical aneurysm treatment	198 (45.5%)	56 (60.1%)	<.001*
Endovascular aneurysm treatment	230 (52.9%)	34 (37.0%)	<.001*
No aneurysm treatment	7 (1.6%)	2 (1.1%)	.545
Angiographic vasospasm	196 (45.1%)	46 (50.0%)	.387
Follow-up duration (mean ± SD mo)	20.3 ± 23.2	10.3 ± 21.6	<.001*

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.
*Statistically significant ($P < .05$).

TABLE 6. Univariable and Multivariable Logistic Regression Analyses for Predictors of Unfavorable Outcome (mRS 3-6) After aSAH. Only Factors With $P < .20$ in the Univariable Analysis were Listed

	Univariable			Multivariable		
Factor	Odds ratio	95% CI	*P*-value	Odds ratio	95% CI	*P*-value
Shunt placement	6.19	3.76–10.20	<.001*	**5.34**	**2.86–9.99**	**<.001***
Shunt revision	3.36	1.33–8.46	.010*	–	–	NS
Shunt infection	35.74	4.34–294.26	.001*	**10.16**	**1.10–93.49**	**.041***
Older age	1.05	1.03–1.07	<.001*	**1.05**	**1.03–1.07**	**<.001***
Male gender	1.45	0.91–2.33	.120	–	–	NS
Acute hydrocephalus at presentation	2.61	1.51–4.53	.001*	–	–	NS
Presence of IVH	2.85	1.47–5.54	.002*	–	–	NS
EVD placement	3.43	2.16–5.45	<.001*	–	–	NS
Lower GCS at presentation	1.12	1.06–1.18	<.001*	–	–	NS
Higher Fisher's Grade	1.47	1.05–2.06	.025*	–	–	NS
Higher Hunt and Hess Grade	1.54	1.25–1.88	<.001*	–	–	NS
Higher WFNS grade	1.37	1.18–1.59	<.001*	**1.21**	**1.01–1.45**	**.043***
Surgical aneurysm treatment	1.91	1.21–3.03	.006*	–	–	NS

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, WFNS = World Federation of Neurological Surgeons, NS = not significant ($P \geq .05$) in the multivariable analysis. *Statistically significant ($P < .05$)

complications. There were no significant differences between the 2 subgroups of shunt-dependent patients. Notably, patients with or without shunt complications were not found to have significantly different time intervals from aneurysm rupture to shunt placement (1.7 mo vs 1.3 mo; $P = .596$) or usage rates of a programmable valve (71.4% vs 70.3%; $P = .718$).

Functional Outcomes in Shunt-Dependent aSAH Patients

Follow-up was available for 97 shunt-dependent aSAH patients at a mean duration of 28.3 mo (range: 1-132 mo). The mRS was 0 in 12 (12.4%), 1 in 26 (26.8%), 2 in 16 (16.5%), 3 in 6 (6.2%), 4 in 10 (10.3%), 5 in 20 (20.6%), and 6 in 7 (7.2%). Favorable

TABLE 7. Comparison of Characteristics between Shunt-Dependent aSAH Patients with and Without Shunt Complications

Factor	Complication ($n = 21$)	No complication ($n = 95$)	P-value
Time interval from aSAH to shunt placement (mean ± SD mo)	1.7 ± 5.0	1.3 ± 2.5	.596
Shunt with programmable valve	15 (71.4%)	64 (70.3%)	.718
Age (mean ± SD yr)	55.8 ± 12.9	58.7 ± 14.0	.383
Female gender	14 (66.7%)	60 (63.2%)	.762
Acute hydrocephalus at presentation	20 (95.2%)	89 (93.7%)	.787
Presence of IVH	20 (95.2%)	85 (89.5%)	.415
EVD placement	16 (76.2%)	66 (69.5%)	.541
GCS at presentation	9.5 ± 4.7	10.7 ± 5.0	.312
Fisher's Grade (mean ± SD)	3.9 ± 0.7	3.9 ± 0.4	.788
Hunt and Hess Grade (mean ± SD)	3.4 ± 1.3	3.3 ± 1.3	.768
WFNS Grade (mean ± SD)	3.3 ± 1.7	2.9 ± 1.7	.343
Posterior circulation aneurysm location	10 (47.6%)	49 (51.6%)	.743
Aneurysm size (mean ± SD mm)	6.3 ± 3.1	6.9 ± 4.9	.598
Surgical aneurysm treatment	11 (52.4%)	53 (55.8%)	.776
Endovascular aneurysm treatment	10 (47.6%)	39 (41.1%)	.581
No aneurysm treatment	0 (0.0%)	3 (3.2%)	1.000
Angiographic vasospasm	16 (76.2%)	57 (60.0%)	.164
Survival of initial hospitalization	21 (100.0%)	91 (95.8%)	1.000

EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.
*Statistically significant ($P < .05$).

(mRS 0-2) and unfavorable (mRS 3-6) outcomes were noted in 54 (55.7%) and 43 (44.3%), respectively.

Table 8 summarizes the comparison of characteristics between shunt-dependent aSAH patients with favorable and unfavorable outcomes. Those with favorable outcomes had longer time intervals from aneurysm rupture to shunt placement (mean 1.8 vs 1.1 mo; $P < .001$) and lower rates of shunt infection (1.9% vs 16.3%; $P = .020$) and were less likely to undergo surgical aneurysm treatment (44.4% vs 65.1%; $P = .043$).

DISCUSSION

Key Results

Our analysis reports a shunt dependency rate of 13%, which is consistent with the literature. We were able to identify numerous independent risk factors for shunt dependency, including older age, higher WFNS grade, IVH, surgical aneurysm treatment, and angiographic vasospasm. Many of these risk factors have been found in prior studies.[16] In our analysis, EVD placement occurred more frequently in patients who developed chronic hydrocephalus. Therefore, we sought to identify differences between shunt-dependent patients who underwent EVD placement during the initial hospitalization and those who did not require an EVD. As expected, patients with a worse baseline clinical status (ie, lower GCS score, higher Hunt and Hess grade, higher WFNS grade) were more likely to undergo EVD placement, which suggests the deleterious effects of acute hydrocephalus and/or IVH on neurological presentation. Patients who received an EVD were less likely to undergo surgical intervention for their ruptured aneurysms, which implicates an institutional bias toward endovascular or conservative management of aSAH patients who present with poor clinical grades.

Unlike many prior studies, we were also able to assess the relationship between shunt-dependent hydrocephalus and functional outcomes in 527 patients with available follow-up. Although neurological status at presentation and at discharge from acute hospitalization has been found to correlate with long-term functional outcomes after aSAH, the effect of shunt dependency on functional status has not been widely investigated.[17] We found that shunt dependency was a strong, independent variable associated with an unfavorable outcome (mRS 3-6), with a 44% rate of functional dependency or death at last follow-up. This is in agreement with a recent analysis of patients enrolled in the Barrow Ruptured Aneurysm Trial, which reported that those who underwent shunting were less likely to achieve functional independence and return to work.[11]

In our analysis, shunt infection was the strongest independent predictor of unfavorable outcome. However, this association may be confounded by the fact that more seriously ill patients are also likely prone to developing infections. Nonetheless, the importance of developing and enforcing institutional practices for minimizing risks for infection should be emphasized. It is also interesting to note that while a higher WFNS grade was significantly associated with an unfavorable functional outcome in the multivariate analysis ($P = .043$), GCS at presentation was not. As the WFNS grading scale accounts for motor deficits in addition to GCS, this underscores the importance of conducting

TABLE 8. Comparison of Characteristics between Shunt-Dependent aSAH Patients with Favorable (mRS 0-2) vs Unfavorable (mRS 3-6) Outcome

Factor	mRS 0-2 (*n* = 54)	mRS 3-6 (*n* = 43)	*P*-value
Time interval from aSAH to shunt placement (mean ± SD mo)	0.7 ± 1.3	0.9 ± 1.2	.438
Shunt with programmable valve	40 (74.1%)	32 (74.4%)	.969
Shunt revision	12 (22.2%)	8 (18.6%)	.662
Shunt infection	1 (1.9%)	7 (16.3%)	.020*
Shunt complication	8 (14.8%)	11 (25.6%)	.184
Age (mean ± SD yr)	55.3 ± 14.7	60.1 ± 13.3	.094
Female gender	34 (63.0%)	31 (72.1%)	.342
Acute hydrocephalus at presentation	51 (94.4%)	43 (100.0%)	.116
Presence of IVH	51 (94.4%)	42 (97.7%)	.427
EVD placement	38 (70.4%)	34 (79.1%)	.330
GCS at presentation	10.8 ± 5.2	9.7 ± 4.6	.295
Fisher's Grade (mean ± SD)	3.9 ± 0.8	3.9 ± 0.9	.816
Hunt and Hess Grade (mean ± SD)	3.3 ± 1.2	3.5 ± 1.2	.140
WFNS Grade (mean ± SD)	2.9 ± 1.7	3.3 ± 1.6	.361
Posterior circulation aneurysm location	32 (59.3%)	25 (58.1%)	.911
Aneurysm size (mean ± SD mm)	6.9 ± 4.7	7.0 ± 4.4	.940
Surgical aneurysm treatment	24 (44.4%)	28 (65.1%)	.043*
Endovascular aneurysm treatment	27 (50.0%)	13 (30.2%)	.050
No aneurysm treatment	1 (1.9%)	2 (4.7%)	.583
Angiographic vasospasm	38 (70.4%)	25 (58.1%)	.210
Follow-up duration (mean ± SD mo)	42.1 ± 21.6	11.7 ± 23.2	<.001*

*Statistically significant ($P < .05$); EVD = external ventricular drain, GCS = Glasgow Coma Scale, IVH = intraventricular hemorrhage, SD = standard deviation, WFNS = World Federation of Neurological Surgeons.

an efficient but thorough neurological exam, particularly with regard to strength testing, in patients presenting with aSAH.[14]

In addition to determining factors associated with shunt dependency, we analyzed our data for predictors of shunt complications, which have not been rigorously assessed in most prior studies. Higher WFNS grade at presentation, posterior circulation aneurysm location, and angiographic vasospasm were independent variables associated with shunt complications. Patients with one or more of these risk factors may be hospitalized for longer durations, thereby increasing their susceptibility to shunt complications, particularly infection. In our study, programmable shunts did not have lower complication rates, nor did they yield better functional outcomes, suggesting that fixed-pressure, nonprogrammable valves have equivalent outcomes to programmable valves.

The pathophysiology of chronic hydrocephalus after aSAH is not well defined. However, a generally accepted hypothesis is that it results from the impairment of CSF reabsorption through the arachnoid granulations. There is mounting evidence that post-aSAH chronic hydrocephalus is a multifactorial process that involves upregulation of pro-inflammatory cytokines and fibroblasts, enhanced collagen production, and the toxic effects of iron that develop in the weeks following aneurysm rupture.[18-21] As such, the pathoetiologies of early- vs late-onset chronic hydrocephalus in aSAH patients may be distinct. In our analysis, we were unable to identify any significant differences between aSAH patients who were shunted prior to discharge and those who underwent shunt placement after discharge. Additionally, we failed to find a significant correlation between time to shunt placement and long-term functional outcome. Therefore, despite potential mechanistic differences between early- and late-onset chronic hydrocephalus after aSAH, it is unclear whether the overall clinical courses of these 2 subsets of patients diverge, and whether a differential response to permanent CSF diversion exists.

Although we found no difference in long-term functional outcome between patients who received shunts before and after discharge, we suspect that patients who underwent shunt placement after discharge likely presented to medical attention due to a decline in functional status. Although we assume that many of these patients experience functional recovery after shunting, it may be beneficial to more closely monitor patients with 1 or more risk factors for shunt-dependent hydrocephalus who did not undergo permanent CSF diversion prior to discharge. Shorter follow-up intervals in this subset of high-risk patients may yield earlier detection of post-aSAH chronic hydrocephalus. However, the effect of closer surveillance on long-term functional outcomes in this patient population is unknown, and is therefore a potential topic for future studies.

Limitations and Generalizability

Our study has several limitations. Although we accrued a large cohort of aSAH patients, they were all treated at a single center, which subjects our findings to the selection, treatment, and referral biases of the institution and its physicians. During the 15-yr time period of this study, the management paradigm and available technology for the treatment of ruptured aneurysms has changed dramatically.[22,23] The effect of these changes on the rate of shunt dependency over time was not evaluated. Because we were unable to obtain preshunt mRS scores due to lack of documentation, the temporal relationship between shunt placement and functional outcome could not be assessed. Additionally, the retrospective design of our study may bias our evaluation of functional outcomes. Specifically, approximately 25% of patients were lost to follow-up and thus could not be assessed for functional outcomes. Due to these limitations, our findings may not be generalizable to all aSAH patients.

CONCLUSION

We identified a number of risk factors for the development of shunt-dependent hydrocephalus after aSAH. Furthermore, we also found shunt dependence to be a strong independent risk factor for an unfavorable functional outcome, suggesting that aSAH patients who undergo shunting are significantly less likely to achieve long-term functional independence. Therefore, patients with an elevated risk for developing shunt dependency may benefit from more rigorous clinical and radiographic surveillance. The efficacy of such additional screening measures warrants future study.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors investigated the effects of shunt dependence on long-term functional outcomes after aneurysmal subarachnoid hemorrhage (aSAH) via a retrospective, single center study of 527 patients from 2000–2015. Notable findings were: 1) older age, IVH, higher WFNS grade, aneurysm surgery, and angiographic vasospasm were associated with shunt-dependent hydrocephalus; 2) shunt placement, shunt infection, older age, and higher WFNS grade were associated with unfavorable outcome; and 3) higher WFNS grade, posterior circulation aneurysm, and vasospasm were associated with shunt complications. They conclude that aSAH patients who undergo shunting are significantly less likely to achieve favorable long-term functional outcomes. Interestingly, no differences were identified in patients who underwent shunt placement prior or subsequent to discharge. The authors are commended for attempting to further our understanding of the impact of shunt-dependent hydrocephalus upon outcomes after aSAH, and it is clear that future studies are needed.

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The authors are to be commended for their labor intensive study that provides light on the functional outcomes of both early and chronic shunt dependent hydrocephalic patients after aSAH. Although it fails to find a significant correlation between time to shunting and outcome, this study can serve as a backbone for prognostication/goals of care discussions with patients and families as well as encouragement for development of appropriate surveillance protocols for post aSAH chronic hydrocephalus. Unfortunately, 25% of patients were lost to follow-up, likely confounding the conclusions of this paper regarding overall frequency of post aSAH hydrocephalus. We therefore encourage the authors to continue to study this patient population with the hope of improving outcomes, a goal the field of neurosurgery has been chasing since conception with only modest success.

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