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Predictive factors for ventriculoperitoneal shunt placement in aneurysmatic subarachnoid hemorrhages

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ABSTRACT

Introduction: Aneurysmatic subarachnoid hemorrhages (aSAH) are life-threatening events with high mortality and morbidity. Hydrocephalus is a common complication, initially managed with an external ventricular drain (EVD). Persistent hydrocephalus often requires ventriculoperitoneal shunt (VPS) placement to relieve intracranial pressure and prevent further neurological damage.
Research question: What factors predict the need for VPS placement in patients with aSAH, and how does a new predictive model compare to the Mayo Age, Grades, EVD score (MAGE score)?
Materials and methods: A retrospective study of 105 patients with aSAH treated with EVD between 2014 and 2023 was conducted. Patients were divided into two groups: those requiring VPS (n= 45) and those not requiring VPS (n= 60). Sociodemographic, clinical, and treatment variables were analysed, and a new predictive model (SAH-VP) was developed and compared to the MAGE score.
Results: Patients who required VPS had higher WFNS scores on admission (p= 0.045), more infections requiring antibiotics (p= 0.002), more failed weaning attempts (p= 0.004), more failed closure attempts (p= 0.002), and longer EVD use (p< 0.01). The new SAH-VP model demonstrated an area under the curve (AUC) of 0.800.
Discussion and conclusion: There is no consensus on the factors predicting VPS need in SAH patients. This study identified key predictors and developed a new predictive model, SAH-VP, which could improve patient management by identifying those at higher risk of requiring VPS, offering an alternative to the existing MAGE score.

LIST OF ABBREVIATIONS

aSAH	*Aneurismatic Subarachnoid Hemorrage*
AUC	*Area Under Curve*
CI	*Confidence Interval*
CSF	*Cerebrospinal fluid*
CT	*Computed Tomography*
EVD	*External Ventricular Drain*
GCS	*Glasgow Come Scale*
HB	*Hospital de Braga*
ICU	*Intensive Care Unit*
M	*Mean*
MAGE	*Mayo Age, Grades, EVD*
Mdn	*Median*
mRS	*Modified Rankin Scale*
mFisher	*Modified Fisher*
N	*Absolute Frequency*
NCCU	*Neurocritical Care Unit*
OR	*Odds Ratio*
p-value	*Level of statistical significance*
T	*T test for Independent Samples*

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(*continued*)

SAH	*Subarachnoid hemorrages*
sSAH	*Spontaneous Subarachnoid hemorrages*
SD	*Standard deviation*
SPSS®	*Statistical Package for the Social Sciences*
VPS	*Ventriculoperitoneal shunt*
WFNS	*World Federation of Neurosurgeons*

1. Introduction

Spontaneous subarachnoid hemorrhages (sSAH) account for 2–7% of all strokes (De Rooij et al., 2007; Etminan et al., 2019; Maher et al., 2020), with a global incidence of 6–8 cases per 100.000 people annually (De Rooij et al., 2007; Etminan et al., 2019; Maher et al., 2020; Hoh et al., 2023; Molyneux, 2002). Despite its rarity, sSAH is associated with high mortality and significant long-term morbidity (Hoh et al., 2023; Molyneux, 2002; Long et al., 2017).

The leading cause of spontaneous SAH is the rupture of intracerebral aneurysms, aneurysmatic SAH (aSAH), responsible for 85% of cases (Maher et al., 2020; Macdonald and Schweizer, 2017). Other causes include drug abuse (McEvoy, 2000), coagulation disorders, arteriovenous malformations, and tumors (Sweeney et al., 2016; Rinkel et al., 1993). Major risk factors include smoking, hypertension, alcohol abuse and advanced age, particularly in women (Etminan et al., 2019; Feigin et al., 2005; Vivancos et al., 2014; Harrison et al., 2023). SAH often presents with a sudden, severe headache, nausea, vomiting, neck stiffness, and altered consciousness (Ziu et al., 2024; Togha et al., 2009). CT scans are the primary diagnostic tool (Hoh et al., 2023; Long et al., 2017; Ziu et al., 2024). Severity is evaluated using the Hunt and Hess (1968), World Federation of Neurosurgeons (WFNS) (Teasdale et al., 1988) and the modified Fisher (mFisher) (Frontera et al., 2006) scales, which help predict patient prognosis (Hoh et al., 2023).

Hydrocephalus, a common complication, affects 20–30% of aSAH patients (Chen et al., 2017; Shaikh et al., 2023) and is characterized by excess cerebrospinal fluid (CSF) in the brain (Rekate, 2009), which may require intervention with external ventricular drains (EVDs) or ventriculoperitoneal shunts (VPS) if persistent (Chen et al., 2017; Chung et al., 2018; Koleva and De Jesus, 2024; Fowler et al., 2024; Steinke et al., 1987).

Recent advancements include the "Mayo Age, Grades, EVD score"- The MAGE score Table 1 (Perry et al., 2020), a model developed by the Mayo Clinic to predict the need for VPS after SAH. This model incorporates factors such as age, the modified Fisher scale, the WFNS scale, mean daily EVD output, and the number of weaning and closure attempts.

This study aims to understand the factors that may predict the need for VPS placement for the management of hydrocephalus in cases of aSAH and create a new predictive model. We also compare our new model to the MAGE score.

Table 1
MAGE score.

Variable	Points
Age ≥ 65	1
mFisher 2 or 4	1
WFNS 5	1
Mean daily EVD output ≥ 200 ml, days 0–2	1
Wean failures ≥2	1
Any clamp failure	1

Adapted from: Perry A, Graffeo CS, Kleinstern G, Carlstrom LP, Link MJ, Rabinstein AA. Quantitative Modeling of External Ventricular Drain Output to Predict Shunt Dependency in Aneurysmal Subarachnoid Hemorrhage: Cohort Study. Neurocrit Care. 2020; 33(1).

2. Methods

2.1. Study design and population

This retrospective cohort study included patients diagnosed with aSAH who were admitted to the Neurosurgery Department at Hospital de Braga (HB) between January 2014 and December 2023. The inclusion criteria required patients to have a diagnosis of aSAH, admission to HB during the specified period and the need for EVD to manage hydrocephalus. Patients with <18 years old would be excluded, however, all participants met the inclusion criteria.

2.2. Data collection

Most of the data were obtained from electronic medical records using the B-Simple® platform, while Modified Rankin Scale (mRS) scores were gathered using Glintt®. The data was entered into a Microsoft Office Excel® database. Following data collection, the data was anonymized to ensure confidentiality.

We collected data encompassing sociodemographic characteristics, clinical information, and imaging findings, including mFisher, WFNS, and Hunt and Hess scores. Additionally, we gathered data on EVD parameters, such as the number of days in use, management strategies, daily output values, and complications. Finally, patient outcomes were assessed using the mRS scale.

2.3. Endpoints

Following data collection, we analysed factors significantly associated with the need for a VPS and incorporated them into the development of a novel predictive model. This model was applied to our study population. The MAGE score was also applied in our population, to evaluate model strength and to later compare it to our own model. We calculated outcome probabilities for each score and evaluated its performance using ROC curve analysis, alongside sensitivity and specificity metrics. A similar performance analysis was conducted for the MAGE score, enabling a direct comparison between the two predictive models.

2.4. Statistical analysis

Data analysis was performed using IBM SPSS Statistics® software (version 30.0). A significance threshold of $p < 0{,}05$ was used, and 95% confidence intervals (CI) were calculated. The normality of continuous variables was checked using standard tests and visual inspections.

Descriptive statistics included frequencies and percentages for categorical variables and means with standard deviations for normally distributed continuous variables. Non-normally distributed continuous variables were described with medians. Inferential statistics involved Pearson's Chi-square test for associations among categorical variables, with Fisher's Exact Test applied as needed.

For comparing VPS dependency, Student's t-test was used for normally distributed numeric variables, with Levene's test for equality of variances. Non-normally distributed variables were analysed with the Mann-Whitney *U* test. Logistic regression models assessed predictors of VPS placement, with odds ratio (OR) and their significance evaluated.

Model performance was gauged using receiver-operator curve (ROC) analysis, plotting sensitivity against 1-specificity. The area under the ROC curve (AUC) was used to measure discrimination, where an AUC>0,5 indicates effective performance (Appendix A) (Corbacioglu and Aksel, 2023). The Hosmer-Lemeshow Test assessed model fit, with a higher p-value suggesting a good fit.

3. Results

From a total population of 450 patients admitted for spontaneous SAH at HB from 2014 to 2023, 286 (63.6%) were due to aneurysmatic rupture. 105 (36.7%) of those underwent EVD placement for acute hydrocephalus management. Out of these patients, 45 (42.8%) required VPS. Patients with aSAH who did not require EVD were not considered for this study, but in that group 9 patients (5.0%) ended up needing VPS in the long term.

The majority of these patients were women (72.5%), with similar gender proportions across both groups. The mean age was 63 years, and hypertension was present in 54.3% of cases. Baseline sociodemographic characteristics, as detailed in Table 2, showed no significant differences between the VPS and non-VPS groups.

Regarding initial clinical assessments, 64.5% of patients were admitted to the Neurocritical Care Unit (NCCU) and the rest to the Intensive Care Unit (ICU). The median WFNS score was 4. A higher WFNS score at admission was observed in the VPS group (4 vs 3, $p = 0.045$). Dichotomization of the WFNS score revealed that scores of 4 or higher were more predictive of VPS need. Most patients had a mFisher score of 4 and a Hunt and Hess score of 3, with no significant differences between groups.

The majority of the aneurysms were treated with endovascular procedures (47.6%) No significant differences were found between groups or treatment modality, as detailed in Table 2.

Complications included sodium disturbances and anaemia, with most patients developing anaemia by day 3. Vasospasm, treated invasively in more than half of the cases, occurred similarly in both groups. Patients with VPS placement had longer ICU/NCCU stays (30 vs 20 days, $p < 0{,}01$) and longer infirmary stays (19 vs 6 days, $p < 0{,}01$). Mortality during hospitalization was higher in the non-VPS group (18.3% vs 2.2%, $p = 0.012$). 12 patients (11.4%) died during their hospital stay and 6 more (5.7%) died in the subsequent 2-year period. At the first appointment and 2 years after the event, those submitted to VPS placement had similar functional outcomes (mRS ≤2 at 1st appointment $p = 0.054$, mRS ≤2 at 2 years $p = 0.389$).

Table 2
Sociodemographic statistical analysis between patients submitted to VPS and no VPS.

	All (n = 105)		Submitted to VPS placement				P value
			No (n = 60) (n = 80)		Yes (n = 45) (n = 55)		
	n	%	n	%	n	%	
Age (mean ± sd))	63.2	(±14.1)	63.1	(±14.3)	63.4	(±14.0)	0.899
Sex (Female)	79	75.2	43	71.7	36	80.0	0.328
Risk Factors							
Hypertension	57	54.3	32	53.3	25	55.6	0.821
Active nicotine use	24	22.9	17	26.2	7	15.6	0,123
Alcohol consumption	9	8.6	6	9.2	3	6.7	0.729
Anti-platelet drugs	11	10.5	3	4.6	8	17.8	0.060
Anticoagulants	6	5.7	3	4.6	3	6.7	0.693
Admission Unit							0.723
ICU	37	34.5	22	36.6	15	33.3	
NCCU	68	64.5	38	63.3	30	66.7	
Clinical and Imagiologic Assessment							
WFNS at presentation (median (range))	4	1–5	3	1–5	4	1–5	0.045
WFNS ≥2	80	76.2	42	70.0	38	84.4	0.085
WFNS ≥3	67	63.8	35	58.3	32	71.1	0.178
WFNS ≥4	53	50.5	25	41.7	28	62.2	0.037
WFNS 5	22	21.0	10	16.7	12	26.7	0.123
Hunt and Hess (median (range))	3	1–5	1	1–5	3	1–5	0.125
mFISHER, cont scale (median (range)	4	1–4	4	1–4	4	1–4	0.421
mFISHER ≥3	90	85.7	50	83.3	40	88.9	0.421
mFISHER 2 or 4	94	89.5	53	88.3	41	91.1	0.865
mFISHER 4	80	76.2	44	73.3	36	80.0	0.427
Anterior circulation aneurysm	63	60	35	58.3	28	62,2	0.687
Number of aneurysms (median (range))	1	1–3	1	1–3	1	1–3	0.741
Primary treatment modality of aneurysm:							0,294
Endovascular	50	47,6	31	51,7	19	42,2	
Surgery	34	32,4	16	26,7	18	40	
Both	12	11,4	6	10	6	13,3	
Complications following admission							
Aneurysm Re-bleed	8	7.6	5	8.3	3	6.7	1.000
Intraparenchymatous hematoma	8	7.6	4	6.7	4	8.8	0.671
Intraventricular hematoma	2	1.9	1	1.7	1	2.2	1.000
Epileptic crisis (inaugural)	9	8.6	5	8.3	4	8.8	1.000
Epileptic crisis (hospitalization)	4	3.8	1	1.7	3	6.6	0.311
Vasospasm	40	38.1	23	38.3	17	37.8	0.954
Vasospasm with invasive treatment[a]	27	67.5	14	60.9	13	76.4	0.298
Sodium disturbances	87	82.8	46	76.7	41	91.1	0.68
Anaemia (admission)	44	41.9	25	41.6	19	42.2	0.954
Anaemia (day 3)	83	79.0	46	76.7	37	82.2	0.489
ICU and/or NCUU length-of-stay (median (range))	23	1–130	20	1–85	30	13–130	<0.01
Infirmary length-of-stay (median (range)	11	0–159	6	0–89	19	0–159	<0.01
mRS ≤2 at 1st appointment[b]	54	52.9	35	61.4	19	40.9	0.054
mRS ≤2 at 2 years[c]	43	61.1	25	65.8	18	55.8	0.389
Death	12	11.4	11	18.3	1	2.2	0.012

ICU, intensive care unit; NCCU, neurocritical care unit; mRS, modified Rankin Scale; WFNS, *World Federation of Neurosurgeons;* mFISHER, modified FISHER; sd, standard deviation.
[a] n = 17 for patients with a shunt and n = 23 for those without.
[b] n = 44 for patients with a shunt and n = 57 for those without.
[c] n = 34 for patients with a shunt and n = 38 for those without.

Descriptive analysis of EVD parameters showed that most patients did not undergo weaning attempts and had few failed attempts. However, 45 patients (42.8%) developed EVD infections requiring antibiotic treatment. There were no statistical significant differences regarding EVD output. The duration of EVD placement was longer in individuals with VPS (16 vs 9 days, p < 0.01). The VPS group also had a higher incidence of infections requiring antibiotics (60% vs 30%, p = 0.002). Significant differences were also observed in the number of weaning attempts (0 vs 0, p = 0.004) and failed closure attempts (1 vs 0, p = 0.002). Dichotomizing these variables revealed that a single failed closure attempt was significantly associated with VPS placement (51.1% vs 23.3%, p = 0.003), while two or more weaning attempts were necessary to observe significant differences (22.2% vs 3.3%, p = 0.003). Detailed results are shown in Table 3.

3.1. Predictive model – SAH-VP

We identified several parameters significantly associated with the need for a VPS, which were included in our predictive model: WFNS score ≥4, days with an open EVD, two or more failed weaning attempts, one or more closure attempts and EVD infection. The threshold for the total number of days with an open EVD was determined to be 14 days.

Our binary logistic regression analysis is detailed in Table 4. To optimize the scoring system, we first normalized the logistic regression coefficients to fit a 1 to 5 scale. This was done by identifying the smallest and largest coefficients and then applying a normalization formula to proportionally scale them, ensuring that each variable's contribution to the outcome was accurately reflected. Each variable was assigned a score from 1 to 5, with higher scores indicating stronger associations with the outcome. This optimal permutation, named the SAH-VP score, achieved the highest AUC of 0,800, with a 95% CI of (0,720–0,885), indicating excellent performance in predicting shunt dependence and considerable discriminatory ability. The overall model quality was 0,72, reflecting a high fit. Fig. 1 compares the ROC curve of the SAH-VP score with that of the MAGE score.

We determined that the optimal cut-off point for our score was 5, with a sensitivity of 68.9% and a specificity of 83.1%. Additionally, we assessed the model's goodness-of-fit using the Hosmer-Lemeshow test. The test yielded a chi-square statistic of 4.504, with a p-value of 0.720, suggesting that the model demonstrates good calibration and fits the observed data adequately.

The SAH-VP score includes the following settings, also presented in Table 5.

- **Days with an Open EVD ≥ 14:** Assigned 0 or 3 points.
- **Infection of EVD Treated:** Assigned 0 or 2 points

Table 4
Selection of predicting variables of VPS through binary logistic regression.

Variable	B	Wald	Sig.	Exp (B)	95% CI for Exp (B)
WFNS Score ≥ 4	0.335	4.337	0.037	2.731	(1175–10,061)
Days with an open EVD ≥ 14	0.265	7.057	<0,001	1.304	(1.072–1.916)
≥ 2 Weaning attempts	0.500	5.008	0,025	1.532	(1.064–2.553)
Infection of EVD treated with antibiotic	0.260	4.682	0.030	1.293	(1.025–1.642)
Closure attempts ≥ 1	0.123	2.537	0.045	2.575	(0,491–2938)

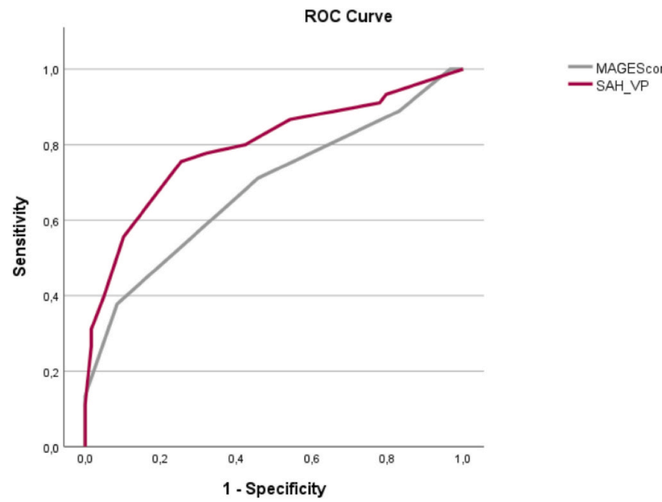

Fig. 1. Comparing the MAGE score with SAH-VP.

Table 5
SAH-VP score.

Variable	Points
Days with an Open EVD ≥ 14	3
Infection of EVD	2
Failed weaning attempts ≥ 2	2
WFNS Score ≥ 4	2
Failed closure attempts ≥ 2	1

Table 3
Analysis of EVD parameters in VPS patients with no VPS patients.

	All (n = 105)		Submitted to VPS placement				P value
			No (n = 60) (n = 80)		Yes (n = 45) (n = 55)		
	n	%	n	%	n	%	
EVD parameters							
Day of placement (median (range))	1	1–40	1	1–8	1	1–40	0.572
Total days (median (range))	12	1–44	9	1–44	16	2–40	<0.01
Mean daily output in the first 72 h (mL, mean ± sd)	226.8	(±100.2)	213.7	(±87,2)	244.3	(±114,1)	0.137
Mean daily output (mL, mean ± sd)	193.5	(±77.0)	189.1	(±72.1)	199.4	(±83.7)	0.519
Failed wean tries (median (range))	0	0–3	0	0–2	0	0–3	0.004
1 failed wean try	27	25.7	17	28.3	10	22.2	0.478
≥ 2 failed wean tries	12	11.4	2	3.3	10	22.2	0.003
Total failed closures (median (range))	0	0–3	0	0–3	1	0–3	0.002
≥ 1 Failed closure	37	35.2	14	23.3	23	51.1	0.003
Dysfunctional EVD	33	31.4	17	28.3	16	35.6	0.430
EVD infection	45	42.8	18	30	27	60	0.002

EVD, External Ventricular Drainage; sd, standard deviation.

- **2 or more failed weaning attempts:** Assigned 0 or 2 points
- **WFNS Score ≥ 4:** Assigned 0 or 2 points
- **1 or more failed closure attempts:** Assigned 0 or 1 point.

We subsequently calculated the likelihood of needing VPS based on the scores obtained in our population. The detailed results are presented in Table 6. When we applied the scoring system to our population, 76% of the cases were identified correctly, and the model achieved a specificity of 84.7% and sensitivity of 64.4%.

3.2. MAGE score

When we applied the MAGE score to our population, we found that the median score was 3, with values ranging from 0 to 5. The shunted group had significantly higher MAGE Scores (3 vs 2, p = 0.003). To evaluate the discriminatory ability of the MAGE Score, we performed a ROC curve analysis. The AUC was 0,687, with a 95% CI of (0,565–0,755), indicating fair discriminatory power for predicting the need for VPS. The model's overall fit statistic was 0,58, suggesting that it explains a moderate proportion of the variability in the outcome.

The optimal cut-off point for the MAGE Score was determined to be 3, with a sensitivity of 71.1% and a specificity of 55.0%. The model's goodness-of-fit was further assessed using the Hosmer-Lemeshow test, which yielded a chi-square of 5.692 and a p-value of 0.128, indicating that the model has good calibration and adequately fits the observed data.

We calculated the likelihood of needing a VPS based on the MAGE scores obtained from our population. Detailed results are presented in Table 7. When we applied the scoring system to our population, 68.6% of the cases were identified correctly, and the model achieved a specificity of 91.7% and sensitivity of 37.8%.

4. Discussion

Our study aimed to identify and evaluate factors influencing the need for a VPS in patients with aSAH. We found that 36.7% of patients required EVD placement, and 15.7% needed VPS, data consistent with literature (Wang et al., 2012; Weigl et al., 2020).

The demographic data aligns with existing literature, indicating a higher incidence of the condition in females (75.5%, n = 79) and increasing incidence with age (mean age at diagnosis = 63.2 ± 14.1) (De Rooij et al., 2007; Etminan et al., 2019). Most patients had hypertension (54.3%, n = 57), reinforcing the known link between this disease and SAH (Ziu et al., 2024; Ewbank et al., 2024; McGurgan et al., 2019). Regarding the consequential hydrocephalus, some studies show that age (Dorai et al., 2003; Graff-Radford, 1989; Lanzino et al., 1996; Tapaninaho et al., 1993; Paisan et al., 2018; Rincon et al., 2010) and female sex (Dorai et al., 2003; Tapaninaho et al., 1993; Sheehan et al., 1999; Chan et al., 2009) are risk factors for shunt dependency, while ours did not find any significant differences in these factors.

Table 6
Probability of needing VPS for each SAH-VP score.

Score	Probability of needing VPS
0	10.2%
1	16.3%
2	25%
3	36.3%
4	49.4%
5	62.6%
6	74.1%
7	83.1%
8	89.4%
9	93.5%
10	96.1%
To sum up:	
0–2	≤25%
3–4	26–50%
5–6	51–75%
7–10	>80%

Table 7
Probability of needing VPS for each MAGE score.

MAGE score	Probability of needing VPS
0	9.8%
1	18.1%
2	31.0%
3	47.8%
4	65.1%
5	79.2%
6	88.5%

Our study identified the WFNS scale as a significant predictor of VPS need, particularly with scores of 4 or above. The Hunt and Hess and mFISHER scales did not show significant differences, contrasting with other studies (Dorai et al., 2003; Paisan et al., 2018; Rincon et al., 2010; Chan et al., 2009; Akinduro et al., 2020).

Our study found that aneurysm characteristics, location and treatment type are not strong predictors of shunt dependency in aSAH patients, which is supported by some studies (Perry et al., 2020; Tapaninaho et al., 1993; Akinduro et al., 2020; Tso et al., 2016), and contradicted by others (Weigl et al., 2020; Paisan et al., 2018; Chan et al., 2009; Aboul-Ela et al., 2018; Erixon et al., 2014).

The longer ICU and infirmary stays observed in patients requiring VPS likely reflect the need for more invasive procedures rather than serving as a predictor for VPS placement, since patients requiring more invasive procedures typically experience longer hospitalizations (Snow et al., 2024). Vasospasm was a frequent complication in our population. While some studies indicate that vasospasm increases the likelihood of requiring a shunt (Dorai et al., 2003; Paisan et al., 2018; Akinduro et al., 2020), our study, along with others (Perry et al., 2020; Wang et al., 2012; Rincon et al., 2010; Tso et al., 2016), found no significant association between vasospasm and VPS dependency.

We found that more patients died in the non-shunted group, as previously described by other studies (Perry et al., 2020; Paisan et al., 2018). This could be due to more severe conditions or complications that precluded shunt placement in this group.

Our study also found that longer the EVD duration and the number of failed closure or weaning attempts were significant predictors of VPS dependency consistent with the findings of Perry et al. (2020). EVD-related infections increased the likelihood of shunt dependency (Rincon et al., 2010; Tso et al., 2016; Sanusi et al., 2020).

The MAGE score showed moderate ability to distinguish between patients who would need a shunt and those who would not, as indicated by its AUC, and it was well-calibrated. However, our optimised SAH-VP score outperformed the MAGE score, achieving a higher AUC of 0,800 and demonstrating greater sensitivity and specificity, suggesting it is more accurate and useful for clinical decision-making.

When comparing the performance metrics of the two scoring systems, the SAH-VP score demonstrated higher overall accuracy, correctly identifying 76% of cases compared to 68.6% for the MAGE score. The SAH-VP score also achieved a better balance between sensitivity and specificity, with a sensitivity of 64.4% and a specificity of 84.7%. In contrast, the MAGE score showed higher specificity at 91.7% but at the expense of sensitivity, which was notably lower at 37.8%. This indicates that while the MAGE score is more effective at correctly identifying patients who do not require a ventriculoperitoneal shunt, the SAH-VP score is better at identifying those who do, providing a more balanced predictive performance.

The inclusion of variables that were not significant in the MAGE score, such as age (significant only in multivariate analysis) and WFNS score, may have contributed to the improved predictive performance of the SAH-VP score compared to the MAGE score. Contrasting the MAGE score, the WFNS score emerged as a significant predictor in both univariate and multivariate analyses in our study.

Conversely, variables like the mean daily EVD output in the first 72 h, which were significant in both univariate and multivariate analyses in the original study, did not reach significance in our model. This lack of significance may have influenced the predictive accuracy and overall quality of their model within this specific population. The observed discrepancy in the significance of these variables between studies highlights how certain factors can exhibit differing predictive values depending on the population characteristics and clinical context.

It would seem logical that higher thresholds might be better predictors of shunt dependency. However, our findings may indicate that early drainage output alone is a limited predictor of shunt dependency. This highlights the need for more comprehensive research to develop more accurate predictive models that concern EVD parameters.

Despite the valuable insights, our study has limitations, including the retrospective design, which may induce some bias, as the records may not be as accurate, for instance all weaning or closure attempts may not be registered, the EVD volume drainages values may not be as accurate, as they were retrieved retrospectively. Other limitations include the small sample size, potential for residual confounding, and the exclusion of non-EVD patients, which might affect generalizability. Additionally, the observational nature of the study and potential biases due to varying clinician practices could impact the findings. Nevertheless, our study represents a meaningful attempt to improve patient management and outcomes.

5. Conclusion

Aneurysmatic SAH is a critical neurological condition that can result in severe complications, such as hydrocephalus. Our analysis reveals that EVD factors are important in predicting shunt dependency. We developed a predictive model that includes several key factors: EVD infection, a WFNS score of 4 or higher, an open EVD for 14 days or more, two or more failed weaning attempts. And one or more failed closure attempts.

Our findings suggest that a SAH-VP score of 5 or higher should be a strong indicator for considering VPS placement. However, further prospective research is needed to provide more reliable and generalizable results for the broader population.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. AUC value interpretation (Corbacioglu and Aksel, 2023)

AUC value	Test quality
0.9–1.0	Excellent
0.8–0.9	Considerable
0.7–0.8	Fair
0.6–0.7	Poor
0.5–0.6	Fail

Adapted from: Corbacioglu Ş, Aksel G. Receiver operating characteristic curve analysis in diagnostic accuracy studies: A guide to interpreting the area under the curve value. Turk J Emerg Med. 2023; 23 (4):195.

References

Aboul-Ela, H.M., Salah El-Din, A.M., Zaater, A.A., Shehab, M., El Shahawy, O.A., 2018. Predictors of shunt-dependent hydrocephalus following aneurysmal subarachnoid hemorrhage: a pilot study in a single Egyptian institute, Egypt. J. Neurol. Psychiatr. Neurosurg. 54, 11. https://doi.org/10.1186/s41983-018-0015-1.

Akinduro, O.O., Vivas-Buitrago, T.G., Haranhalli, N., Ganaha, S., Mbabuike, N., Turnbull, M.T., Tawk, R.G., Freeman, W.D., 2020. Predictors of ventriculoperitoneal shunting following subarachnoid hemorrhage treated with external ventricular drainage. Neurocrit. Care 32, 755–764. https://doi.org/10.1007/s12028-019-00802-8.

Chan, M., Alaraj, A., Calderon, M., Herrera, S.R., Gao, W., Ruland, S., Roitberg, B.Z., 2009. Prediction of ventriculoperitoneal shunt dependency in patients with aneurysmal subarachnoid hemorrhage: clinical article. JNS 110, 44–49. https://doi.org/10.3171/2008.5.17560.

Chen, S., Luo, J., Reis, C., Manaenko, A., Zhang, J., 2017. Hydrocephalus after subarachnoid hemorrhage: pathophysiology, diagnosis, and treatment. BioMed Res. Int. 2017, 1–8. https://doi.org/10.1155/2017/8584753.

Chung, D.Y., Mayer, S.A., Rordorf, G.A., 2018. External ventricular drains after subarachnoid hemorrhage: is less more? Neurocrit. Care 28, 157–161. https://doi.org/10.1007/s12028-017-0443-2.

Corbacioglu, Ş., Aksel, G., 2023. Receiver operating characteristic curve analysis in diagnostic accuracy studies: a guide to interpreting the area under the curve value. Turk. J. Emerg. Med. 23, 195. https://doi.org/10.4103/tjem.tjem_182_23.

De Rooij, N.K., Linn, F.H.H., Van Der Plas, J.A., Algra, A., Rinkel, G.J.E., 2007. Incidence of subarachnoid haemorrhage: a systematic review with emphasis on region, age, gender and time trends. J. Neurol. Neurosurg. Psychiatr. 78, 1365–1372. https://doi.org/10.1136/jnnp.2007.117655.

Dorai, Z., Hynan, L.S., Kopitnik, T.A., Samson, D., 2003. Factors related to hydrocephalus after aneurysmal subarachnoid hemorrhage. Neurosurg. 52, 763–771. https://doi.org/10.1227/01.NEU.0000053222.74852.2D.

Erixon, H.O., Sorteberg, A., Sorteberg, W., Eide, P.K., 2014. Predictors of shunt dependency after aneurysmal subarachnoid hemorrhage: results of a single-center clinical trial. Acta Neurochir. 156, 2059–2069. https://doi.org/10.1007/s00701-014-2200-z.

Etminan, N., Chang, H.-S., Hackenberg, K., De Rooij, N.K., Vergouwen, M.D.I., Rinkel, G.J.E., Algra, A., 2019. Worldwide incidence of aneurysmal subarachnoid hemorrhage according to region, time period, blood pressure, and smoking prevalence in the population: a systematic review and meta-analysis. JAMA Neurol. 76, 588. https://doi.org/10.1001/jamaneurol.2019.0006.

Ewbank, F., Gaastra, B., Hall, S., Galea, I., Bulters, D., 2024. Risk of subarachnoid haemorrhage reduces with blood pressure values below hypertensive thresholds. Eur. J. Neurol. 31, e16105. https://doi.org/10.1111/ene.16105.

Feigin, V.L., Rinkel, G.J.E., Lawes, C.M.M., Algra, A., Bennett, D.A., Van Gijn, J., Anderson, C.S., 2005. Risk factors for subarachnoid hemorrhage: an updated systematic review of epidemiological studies. Stroke 36, 2773–2780. https://doi.org/10.1161/01.STR.0000190838.02954.e8.

Fowler, J.B., De Jesus, O., Mesfin, F.B., 2024. Ventriculoperitoneal shunt. In: StatPearls. StatPearls Publishing, Treasure Island (FL). http://www.ncbi.nlm.nih.gov/books/NBK459351/. (Accessed 14 February 2024).

Frontera, J.A., Claassen, J., Schmidt, J.M., Wartenberg, K.E., Temes, R., Connolly, E.S., Macdonald, R.L., Mayer, S.A., 2006. Prediction of symptomatic Vasospasmafter subarachnoid hemorrhage: the modified Fisher scale. Neurosurg. 59, 21–27. https://doi.org/10.1227/01.neu.0000243277.86222.6c.

Graff-Radford, N.R., 1989. Factors associated with hydrocephalus after subarachnoid hemorrhage: a report of the cooperative aneurysm study. Arch. Neurol. 46, 744. https://doi.org/10.1001/archneur.1989.00520430038014.

Harrison, C.H., Taquet, M., Harrison, P.J., Watkinson, P.J., Rowland, M.J., 2023. Sex and age effects on risk of non-traumatic subarachnoid hemorrhage: retrospective cohort study of 124,234 cases using electronic health records. J. Stroke Cerebrovasc. Dis. 32, 107196. https://doi.org/10.1016/j.jstrokecerebrovasdis.2023.107196.

Hoh, B.L., Ko, N.U., Amin-Hanjani, S., Chou, S.H.-Y., Cruz-Flores, S., Dangayach, N.S., Derdeyn, C.P., Du, R., Hänggi, D., Hetts, S.W., Ifejika, N.L., Johnson, R., Keigher, K. M., Leslie-Mazwi, T.M., Lucke-Wold, B., Rabinstein, A.A., Robicsek, S.A., Stapleton, C.J., Suarez, J.I., Tjoumakaris, S.I., Welch, B.G., 2023. Guideline for the management of patients with aneurysmal subarachnoid hemorrhage: a guideline from the American heart association/American stroke association. Stroke 54 (2023). https://doi.org/10.1161/STR.0000000000000436.

Hunt, W.E., Hess, R.M., 1968. Surgical risk as related to time of intervention in the repair of intracranial aneurysms. J. Neurosurg. 28, 14–20. https://doi.org/10.3171/jns.1968.28.1.0014.

Koleva, M., De Jesus, O., 2024. Hydrocephalus, in: StatPearls. StatPearls Publishing, Treasure Island (FL). http://www.ncbi.nlm.nih.gov/books/NBK560875/. (Accessed 26 July 2024).

Lanzino, G., Kassell, N.F., Germanson, T.P., Kongable, G.L., Truskowski, L.L., Torner, J. C., Jane, J.A., 1996. _, Age and outcome after aneurysmal subarachnoid hemorrhage: why do older patients fare worse? J. Neurosurg. 85, 410–418. https://doi.org/10.3171/jns.1996.85.3.0410.

Long, B., Koyfman, A., Runyon, M.S., Hemorrhage, Subarachnoid, 2017. Emerg. Med. Clin. 35, 803–824. https://doi.org/10.1016/j.emc.2017.07.001.

Macdonald, R.L., Schweizer, T.A., 2017. Spontaneous subarachnoid haemorrhage. Lancet 389, 655–666. https://doi.org/10.1016/S0140-6736(16)30668-7.

Maher, M., Schweizer, T.A., Macdonald, R.L., 2020. Treatment of spontaneous subarachnoid hemorrhage: guidelines and gaps. Stroke 51, 1326–1332. https://doi.org/10.1161/STROKEAHA.119.025997.

McEvoy, A.W., 2000. Lesson of the week: intracerebral haemorrhage in young adults: the emerging importance of drug misuse. BMJ 320, 1322–1324. https://doi.org/10.1136/bmj.320.7245.1322.

McGurgan, I.J., Clarke, R., Lacey, B., Kong, X.L., Chen, Z., Chen, Y., Guo, Y., Bian, Z., Li, L., Lewington, S., 2019. For the China kadoorie biobank consortium, blood pressure and risk of subarachnoid hemorrhage in China. Stroke 50, 38–44. https://doi.org/10.1161/STROKEAHA.118.022239.

Molyneux, A., 2002. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised trial. Lancet 360, 1267–1274. https://doi.org/10.1016/S0140-6736(02)11314-6.

Paisan, G.M., Ding, D., Starke, R.M., Crowley, R.W., Liu, K.C., 2018. Shunt-Dependent hydrocephalus after aneurysmal subarachnoid hemorrhage: predictors and long-term functional outcomes. Neurosurg. 83, 393–402. https://doi.org/10.1093/neuros/nyx393.

Perry, A., Graffeo, C.S., Kleinstern, G., Carlstrom, L.P., Link, M.J., Rabinstein, A.A., 2020. Quantitative modeling of external ventricular drain output to predict shunt dependency in aneurysmal subarachnoid hemorrhage: cohort study. Neurocrit. Care 33, 218–229. https://doi.org/10.1007/s12028-019-00886-2.

Rekate, H.L., 2009. A contemporary definition and classification of hydrocephalus. Semin. Pediatr. Neurol. 16, 9–15. https://doi.org/10.1016/j.spen.2009.01.002.

Rincon, F., Gordon, E., Starke, R.M., Buitrago, M.M., Fernandez, A., Schmidt, J.M., Claassen, J., Wartenberg, K.E., Frontera, J., Seder, D.B., Palestrant, D., Connolly, E. S., Lee, K., Mayer, S.A., Badjatia, N., 2010. Predictors of Long-Term Shunt-dependent Hydrocephalus after Aneurysmal Subarachnoid Hemorrhage: Clinical Article, JNS, vol. 113, pp. 774–780. https://doi.org/10.3171/2010.2.JNS09376.

Rinkel, G.J., Van Gijn, J., Wijdicks, E.F., 1993. Subarachnoid hemorrhage without detectable aneurysm. A review of the causes. Stroke 24, 1403–1409. https://doi.org/10.1161/01.STR.24.9.1403.

Sanusi, T.D., McLarnon, M., Abouharb, A., 2020. Risk factors of chronic shunt dependent hydrocephalus following aneurysmal subarachnoid haemorrhage. Clin. Neurol. Neurosurg. 198, 106095. https://doi.org/10.1016/j.clineuro.2020.106095.

Shaikh, N., Chanda, A., Mohammed, K., Balfaqih, A., Mohsin Khan, M., Nahid, S., Balal, A., Zubair, M., Ma, R., Algallie, H., Al-Ameri, G., Thabet, A., Ayad, A., 2023. Aneurysmal subarachnoid haemorrhage (aSAH) and hydrocephalus: fact and figures. In: Lv, X., Wu, Y., Liang, S. (Eds.), Frontiers in Hydrocephalus, IntechOpen. https://doi.org/10.5772/intechopen.110250.

Sheehan, J.P., Polin, R.S., Sheehan, J.M., Baskaya, M.K., Kassell, N.F., 1999. Factors associated with hydrocephalus after aneurysmal subarachnoid hemorrhage. Neurosurgery 45, 1120–1128. https://doi.org/10.1097/00006123-199911000-00021.

Snow, R., Shamshad, A., Helliwell, A., Wendell, L.C., Thompson, B.B., Furie, K.L., Reznik, M.E., Mahta, A., 2024. Predictors of hospital length of stay and long-term care facility placement in aneurysmal subarachnoid hemorrhage. World Neurosurg.: X 22, 100320. https://doi.org/10.1016/j.wnsx.2024.100320.

Steinke, D., Weir, B., Disney, L., 1987. Hydrocephalus following aneurysmal subarachnoid haemorrhage. Neurol. Res. 9, 3–9. https://doi.org/10.1080/01616412.1987.11739764.

Sweeney, K., Silver, N., Javadpour, M., 2016. Subarachnoid haemorrhage (spontaneous aneurysmal). Clin. Evid. 2016, 1213.

Tapaninaho, A., Hernesniemi, J., Vapalahti, M., Niskanen, M., Kari, A., Luukkonen, M., Puranen, M., 1993. Shunt-dependent hydrocephalus after subarachnoid haemorrhage and aneurysm surgery: timing of surgery is not a risk factor. Acta Neurochir. 123, 118–124. https://doi.org/10.1007/BF01401866.

Teasdale, G.M., Drake, C.G., Hunt, W., Kassell, N., Sano, K., Pertuiset, B., De Villiers, J.C., 1988. A universal subarachnoid hemorrhage scale: report of a committee of the World Federation of Neurosurgical Societies. J. Neurol. Neurosurg. Psychiatr. 51. https://doi.org/10.1136/jnnp.51.11.1457, 1457–1457.

Togha, M., Sahraian, M.A., Khorram, M., Khashayar, P., 2009. Warning signs and symptoms of subarachnoid hemorrhage. South. Med. J. 102, 21–24. https://doi.org/10.1097/SMJ.0b013e318188383c.

Tso, M.K., Ibrahim, G.M., Macdonald, R.L., 2016. Predictors of shunt-dependent hydrocephalus following aneurysmal subarachnoid hemorrhage. World Neurosurg. 86, 226–232. https://doi.org/10.1016/j.wneu.2015.09.056.

Vivancos, J., Gilo, F., Frutos, R., Maestre, J., García-Pastor, A., Quintana, F., Roda, J.M., Ximénez-Carrillo, A., Díez Tejedor, E., Fuentes, B., Alonso De Leciñana, M., Álvarez-Sabin, J., Arenillas, J., Calleja, S., Casado, I., Castellanos, M., Castillo, J., Dávalos, A., Díaz-Otero, F., Egido, J.A., Fernández, J.C., Freijo, M., Gállego, J., Gil-Núñez, A., Irimia, P., Lago, A., Masjuan, J., Martí-Fábregas, J., Martínez-Sánchez, P., Martínez-Vila, E., Molina, C., Morales, A., Nombela, F., Purroy, F., Ribó, M., Rodríguez-Yañez, M., Roquer, J., Rubio, F., Segura, T., Serena, J., Simal, P., Tejada, J., 2014. Guía de actuación clínica en la hemorragia subaracnoidea. Sistemática diagnóstica y tratamiento. Neurologia 29, 353–370. https://doi.org/10.1016/j.nrl.2012.07.009.

Wang, Y.-M., Lin, Y.-J., Chuang, M.-J., Lee, T.-H., Tsai, N.-W., Cheng, B.-C., Lin, W.-C., Su, B.Y.-J., Yang, T.-M., Chang, W.-N., Huang, C.-C., Kung, C.-T., Lee, L.-H., Wang, H.-C., Lu, C.-H., 2012. Predictors and outcomes of shunt-dependent hydrocephalus in patients with aneurysmal sub-arachnoid hemorrhage. BMC Surg. 12, 12. https://doi.org/10.1186/1471-2482-12-12.

Weigl, C., Bruendl, E., Schoedel, P., Schebesch, K.-M., Brawanski, A., Kieninger, M., Bele III, S., 2020. Ventricle diameter increase during ventricular drainage challenge – a predictor of shunt dependency after subarachnoid hemorrhage. J. Clin. Neurosci. 72, 198–201. https://doi.org/10.1016/j.jocn.2019.12.011.

Ziu, E., Khan Suheb, M.Z., Mesfin, F.B., 2024. Subarachnoid hemorrhage. In: StatPearls. StatPearls Publishing, Treasure Island (FL). http://www.ncbi.nlm.nih.gov/books/NBK441958/. (Accessed 14 February 2024).