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Application of a simple scoring scale to predict prognosis of poor-grade subarachnoid haemorrhage using intraventricular haemorrhage

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Intraventricular haemorrhage (IVH) is a key prognostic factor for subarachnoid haemorrhage (SAH). However, no simple or rapid scoring method for its evaluation exists. We aimed to modify and validate a simple scale for rapid IVH grading. We engaged two study groups to generate scores and examine their utility. Study 1 identified prognostic factors in poor-grade SAH and developed a prognostic scoring system. Study 2 evaluated the utility of the score by analysing data from a multicentre patient registry, including all severity levels, and confirmed its generalisability. Outcomes were defined using the modified Rankin scale (score ≥ 3: poor outcome). Study 1 (including 110 patients with poor-grade SAH) created a simple IVH score (IVHAge) based on two slices of computed tomography images and confirmed that it was as predictive as the modified Graeb score (area under the curve: IVHAge score, 0.815; modified Graeb score, 0.752). Study 2 examined 493 patients and found that for each 1-unit increase in the IVHAge score, the odds of a poor outcome increased by 37% (unit odds ratio, 1.37; 95% confidence interval 1.10–1.70; *P* = 0.005). The IVHAge score, which comprises a simplified IVH score and age-related factors, has prognostic value and is suitable for rapid clinical application.

Keywords Endovascular treatment, Graeb score, Intraventricular haemorrhage, Prognostic factor, Subarachnoid haemorrhage, Prognostic factor

Intraventricular haemorrhage (IVH) is known to complicate 28 to 60% of ruptured cerebral aneurysms, and these complications result in a poor prognosis and a high mortality rate[1–5]. Furthermore, IVH is observed in over two-thirds of patients with World Federation of Neurosurgical Societies (WFNS) grades 4–5[5,6]. The extent of IVH has been reported to influence prognosis, with a higher volume correlating with poorer outcomes[5,7]. Therefore, it is important to validate the volume of IVH. Several scales exist, with the Graeb scale being a typical one[8]. Although the Graeb scale and modified Graeb scale are available for haemorrhage volume assessment, they are deemed more precise and research-oriented, compared with the simplistic scoring methods commonly used in clinical practice[7,8]. Although the WFNS grade, which assesses the level of consciousness upon subarachnoid haemorrhage (SAH) onset, is widely employed in clinical practice as a valuable prognostic tool[9], accurately evaluating consciousness levels in patients with poor-grade SAH is often challenging, owing to early sedation. Therefore, this study focused on IVH, with the aim of developing a straightforward scoring system that excludes the assessment of impaired consciousness.

Study 1 examined poor prognostic factors in patients with poor-grade SAH (WFNS grades IV or V) and developed a prognostic score. Study 2 assessed the usefulness of this score and confirmed its generalisability by analysing data from a multicentre patient registry that included all severity levels.

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Methods

Study 1: prognostic evaluation of IVH in SAH, creation of IVH-related scoring, and comparison with previous scales (Graeb scale, modified Graeb scale)

This retrospective cohort study, conducted at our institution between January 2011 and December 2021, examined 110 consecutive patients with poor-grade SAH (WFNS grades IV or V), excluding those with trauma, infection, or iatrogenic factors. This study specifically focused on patients with cerebral aneurysms, excluding those with cardiopulmonary arrest at presentation, bilateral pupillary dilation, or other conditions that precluded surgical intervention. The study included various clinical, radiological, and treatment-related parameters, including aneurysm characteristics, complications, and 90-day modified Rankin scale (mRS) scores. The study included all eligible patients with aneurysmal SAH, regardless of whether they received specific clinical management or treatment. All patients were transported to the emergency room and underwent head computed tomography (CT) immediately after arrival at the hospital. We assessed each scan using both the Graeb scale[8] and modified Graeb scale[7].

Statistical analysis for study 1

First, we analysed all patients with poor-grade SAH and subsequently focused on those with a ruptured aneurysm. The analysis was performed after the study period to account for any bias. The results were presented as mean standard deviation for quantitative data and frequencies (percentages) for categorical data. The data were not normalised because of the limited number of enrolled patients. The Pearson chi-square test for bivariate relationships and the Wilcoxon test for continuous variables were used for comparisons between groups. A multivariate regression model was used to determine the significant differences in clinical variables between the favourable and unfavourable outcome groups. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated for each variable. The area under the receiver operating characteristic curve (AUC) was used to evaluate the predictive ability of the model. An AUC ranging from 0.70 to 0.79 was considered indicative of average discrimination, whereas values between 0.80 and 0.89 signified good discrimination, and values from 0.90 to 1.00 represented excellent discrimination. Statistical significance was set at $P < 0.05$. All statistical analyses were conducted using JMP version 15 software (SAS Institute Inc., Cary, NC, USA).

IntraVentricular Haemorrhage plus Age (IVHAge) score

We created a score that is simple to use at bedside without the need for specialised analytical tools. Based on the IVH scoring, we used the results of the factors associated with prognosis in Study 1 to add items to the score. The IVH scoring method uses two key slices of CT images, those at the basal ganglia and lateral ventricle levels, which mimic the Alberta Stroke Program Early CT Score[10]. These slices were subdivided into four regions, considering both the anterior–posterior and left–right orientations. Each region received 1 point if a haemorrhage was present in both slices, and 1 point was added if the patient was aged over 70 years, with a total score of up to 5 points (Fig. 1A–C). We named this the 'IntraVentricular Haemorrhage plus Age score (IVHAge score)'.

Study 2: relationship between the IVHAge score and outcomes

This retrospective multicentre cohort study included data from patients in the stroke registry who underwent endovascular procedures for ruptured cerebral aneurysms at eight institutes between January 2018 and December 2023. All patients with IVH, a baseline head CT scan, and mRS scores at discharge were included. Of the 533 patients with ruptured aneurysm in the stroke registry study, 493 (94.9%) were analysed, excluding those with missing data, such as 90-day mRS scores or CT scans. Of these, 236 (47.9%) patients with IVH were included in further analyses. The presence of IVH and IVHAge scores were recorded independently by two blinded observers (one person at each institution and S.F.). When the scores differed between observers, the scans were reviewed and disputes resolved by consensus.

Statistical analysis for study 2

The primary endpoint was an unfavourable outcome, defined as an mRS score of 3–6. Variables associated with unfavourable outcomes were identified using the Pearson chi-square test for bivariate relationships and the Wilcoxon test for continuous variables. These variables were incorporated into a binary logistic regression model to evaluate the relationship between the IVHAge score and outcome. We repeated the analysis to examine the sensitivity of our findings, including only those patients with no missing data.

Ethics and study approval

The study protocol was reviewed and approved by the Ethics Committees of Yokohama City University Graduate School of Medicine and each participating institute (approval numbers: B200700036 and F240600038). Owing to the retrospective study design, the Ethics Committee waived the requirement for written informed consent, offering participants an opt-out option in accordance with the Personal Information Protection Law and the National Research Ethics Guidelines.

Results

Characteristics of patients in study 1

A total of 110 consecutive patients with aneurysmal SAH with WFNS grades IV and V were included in this study. The mean age was 62.8 years, with a standard deviation of 15.2 years. All patients were transported to the hospital within 1 day of onset. There were 73 patients (66.4%) with WFNS grade V. Of all, 74 (67.3%) patients had IVH, and 47 (42.7%) had intracerebral haemorrhage (ICH). Endovascular treatment was performed in 53

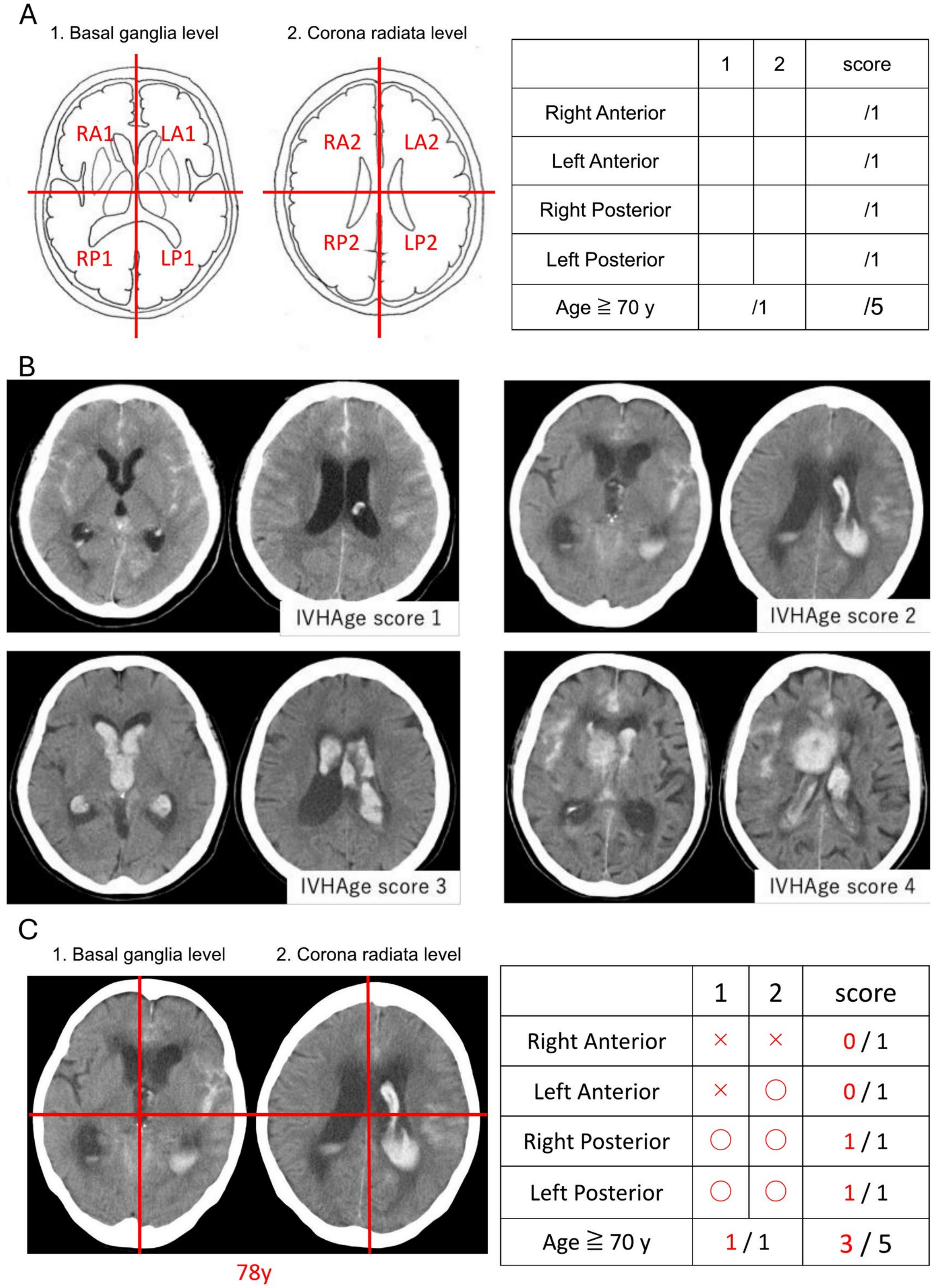

Fig. 1. IntraVentricular Haemorrhage plus Age score (IVHAge score). (**A**) Intraventricular haemorrhage scoring method uses two key slices of computed tomography (CT) images, namely those at the basal ganglia. lateral ventricle levels, in accordance with the Alberta Stroke Program Early CT Score. These slices are subdivided into four regions, considering both the anterior–posterior and left–right orientations. Each region receives 1 point if a haemorrhage is present in both slices, and 1 point is added if the patient is aged over 70 years, with a total score of up to 5 points. We named this the 'IntraVentricular Haemorrhage plus Age score (IVHAge score)'. (**B**) IVHAge score of 1–4 in patients aged over 70 years. (**C**) Example of scoring in a patient aged over 70 years.

patients (48.2%); 15 (13.6%) underwent clipping surgery, and 42 (38.2%) were treated conservatively. Favourable outcomes after 90 days were observed in 24 (21.8%) patients. The other characteristics are listed in Table 1.

Univariate and multivariate analyses for 90-day outcomes

The results of univariate and multivariate analyses of mRS score deterioration after coiling are presented in Table 1. The analysis of the 90-day mRS scores showed that IVH (OR, 2.09; 95% CI 1.12–3.93; $P=0.022$) and ICH (OR, 2.63; 95% CI 1.06–6.47; $P=0.036$) were independently associated with unfavourable outcomes (mRS score of 3–6).

Consideration of the prediction score for prognosis

Older age was associated with unfavourable outcomes (unit OR, 1.04; 95% CI 0.92–1.46; $P=0.074$). The AUC for the prediction of an unfavourable 90-day outcome was 0.64 (data not shown). When the cut-off was set at 67 years, the sensitivity was 0.50, specificity 0.83 (1 – specificity was 0.17), and sensitivity – (1 – specificity) 0.33. Multivariate analysis with a cut-off of ≥ 70 years showed that age ≥ 70 years (OR, 5.28; 95% CI 1.94–25.3; $P=0.006$) and IVH (OR, 2.18; 95% CI 1.11–4.62; $P=0.030$) were independently associated with unfavourable outcomes (Table 2).

Prediction of 90-day outcomes using the IVHAge score

The IVHAge score was used to predict outcomes. The AUC for the prediction of an unfavourable 90-day outcome was 0.745 (95% CI 0.65–0.82) for the Graeb score, 0.752 (95% CI 0.66–0.83) for the modified Graeb score, and 0.815 (95% CI 0.69–0.87) for the IVHAge score (Fig. 2).

				Univariate analysis	Multivariate analysis	
Variable	**Overall (n = 110)**	**mRS 0–2 (n = 24)**	**mRS 3–6 (n = 86)**	***P* Value**	**OR (95% CI)**	***P* value**
Age, y (SD)	62.8 (± 15.2)	58.3 (± 11.4)	64.1 (± 16.0)	**0.036**	1.04† (1.00–1.08)	0.074
Male sex (%)	37 (33.6)	10 (41.7)	27 (31.4)	0.346		
Hypertension (%)	39 (35.5)	8 (33.3)	31 (36.1)	0.806		
Diabetes mellitus (%)	7 (6.4)	1 (4.2)	6 (7.0)	0.618		
Dyslipidaemia (%)	15 (13.6)	1 (4.2)	14 (16.3)	0.126		
CKD (%)	2 (1.8)	0 (0)	2 (2.3)	0.451		
Aneurysm size, mm (SD)	7.1 (± 4.3)	5.3 (± 1.9)	7.7 (± 4.7)	**0.029**	1.16† (0.92–1.46)	0.186
Aneurysm location				0.391		
Acom (%)	22 (20.0)	7 (29.2)	15 (17.4)			
ACA (%)	3 (2.7)	0 (0)	3 (3.5)			
MCA (%)	24 (21.8)	7 (29.2)	17 (19.8)			
ICPcom (%)	15 (13.6)	2 (8.3)	13 (15.1)			
ICA (%)	5 (4.6)	1 (4.2)	4 (4.7)			
Posterior circulation artery (%)	26 (23.6)	7 (29.2)	19 (22.1)			
WFNS grade V (%)	73 (66.4)	12 (50.0)	61 (70.9)	0.055	1.03 (1.87–1.97)	0.936
ICH (%)	47 (42.7)	4 (16.7)	43 (50.0)	**0.004**	2.63 (1.06–6.47)	**0.036**
IVH (%)	74 (67.3)	11 (45.8)	63 (73.3)	**0.011**	2.09 (1.12–3.93)	**0.022**
Graeb score, median (IQR)	4 (0–8)	0 (0–2.75)	5 (0–8)	0.068		
Modified Graeb score, median (IQR)	7.5 (0–15.25)	0 (0–8)	10.5 (0–17.25)	0.220		
Acute phase ventricular drainage (%)	17 (15.5)	1 (4.2)	16 (18.6)	**0.113**		
Treatment for aneurysm				**< 0.001**		
Endovascular treatment (%)	53 (48.2)	18 (75.0)	35 (40.7)			
Clipping surgery (%)	15 (13.6)	6 (25.0)	9 (10.5)			
Treated conservatively (%)	42 (38.2)	0 (0)	42 (48.8)			
Date of treatment intervention (day)* median (IQR)	1 (0–1)	1 (0–1.5)	0 (0–1)	0.309		
Symptomatic spasm (%)	35 (31.8)	9 (37.5)	26 (30.2)	0.499		
Surgery for post-aSAH hydrocephalus (%)	15 (13.6)	2 (8.3)	13 (15.1)	0.392		

Table 1. Baseline patient characteristics of study 1. †Unit odds ratio, *The treatment on the day of onset was set to 0 days, ACA: anterior cerebral artery, Acom: anterior communicating artery, AF: atrial fibrillation, CI: confidence interval, CKD: chronic kidney disease, EVD: external ventricular drainage, ICA: internal carotid artery, ICPcom: internal carotid artery-posterior communicating artery, ICH: intracerebral haemorrhage, IQR: interqartile range, IVH: intraventricular haemorrhage, MCA: middle cerebral artery, mRS: modified Rankin scale, OR: odds ratio, SAH: subarachnoid haemorrhage, SD: standard deviation, WFNS: World Federation of Neurosurgical Societies. Significant values are in bold.

Variable	OR (95% CI)	*P* value
Age ≥ 70 y	5.28 (1.94–25.3)	**0.006**
Aneurysm size, mm	1.18† (0.87–1.60)	0.283
WFNS grade V	1.39 (1.50–3.02)	0.385
ICH	2.43 (1.04–7.03)	0.059
IVH	2.18 (1.11–4.62)	**0.030**

Table 2. Multivariate analysis for unfavourable outcome in Study 1. †unit odds ratio. CI: confidence interval, ICH: intracerebral haemorrhage, IVH: intraventricular haemorrhage, OR: odds ratio, WFNS: World Federation of Neurosurgical Societies. Significant values are in bold.

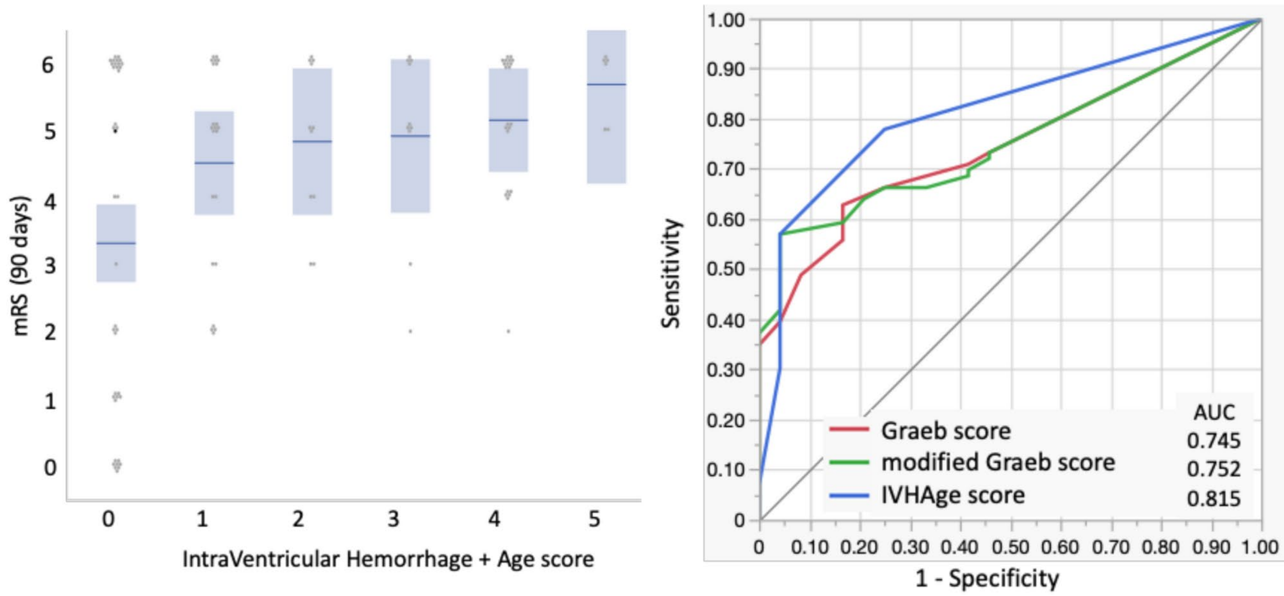

Fig. 2. A plot of the modified Rankin scale score after 90 days versus the IntraVentricular Haemorrhage plus Age score (IVHAge score) and receiver operating characteristic curves for each score in study 1. Left: Plot of the modified Rankin scale score after 90 days and the IVHAge score in study 1. Right: Receiver operating characteristic curves for the Graeb, modified Graeb, and IVHAge scores for the prediction of unfavourable outcomes at 90 days. The area under the curve (AUC) for the baseline Graeb score is 0.745 (95% confidence interval [CI], 0.65–0.82), that for the modified Graeb score was 0.752 (95% CI 0.66–0.83), and that for IVHAge score 0.815 (95% CI 0.69–0.87).

Characteristics of patients in study 2

Of the 533 consecutive patients who underwent endovascular treatment for aneurysmal SAH in a multicentre study, 493 were included after excluding 40 with missing data. The mean age of the patients was 62.8 ± 15.0 years. There were 90 patients (18.3%) with WFNS grade IV and 136 (27.6%) with grade V. IVH was observed in 236 patients (47.9%). A favourable outcome at 90 days was observed in 252 patients (51.1%). The characteristics of patients in Study 2 are shown in Supplemental Table S1. Regarding the interobserver concordance of IVHAge scores, discrepancies were observed in 53 cases. These disagreements were resolved through scan review, resulting in an initial concordance rate (kappa-ratio) of 0.89.

The anatomical distribution of aneurysms in Study 1 and Study 2 is presented in Table 1 and Supplementary Table S1. Compared to Study 1, Study 2 had a significantly higher percentage of aneurysms in the internal carotid artery system, excluding ICPC ($P < 0.001$), and a significantly lower percentage of aneurysms in the MCA ($P = 0.006$) (Supplementary Table S3).

IVHAge score and 90-day outcomes in study 2

In the univariate analysis, age ($P < 0.001$), current smoking ($P < 0.001$), presence of diabetes mellitus ($P = 0.005$), internal carotid artery aneurysm location ($P = 0.0053$), WFNS grade ($P < 0.001$), acute hydrocephalus ($P < 0.001$), Fisher grade ($P < 0.001$), ICH ($P = 0.002$), IVH ($P < 0.001$), symptomatic spasm ($P < 0.001$), surgery for post-aSAH hydrocephalus ($P < 0.001$), rupture ($P = 0.047$), haemorrhagic complication ($P = 0.017$), and the IVHAge score ($P < 0.001$) were significant factors (Supplemental Table S1). Further multivariate analysis showed that the IVHAge score was independently associated with unfavourable outcomes. Each unit increase in the score led to

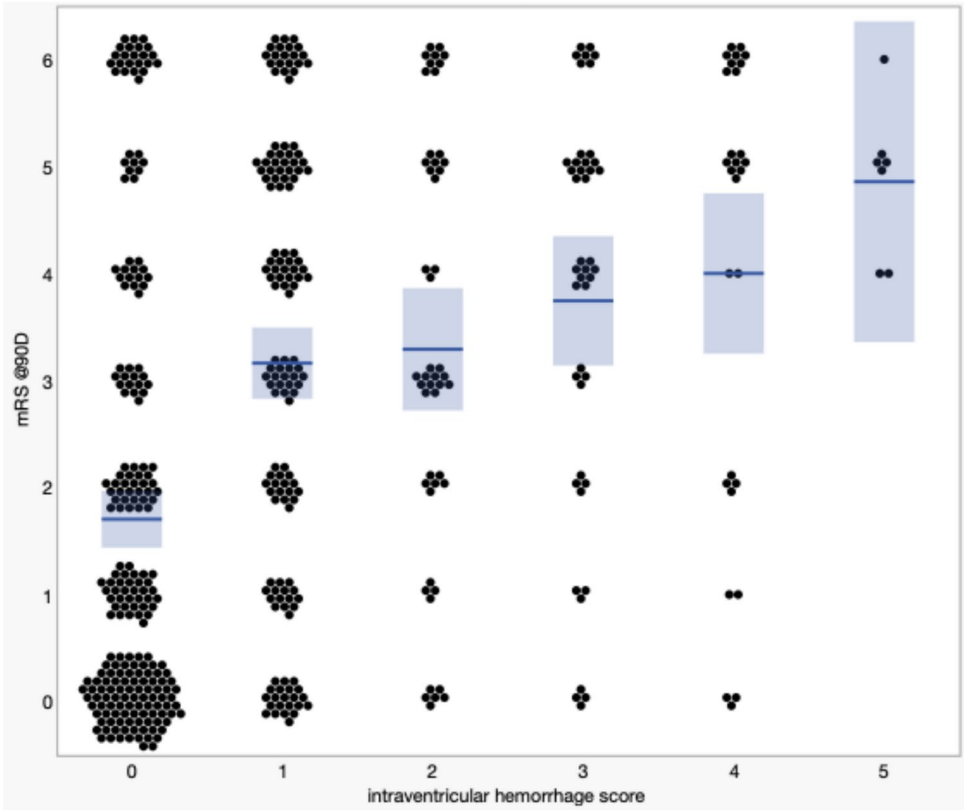

Fig. 3. A plot of the modified Rankin scale score at discharge versus the IntraVentricular haemorrhage plus age score (IVHAge) score in study 2. Plot of the modified Rankin scale score at discharge and the IVHAge score in study 2.

Score	mRS0-2 (n = 58)	mRS3-6 (n = 168)	Univariate analysis	Multivariate analysis	
			P value	OR (95% CI)	*P* value
IVAge score median (range)	0.5 (0–4)	1 (0–5)	**0.0009**	1.38 (1.08–1.81)†	**0.012**
WFNS IV (%)	28 (48.3%)	108 (64.3%)	**0.032**	0.87 (0.46–2.87)	0.866
Hunt and Kosnik median (range)	4 (3–5)	4 (2–5)	**0.005**	1.62 (0.56–3.02)†	0.131
Fisher grade median (range)	3 (2–4)	3 (1–4)	0.303	1.02 (0.57–1.83)†	0.939
Acute phase external ventricular drainage (%)	9 (15.5)	57 (33.9)	**0.0078**	1.81 (0.78–4.15)	0.165
Surgery for post-aSAH hydrocephalus (%)	11 (19.0)	54 (32.1)	0.056	1.58 (0.73–3.45)	0.242
Symptomatic spasm (%)	6 (10.3)	34 (20.2)	0.089	2.59 (0.98–6.83)	0.055

Table 3. Sub-analysis of severe cases in Study 2 (WFNS grade IV, V). †Unit odds ratio. CI: confidence interval, OR: odds ratio, SAH: subarachnoid haemorrhage, WFNS: World Federation of Neurosurgical Societies. Significant values are in bold.

a 37% increase in the odds of unfavourable outcomes (unit OR, 1.37; 95% CI 1.10–1.70; $P = 0.005$, Supplemental Table S1). The IVHAge score was also correlated with unfavourable outcomes in Study 2 (Fig. 3).

In this study, the IVHAge scores were divided into three groups. The ORs for unfavourable outcomes were 3.4 (95% CI 2.1–5.7; $P < 0.001$) for grade II and 4.2 (95% CI 2.0–9.7; $P = 0.0022$) for grade III, using grade I as the reference. A further sub-analysis showed that the IVHAge score (unit OR, 1.38; 95% CI 1.08–1.81; $P = 0.012$) was an independent prognostic factor for poor-grade SAH (WFNS grades IV and V) (Table 3).

Discussion

Our study showed that a rough intraventricular haemorrhage score combined with age (IVHAge score) could predict the prognosis. The IVHAge score can be calculated in a few seconds using two slices of CT images and does not require any analysis software. Complicated scores are difficult to use in daily practice; therefore, the scores used in clinical practice must be simple and versatile. Scores widely used in daily practice, such as the WFNS grade and Spetzler–Martin scale, meet these requirements[11]. Therefore, our score was created with an

WFNS grade	V	14.1% (11/78)	0% (0/41)	4.2% (1/24)
	IV	14.0% (8/57)	18.5% (5/27)	2.2% (2/9)
	III	28.6% (8/28)	0% (0/3)	0% (0/1)
	II	57.5% (42/73)	37.5% (6/16)	33.3% (1/3)
	I	72.5% (95/131)	60.0% (6/10)	0% (0/1)
		I	II	III
		IVHAge score grade		

Table 4. Proportion of good prognosis (mRS: 0–2) groups by WFNS grade and IVHAge score grade in Study 2. IVHAge score: IntraVentricular haemorrhage + Age score, WFNS: World Federation of Neurosurgical Societies.

emphasis on diagnostic simplicity and versatility, and we believe it also meets these requirements. It is a novel scoring system comparable to existing scores that predicts prognosis using only CT imaging.

The IVHAge score is simple and non-inferior to conventional scores (Graeb and modified Graeb scores) in terms of prognostic accuracy. In Study 2, the IVHAge score was an independent predictor of poor prognosis, similar to the WFNS grade[12], and surgery for post-aSAH hydrocephalus[13,14], as previously reported. Additionally, in Study 2, a sub-analysis of poor-grade SAH (WFNS grade IV and V), including age, showed that it was also an independently relevant factor and may be a good prognostic indicator, even for patients who are unconscious.

Although WFNS grade V is generally not considered as an indication for surgery, it is commonly observed that patients diagnosed with WFNS grade V who present with severely impaired consciousness immediately after symptom onset exhibit marked improvements in consciousness levels within a few days of surgery. Recent data indicate that the proportion of patients with SAH showing good prognosis in WFNS grades IV and V is 30% (29.2% specifically in grade V patients) among those eligible for endovascular treatment[15]. Therefore, one weakness of the existing scoring system is that while WFNS is simple, it fails to identify the 30% of patients with good prognosis. Furthermore, existing image scores are complex and unsuitable for clinical application. Prediction of prognosis based on acute neurological and imaging findings alone is limited, and a combination of simple, assessable scoring methods might be the optimal solution. Specifically, we divided the IVHAge score into three categories: 0–1 (grade 1), 2–3 (grade 2), and 4–5 (grade 3), which helps in further refining prognosis even within the same WFNS grade group (Table 4). We believe that combining the IVHAge score with existing grading systems could enhance clinical decision-making.

In a sub-analysis of Study 1, we examined which location of IVH—lateral ventricle, third ventricle, or fourth ventricle—was associated with a poor prognosis (Supplementary Table S5). We found that the lateral ventricle was an independent prognostic factor ($P = 0.004$). Based on these considerations, we developed a score based on the belief that a rough assessment of IVH, such as the present one, may be sufficient to predict prognosis. By incorporating age into the distribution of IVH within the scoring system, we enhanced the prognostic predictive ability compared to that of previous scores for intraventricular haemorrhage. In Supplemental Fig. 1, an analysis using the ROC curve for age and prognosis identified a cutoff value of 67 years. However, we selected 70 years for simplicity. Additionally, we conducted a multivariate analysis of poor prognosis in Study 1 using cutoff values of 60, 65, 67, and 70 years. The results indicated that, while no significant differences were observed among patients aged 60 and 65 years, both 67 and 70 years were identified as independent risk factors for poor prognosis (Supplemental Table S2). Because the odds ratios and *P*-values for these two cutoffs were similar, we adopted 70 years as the cutoff, prioritising its versatility in clinical practice.

The two slices of CT scans that corresponded to the basal ganglia level and lateral ventricle level used in the Alberta Stroke, were divided into four sections: anterior–posterior and left–right. In each region, one point was added if haemorrhage was found in both slices, and one point was added if the patient was over 70 years old, with the total score being up to 5 points. In IVH score, the 4-point scoring system has higher sensitivity and specificity than 8-point scoring system with 1 point per compartment, as well as the 4-point scoring system adopted in this study. Thus, we adopted the 5-point scoring system because it had higher sensitivity and specificity than 9-point scoring system, which adds one point for age to the 8-point scoring system (Supplementary Fig. 2).

The presence and volume of IVH are well-known predictors of mortality and poor prognosis[2,16]. Thus, various semi-quantitative IVH volume assessments exist, in addition to the Graeb scale and modified Graeb scale. However, these assessments are complicated and require the use of analysis software[17,18]. In the present study, even without more precise IVH volume calculations, the simplified version appeared to have good prognostic potential.

As mentioned previously, various complications related to IVH are believed to be associated with poor prognosis, with IVH considered an independent contributing factor for delayed cerebral ischaemia (DCI)[19]. Furthermore, some studies have indicated that IVH independently predicts DCI, with the risk of DCI escalating with larger volumes of IVH[20,21]. In our sub-analysis in Study 2, we investigated the association between symptomatic vasospasm and IVHAge score. Although IVHAge score was not an independent factor associated with symptomatic vasospasm, it was associated with it in univariate analysis. Furthermore, Fisher score, a predictor of vasospasm, was not associated with symptomatic spasm in our study (Supplemental Table S4). This association remains controversial owing to unclear underlying mechanisms and inconsistent confirmation by other investigators[5,22]. In the present study, DCI was not identified as an independent prognostic factor. We hypothesised that recent advancements in the treatment and prevention of vasospasm may have influenced this outcome[23].

Age emerged as a significant predictor of prognosis, prompting a comparison of groups with IVH scores of 0–1, 2–3, and 4–5. A score of 1 was assigned in cases where only the age was considered. However, the group with higher scores had an elevated risk beyond the influence of age alone. The results indicated a worse prognosis with an increasing IVH score. Since most IVH cases are classified as WFNS grade IV or V[6], Study 1 exclusively focused on severe cases. However, the prognosis did not differ significantly between patients with WFNS grades of IV and those with V. Consequently, we deemed it clinically valuable that age and the IVH score, irrespective of the degree of consciousness impairment, could predict the prognosis in critical cases.

Limitations

In Study 1, approximately one-third of the patients did not receive any therapeutic intervention, primarily because of the significant proportion of critical SAH cases included. Given the specific characteristics of this patient population, it is conceivable that the primary target demographics for which this scoring system proves useful are critical cases. Study 2 exclusively enrolled patients who underwent endovascular treatment, potentially encompassing severe cases or older individuals unsuitable for craniotomy. However, they may not include patients with sizable intracerebral haematomas who would benefit from a craniotomy. Since this is an external validity test for such a group of cases, there are limitations to the proof of reproducibility and generalizability.

The difference in the proportion of IVH between Study 1 (67%) and Study 2 (48%) could indeed introduce a potential source of bias. However, the prognostic score we applied was developed based on a cohort of patients with severe cases, and we aimed to test its general applicability in a more diverse patient population in Study 2. Our investigation did not include treatment specifics for IVH (e.g. the use of lytic agents in addition to external ventricular drainage), thereby precluding the assessment of treatment outcomes in patients with elevated IVHAge scores. In Study 2, the prognostic AUC was 0.815 when the IVHAge scores were considered hypothetical continuous variables. This finding suggests the potential utility of this score, despite over half of the patients lacking IVH, with only a minority having high IVHAge scores. However, we advocate for assessing the generalisability of the score in a more diverse spectrum of cases. We contend that the analysis of the implications of the scores for mild- and low-scoring of WFNS grade cases in this study is inadequate.

Conclusions

Prognostic assessment using a simple scoring system based on the degree of IVH and age (IVHAge score) may facilitate clinical decision-making in routine practice. Its prognostic value in situations where the WFNS grade is not predictive, such as in severe cases, may further support clinical judgment. Furthermore, although there are limitations to predicting prognosis from neurological and imaging findings alone in the acute phase, a combination of simple assessable scoring (IVHAge score and WFNS grade) may be the optimal solution for prognosis prediction.

Data availability

Data availability statement The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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References

1. Mohr, G. et al. Intraventricular hemorrhage from ruptured aneurysm. Retrospective analysis of 91 cases. *J. Neurosurg.* **58**, 482–487 (1983).
2. Rosen, D. S. et al. Intraventricular hemorrhage from ruptured aneurysm: Clinical characteristics, complications, and outcomes in a large, prospective, multicenter study population. *J. Neurosurg.* **107**, 261–265 (2007).
3. Hayashi, M. et al. Prognosis of intraventricular hemorrhage due to rupture of intracranial aneurysm. *Zentralbl. Neurochir.* **50**, 132–137 (1989).
4. Fernandez, A. et al. Fever after subarachnoid hemorrhage: Risk factors and impact on outcome. *Neurology* **68**, 1013–1019 (2007).
5. Kramer, A. H. et al. Intraventricular hemorrhage volume predicts poor outcomes but not delayed ischemic neurological deficits among patients with ruptured cerebral aneurysms. *Neurosurgery* **67**, 1044–1052 (2010) (**discussion 1052-1053**).
6. Kramer, A. H. et al. A comparison of three radiographic scales for the prediction of delayed ischemia and prognosis following subarachnoid hemorrhage. *J. Neurosurg.* **109**, 199–207 (2008).
7. Morgan, T. C. et al. The Modified Graeb Score: An enhanced tool for intraventricular hemorrhage measurement and prediction of functional outcome. *Stroke* **44**, 635–641 (2013).
8. Graeb, D. A., Robertson, W. D., Lapointe, J. S., Nugent, R. A. & Harrison, P. B. Computed tomographic diagnosis of intraventricular haemorrhage. Etiology and prognosis. *Radiology* **143**, 91–96 (1982).
9. Report of World Federation of Neurological Surgeons Committee on a Universal Subarachnoid Hemorrhage Grading Scale. *J. Neurosurg.* **68,** 985–986 (1988).
10. Barber, P. A., Demchuk, A. M., Zhang, J. & Buchan, A. M. Validity and reliability of a quantitative computed tomography score in predicting outcome of hyperacute stroke before thrombolytic therapy. ASPECTS Study Group. Alberta Stroke Programme Early CT Score. *Lancet* **355**, 1670–1674 (2000).
11. Nakaji, P. Commentary: Incorporating a modified Graeb score to the modified Fisher scale for improved risk prediction of delayed cerebral ischemia following aneurysmal subarachnoid hemorrhage. *Neurosurgery* **82**, 306 (2018).
12. van Heuven, A. W., Dorhout Mees, S. M., Algra, A. & Rinkel, G. J. Validation of a prognostic subarachnoid hemorrhage grading scale derived directly from the Glasgow Coma Scale. *Stroke* **39**, 1347–1348 (2008).
13. Quigley, M. Risk of shunt-dependent hydrocephalus after occlusion of ruptured intracranial aneurysms by surgical clipping or endovascular coiling: a single-institution series and meta-analysis. *Neurosurgery* **63**, E1209 (2008) (**author reply E1209**).

14. Dorai, Z., Hynan, L. S., Kopitnik, T. A. & Samson, D. Factors related to hydrocephalus after aneurysmal subarachnoid hemorrhage. *Neurosurgery* **52**, 763–769 (2003) (**discussion 769-771**).
15. Akimoto, T. et al. Predictors of outcomes six months after endovascular coil embolization of poor-grade aneurysmal subarachnoid hemorrhage. *J. Neuroendovasc. Ther.* **17**, 47–55 (2023).
16. Naff, N. J. et al. Intraventricular thrombolysis speeds blood clot resolution: results of a pilot, prospective, randomized, double-blind, controlled trial. *Neurosurgery* **54**, 577–583 (2004).
17. Bardera, A. et al. Semi-automated method for brain hematoma and edema quantification using computed tomography. *Comput. Med. Imaging Graph.* **33**, 304–311 (2009).
18. Hallevi, H. et al. The IVH score: A novel tool for estimating intraventricular hemorrhage volume: clinical and research implications. *Crit. Care Med.* **37**, 969–974 (2009).
19. Eagles, M. E., Jaja, B. N. R. & Macdonald, R. L. Incorporating a modified graeb score to the modified fisher scale for improved risk prediction of delayed cerebral ischemia following aneurysmal subarachnoid hemorrhage. *Neurosurgery* **82**, 299–305 (2018).
20. Claassen, J. et al. Effect of cisternal and ventricular blood on risk of delayed cerebral ischemia after subarachnoid hemorrhage: The Fisher scale revisited. *Stroke* **32**, 2012–2020 (2001).
21. Ko, S. B. et al. Quantitative analysis of hemorrhage volume for predicting delayed cerebral ischemia after subarachnoid hemorrhage. *Stroke* **42**, 669–674 (2011).
22. Juvela, S., Siironen, J., Varis, J., Poussa, K. & Porras, M. Risk factors for ischemic lesions following aneurysmal subarachnoid hemorrhage. *J. Neurosurg.* **102**, 194–201 (2005).
23. Endo, H. et al. Effects of clazosentan on cerebral vasospasm-related morbidity and all-cause mortality after aneurysmal subarachnoid hemorrhage: Two randomized phase 3 trials in Japanese patients. *J. Neurosurg.* **137**, 1707–1717 (2022).

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Author contributions

S.F. and T.A. contributed to the conception and design of the study, acquisition of data, and analysis and interpretation of data. T.A., S.F., M.O., Y.I., R .S., S.M., S.H., J.S., Y.N., and K.S. collected clinical data. S.F. and T.A. wrote the draft and conducted the statistical analysis. Y.N. and T.Y. supervised all aspects of this study. All the authors have read the final manuscript and approved its submission for publication. All authors attested to meeting the four ICMJE authorship criteria.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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