Computed tomography in the assessment of aneurysmal subarachnoid haemorrhage for clinical outcome: an observational cohort study

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Research

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Abstract

Background: Aneurysmal subarachnoid haemorrhage (aSAH) is a life-threatening event with major complications such as delayed cerebral infarction (DCI) or acute hydrocephalus and poor neurological outcome. DCI occurs most frequently 7 days after aSAH and can last for a prolonged period. The ability to predict these complications would allow the neuro-intensivist to identify patients at risk and select the most appropriate unit for hospitalization.

Methods: A 3-year single-centre retrospective cohort study was conducted in our neuroscience critical care unit. Initial computed tomography (CT) scans in patients hospitalized for aSAH were blindly assessed using eight grading systems: the Fisher scale, modified Fisher scale, Barrow Neurological Institute scale, Hijdra scale, Intraventricular Haemorrhage (IVH) score, Graeb score, and LeRoux score. We evaluated and compared these radiological scales for the early prediction of DCI, acute hydrocephalus, and poor neurological outcome at 3 months.

Results: Of 200 patients with aSAH who survived to day 7 and were included for DCI analysis, 39% cases were complicated with DCI. The Hijdra scale was the best predictor for DCI, with a receiver operating characteristic area under the curve (ROCAUC) of 0.80 (95% confidence interval [CI], 0.74–0.85). The ideal cut-off score for all patients was 20/42, with a sensitivity of 85% (95% CI, 75%–94%) and specificity of 63% (95% CI, 54%–71%). The IVH score was the most effective grading system for predicting acute hydrocephalus, with a ROC AUC of 0.85 (95% CI, 0.79–0.89). In multivariate analysis, the Hijdra scale was the only independent predictor of the occurrence of DCI (hazard ratio, 1.18; 95% CI, 1.10–1.27).

Conclusions: Although these results have yet to be prospectively confirmed, our findings suggest that the Hijdra scale may be a good predictor of DCI and could be useful in daily clinical practice.

Background

Aneurysmal subarachnoid haemorrhage (aSAH) is a life-threatening event. Severe complications can occur after the aneurysm is secured, such as delayed cerebral ischemia (DCI) or acute hydrocephalus requiring intensive care monitoring for 12–21 days after aSAH [1, 2]. The management of these complications in high-volume hospitals with neurosurgical and endovascular services seems to be associated with better outcome [3]. However, specialized hospitals have limited capacity in terms of neurocritical care unit beds. Optimizing resource allocation requires the ability to select patients at high risk of complications after aSAH. In this context, a radiological score that would be predictive of complications would be useful for identifying patients who need intensive care unit (ICU) monitoring.

Since the early 1980s and publication of the Fisher grade, the occurrence of vasospasm and prognosis with aSAH have been recognized as being influenced by the severity of the initial bleeding, which can be evaluated on an early computed tomography (CT) scan [4–12]. However, several studies demonstrated low sensitivity and specificity of this scale for predicting DCI [6–10]. Recently, a systematic review assessing the association of radiological scales for grading aSAH with DCI showed that patients with

Fisher grade 4 have a significantly lower risk of DCI compared to those with Fisher grade 3 [13]. With current clinical management including nimodipine, hypertensive therapy, and endovascular treatment, the Fisher grade predicts symptomatic vasospasm in only half of cases [14]. For this reason, other radiological scales have been developed to assess the amount of blood present in the subarachnoid spaces [7–10]. These scales qualitatively divide aSAH into categories, as do the Claassen scale [7] and the modified Fisher grade [9], or involve a semi-quantitative assessment, as do the Hijdra [8] or the Barrow Neurological Institute (BNI) [10] grading scales. Other grading systems, including the Graeb [15] or Leroux scales [16], or the IntraVentricular Haemorrhage (IVH) score [17], use a semi-quantitative method to assess the amount of blood present in the ventricles.

The goal of this study was to evaluate eight radiological scales in grading subarachnoid or ventricular haemorrhage or both for predicting DCI, acute hydrocephalus, and functional outcome at 3 months in a large aSAH population.

Methods

Guidelines for reporting this study were derived from the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement [18].

Study design and population

This was a single-centre retrospective cohort study of consecutive patients with an aSAH admitted during a 33-month period (January 1, 2013 to July 30, 2016) at our neuroscience critical care unit (NCCU). Access to health information was approved by an ethics committee (Comité d'éthique pour la recherche en Anesthésie-Réanimation - IRB 000102542019081), which waived the requirement for individual consent according to French law at the time of the study [19]. Inclusion criteria were age older than 18 years, an available head CT scan demonstrating aSAH prior to any neurosurgical intervention (external ventricular drainage (EVD), aneurysm clipping, or endovascular treatment), and confirmed ruptured aneurysm on subsequent digital subtraction angiography. Exclusion criteria were the presence of non-aneurysmal vascular malformations and of intracranial artefacts (prior embolization or aneurysm clipping). Patients with SAH from other causes such as head injury, arteriovenous malformation, or arterial dissection or without aneurysms confirmed on CT or angiography were excluded. Patients for whom an initial CT could not be retrieved, with incomplete CT, or with an initial CT obtained more than 24 hours after bleeding were also excluded.

Clinical management

Our aSAH management policy has been described previously in detail [1]. Briefly, all patients were managed in a dedicated NCCU according to a standardized aSAH protocol in accordance with published European guidelines [20]: administration of intravenous nimodipine and ventricular drainage in cases of hydrocephalus allowing continuous monitoring of intracranial pressure. All aneurysms were secured within 24 hours after admission with endovascular coil embolization or surgery. All patients were

followed with transcranial Doppler sonography. Those with neurological symptoms deemed suspicious for vasospasm underwent CT angiography, followed by conventional angiography in case of moderate or severe vasospasm.

CT grading

For each patient, two independent clinicians blinded to clinical data reviewed the initial 32-slice CT scans. Each head CT was graded according to eight grading systems: the Fisher grade [4], modified Fisher grade [9], Claassen scale [7], Hijdra scale [8], BNI scale [10], Graeb scale [15], LeRoux scale [16], and IVH score [17]. Each grading system is detailed in Additional file 1 (Table S1), and an illustrative example of patient evaluation is depicted in Fig. 1.

Data collection, DCI definition, and outcome assessment

Data corresponding to clinical characteristics such as age, sex, the Glasgow Coma Scale [21], and the World Federation of Neurosurgical Societies (WFNS) scale [22] were recorded at admission. The Simplified Acute Physiology Score 2 (SAPS II) [23] was calculated within 24 hours after NCCU admission.

Based on the latest recommendations [24, 25], DCI was defined as follows: development of focal neurologic signs; reduction by at least 2 points on the Glasgow Coma Scale that lasts for at least one hour and is associated with angiographic cerebral vasospasm, detected either with CT angiography or digital subtraction angiography; or a new cerebral infarction detected on a CT scan, either within 6 weeks after an aSAH or before discharge, after excluding a procedure-related infarction.

Acute hydrocephalus was defined as the need to place an EVD within the first 72 hours.

Outcome was evaluated at 3 months after the bleeding using the Glasgow Outcome Scale Extended (GOSE), and dichotomized into poor (GOSE 1–4) and good outcomes (GOSE 5–8) [26].

Statistical analysis

Means and standard deviations were calculated for continuous variables with normal distributions, and medians and interquartile ranges for non-continuous variables. For categorical variables, numbers and percentages were used. Comparison between continuous variables from two groups was assessed by an unpaired two-sample t-test (normally distributed) or a Wilcoxon–Mann–Whitney U test (no assumption for distribution). Differences between categorical variables were assessed by Fisher's exact test. A receiver operating characteristic (ROC) curve was plotted to determine the ROC area under the curve (ROC_{AUC}) and the optimal cut-off value of grading scales that best predicted DCI, early hydrocephalus requiring EVD, poor outcome, and mortality. The ROC_{AUC} of each scale was compared with those with higher ROC_{AUC} values, using the method described by DeLong et al [27]. The interobserver variability of the eight scales was assessed. A weighted Cohen kappa coefficient (κ) was calculated for each pair per scale used with $\kappa < 0.2$, $\kappa = 0.21$ to 0.4, $\kappa = 0.41$ to 0.6, $\kappa = 0.61$ to 0.8, and $\kappa > 0.8$ corresponding to poor, fair, moderate, strong, and near- complete agreement, respectively [28]. We performed adjusted analyses

via ordinal logistic or linear regression modelling, as appropriate. All statistics were carried out using JMP (version 14.0, SAS, Cary, NC, USA) except for the ROC analyses and kappa coefficient calculation, which were performed using MedCalc (version 9.2, MedCalc Software, Ostend, Belgium). Statistical significance was assumed at p values of 0.05 and below.

Results

Patient demographics

During the study period, of 371 consecutive patients with SAH, 270 suffered acute aSAH and 230 met all inclusion criteria (Fig. 2). Of these, 200 patients survived for more than 7 days and were included in the analysis for factors related to DCI. Patient characteristics are presented in Table 1. A total of 47% of patients were classified as grade 3–5 on the WFNS scale. The in-hospital mortality rate was 24%. DCI was documented in 78 patients (39%) and was related to poor outcome: 42% of patients presenting with DCI suffered a poor outcome (GOSE 1–4), whereas 26% of patients without DCI did so ($p < 0.001$). Poor neurological condition (WFNS 3–5) at admission to NCCU was statistically associated with poor neurological outcome ($p < 0.001$) and occurrence of DCI ($p = 0.01$).

Table 1

Baseline Characteristics of Patients with Aneurysmal Subarachnoid Haemorrhage that Developed Poor or Good Outcome and that Developed or Did Not Delayed Cerebral Infarction (DCI).

		Outcome (n = 230)			DCI (n = 200)		
Variable	All patients (n = 230)	Good (GOSE 5–8) (n = 135)	Poor (GOSE 1–4) (n = 95)	P value †	No (n = 122)	Yes (n = 78)	P value §
Demographic characteristics							
Male sex — no. (%)	96 (42)	49 (36)	47 (49)	0.06	47 (39)	33 (42)	0.66
Age — y	54 ± 13	52 ± 12	56 ± 13	0.01	54 ± 13	52 ± 12	0.20
Clinical presentation							
GCS	13 [7–15]	14 [13–15]	8 [5–12]	< 0.001	14 [10–15]	13 [7–14]	0.01
SAPS II	34 [21–49]	25 [18–34]	47 [39–54]	< 0.001	28 [20–41]	33 [20–47]	0.15
WFNS scale	3 [1–4]	2 [1–4]	4 [3–5]	< 0.001	2 [1–4]	3 [2–4]	0.01
3–5 — no. (%)	107 (47)	37 (27)	70 (74)	< 0.001	51 (42)	45 (58)	0.03
Ruptured aneurysm location — no. (%)							
Anterior circulation	186 (81)	106 (79)	80 (84)	0.31	100 (82)	63 (81)	0.85
ICA	38 (17)	27 (20)	11 (12)	0.11	20 (16)	12 (15)	1.00
ACA	20 (9)	16 (12)	4 (4)	0.06	14 (11)	5 (6)	0.32
MCA	48 (21)	20 (15)	28 (29)	0.01	29 (24)	15 (19)	0.49
AcomA	80 (35)	43 (32)	37 (39)	0.33	37 (30)	31 (40)	0.22
Posterior circulation	44 (19)	29 (21)	15 (16)	0.31	22 (18)	15 (19)	0.85

		Outcome	(n = 230)		DCI (n = 200)		
AcomP	17 (7)	14 (10)	3 (3)	0.04	10 (8)	7 (9)	1.00
ACP	3 (1)	1 (1)	2 (2)	0.57	1 (1)	2 (3)	0.56
PICA/AICA/SCA	5 (2)	3 (2)	2 (2)	1.00	3 (3)	1 (1)	1.00
BA	16 (7)	10 (7)	6 (6)	0.80	6 (5)	5 (6)	0.75
VA	3 (1)	1 (1)	2 (2)	0.57	2 (2)	0 (0)	0.52
Aneurysm treatment — no. (%)							
Coiling / Clipping	164 (71) / 66 (29)	114 (84) / 21 (16)	50 (53) / 45 (47)	< 0.001	91 (75) / 31 (25)	64 (82) / 14 (18)	0.23
Complications — no. (%)							
Early hydrocephalus requiring EVD	121 (53)	60 (44)	61 (64)	0.003	57 (47)	48 (62)	0.38
Intracerebral hematoma	69 (30)	24 (18)	45 (47)	< 0.001	36 (30)	20 (26)	0.63
Rebleeding	21 (9)	5 (4)	16 (17)	< 0.001	11 (9)	6 (8)	0.52
Neurogenic pulmonary edema	10 (4)	7 (5)	3 (3)	0.53	2 (2)	8 (10)	0.01
Angiographic vasospasm	81 (35)	48 (36)	33 (35)	1.00	5 (4)	78 (99)	< 0.001
Minor	30 (13)	19 (14)	11 (12)	0.69	5 (4)	23 (29)	< 0.001
Moderate	28 (34)	19 (39)	9 (26)	0.31	0 (0)	28 (36)	< 0.001
Severe	26 (31)	11 (22)	15 (44)	0.09	0 (0)	26 (33)	< 0.001
Cerebral salt-wasting syndrome	12 (5)	6 (4)	6 (6)	0.56	6 (5)	6 (8)	0.41
Seizure	14 (6)	9 (7)	5 (5)	0.78	8 (7)	5 (6)	1.00
Outcomes							

		Outcome	(n = 230)		DCI (n = 200)		
GOSE at 3 months after SAH	7 [2–8]	8 [7–8]	1 [1–3]	< 0.001	8 [4–8]	6 [3–8]	0.02
In-hospital mortality — no. (%)	55 (24)	0 (0)	55 (58)	< 0.001	16 (13)	9 (12)	0.83
Results are noted as numbers (%), medians [interquartile range], or means ± SD.							
* Data for DCI were collected from a group of 200 patients (30 patients who died before day 7 were excluded).							
† P value for patients with good outcome versus poor outcome.							
§ P value for patients with DCI versus without DCI.							
Boldface values represent significant findings assumed at p values of 0.05 and below.							
ACA denotes anterior cerebral artery; ACP, posterior cerebral artery; AICA, anterior inferior cerebellar artery; AcomA, anterior communicating artery; AcomP, posterior communicating artery; BA, basilar artery; EVD, external ventricular drain; GCS, Glasgow Coma Scale; GOSE, Glasgow Outcome Scale Extended; ICA, internal carotid artery; MCA, middle cerebral artery; SAPS II, Simplified Acute Physiologic Score II; SCA, superior cerebellar artery; PICA, posterior inferior cerebellar artery; VA, vertebral artery; and WFNS, World Federation of Neurological Surgeons Grading System.							

Predictive value of CT grading systems

For all tested scales or scores, a higher value was statistically associated with occurrence of DCI and poor neurological outcome (Table 2). Figure 3A summarizes the results of ROC curves of the main predictors of DCI. Additional file 1 (Table S2) shows the cut-off values with corresponding specificity and sensitivity and ROC_{AUC} for each predictor. The Hijdra scale performed best at predicting DCI, with a ROC_{AUC} of 0.80 (95% confidence interval [CI], 0.74–0.85). The ideal cut-off was a Hijdra scale score ≥20, with a sensitivity of 85% (95% CI, 75–92% and a specificity of 63% (95% CI, 54–71%), but it was less accurate to predict poor outcome (Fig. 3B) or death (Fig. 3C) than the SAPS II score (ROC_{AUC} respectively 0.86 [95% CI, 0.71–0.91] and 0.82 [95% CI, 0.76–0.86]). Figure 4 shows the occurrence of DCI in the subpopulation of low-severity aSAH (WFNS 1–2) and high-severity aSAH (WFNS 3–5). In the WFNS 1–2 subpopulation, the Hijdra scale was also the best-performing scale to predict DCI, with a ROC_{AUC} of 0.82 (95% CI, 0.73–0.89) (Additional file 1 – Fig. S1). The IVH score performed best for predicting early hydrocephalus requiring EVD, with a ROC_{AUC} of 0.85 (95% CI, 0.79–0.89) (Fig. 3D). On univariate analysis, the Hijdra scale and IVH score were of significant prognostic value for the presence of DCI and of early hydrocephalus requiring EVD (Additional file 1 – Table S3). The Fisher scale did not predict any of the three outcome measures.

Table 2

Relationship between CT Grading Systems and the Development of Poor Outcome or Delayed Cerebral Infarction (DCI) in Patients with Aneurysmal Subarachnoid Haemorrhage.

		Outcome	**(N = 230)**		**DCI (n = 200)**		
CT Grading Systems	All patients (N = 230)	Good (GOSE 5–8) (n = 135)	Poor (GOSE 1–4) (n = 95)	P value †	No (n = 122)	Yes (n = 78)	P value §
Fisher grade	4 [4–4]	4 [3–5]	4 [4–4]	0.05	4 [3–4]	4 [4–4]	0.04
3–4 — no. (%)	210 (91)	115 (83)	95 (100)	< 0.001	103 (84)	77 (99)	< 0.001
modified Fisher grade	4 [3–4]	4 [2–4]	4 [4–4]	< 0.001	4 [2–4]	4 [4–4]	< 0.001
III-IV — no. (%)	194 (85)	99 (74)	95 (100)	< 0.001	88 (73)	76 (97)	< 0.001
Claassen scale	3 [3–4]	3 [2–4]	4 [3–4]	< 0.001	3 [2–4]	4 [3–4]	< 0.001
III-IV — no. (%)	193 (84)	99 (74)	94 (99)	< 0.001	88 (73)	76 (97)	< 0.001
BNI grading scale	4 [3–5]	4 [3–5]	5 [4–5]	< 0.001	4 [3–5]	4 [4–5]	0.003
IV-V — no. (%)	167 (73)	81 (60)	86 (91)	< 0.001	73 (60)	67 (86)	< 0.001
IVH score	7 [0–11]	5 [0–10]	10 [4–17]	< 0.001	5 [0–10]	8 [2–11]	0.006

* Data for DCI were collected from a group of 200 patients (30 patients who died before day 7 were excluded).

Results are expressed as numbers (%), medians [interquartile range], or means ± SD.

† P value for patients with good outcome versus poor outcome.

§ P value for patients with DCI versus without DCI.

Boldface values represent significant findings assumed at p values of 0.05 and below.

BNI denotes Barrow Neurological Institute score; CT, computerized tomography; GOSE, Extended Glasgow Outcome Scale; and IVH, Intraventricular Haemorrhage.

		Outcome	(N = 230)		DCI (n = 200)		
IVH volume — mL	4.1 [1.0–9.0]	2.7 [1.0–7.4]	7.4 [2.0–30.0]	< 0.001	2.5 [1.0–7.4]	5.0 [1.5–9.0]	< 0.001
Graeb scale	2 [0–5]	2 [0–3]	4 [2–8]	< 0.001	1 [0–3]	3 [1–5]	< 0.001
Leroux scale	3 [0–7]	2 [0–4]	6 [2–11]	< 0.001	2 [0–4]	4 [2–8]	< 0.001
Hijdra scale	21 ± 11	18 ± 10	27 ± 9	< 0.001	16 ± 10	27 ± 8	< 0.001
* Data for DCI were collected from a group of 200 patients (30 patients who died before day 7 were excluded).							
Results are expressed as numbers (%), medians [interquartile range], or means ± SD.							
† P value for patients with good outcome versus poor outcome.							
§ P value for patients with DCI versus without DCI.							
Boldface values represent significant findings assumed at p values of 0.05 and below.							
BNI denotes Barrow Neurological Institute score; CT, computerized tomography; GOSE, Extended Glasgow Outcome Scale; and IVH, Intraventricular Haemorrhage.							

Rating interobserver agreement

All scales were rated as having a good or very good interobserver agreement. The rating scale with the greatest interobserver agreement was the Fisher scale (κ = 0.91; 95% CI, 0.75–1.00), followed by the Hijdra score (κ = 0.85; 95% CI, 0.80–0.91) (Additional file 1 – Table S4). The lowest interobserver agreement was observed with the IVH score (κ = 0.69; 95% CI, 0.56–0.83).

Multivariate analysis of CT grading systems and clinical parameters

A multivariate analysis was performed including the significant factors ‘clinical grade’ and ‘age’ from the univariate analysis (Table 3). Only SAPS II (adjusted odds ratio per unit, 1.06; 95% CI, 1.03–1.10; p < 0.001) and rebleeding (odds ratio, 9.29; 95% CI, 2.19–52.60; p = 0.01) were associated with poor outcome. The Hijdra scale was the only variable with significant prognostic value for the presence of DCI (adjusted odds ratio per unit, 1.18; 95% CI, 1.10–1.27; p < 0.001). IVH score was the most significant predictor for the occurrence of early hydrocephalus (odds ratio, 1.49; 95% CI, 1.22–1.85; p < 0.001). Of interest, SAPS II was significantly associated with early hydrocephalus occurrence (adjusted odds ratio per unit, 1.04; 95% CI, 1.00–1.07; p = 0.04), whereas a clipping procedure was protective against early hydrocephalus (odds ratio, 0.27; 95% CI, 0.090.76; p = 0.02).

Table 3

Multivariate Statistical analysis of Significant Risk Factors for Poor Patient Outcome (GOSE 1–4), Delayed Cerebral Infarction (DCI) and Early Hydrocephalus Requiring EVD.

		Poor outcome		**DCI†**		**Early hydrocephalus**	
	Numerical values*	Odds ratio [95% CI]	P value	Odds ratio [95% CI]	P value	Odds ratio [95% CI]	P value
SAPS II	0–163	1.06 [1.03–1.10]	< 0.001	0.99 [0.96–1.02]	0.61	1.04 [1.00–1.07]	0.04
Clipping	0, 1	2.09 [0.82 – 5.43]	0.12	0.72 [0.25–2.02]	0.53	0.27 [0.09–0.76]	0.02
Rebleeding	0, 1	9.29 [2.19 – 52.6]	0.01	0.94 [0.22–3.80]	0.93	3.83 [0.92–19.1]	0.08
Hijdra scale	0–42	1.03 [0.97–1.10]	0.38	1.18 [1.10–1.27]	< 0.001	1.02 [0.96–1.09]	0.47
IVH score	0–23	0.91 [0.75–1.10]	0.32	0.84 [0.70–1.00]	0.06	1.49 [1.22–1.85]	< 0.001
* 0 = no, 1 = yes.							
†Data for DCI were collected from a group of 200 patients (30 patients who died before day 7 were excluded).							
Boldface values represent significant findings assumed at p values of 0.05 and below.							
The odds ratio is to be interpreted as follows: for example, for each point increase in SAPS II, the risk for poor outcome increases by 6% (95% CI, 3–10%).							
CI denotes confidence interval; IVH, intraventricular haemorrhage; and SAPS II, Simplified Acute Physiologic Score.							

Discussion

Many studies have compared clinical grading scales such as the Hunt and Hess scale, WFNS, and Glasgow Coma Scale for predicting unfavourable outcome in aSAH [29, 30]. To our knowledge, however, this study is the first to compare eight radiological scales, grading subarachnoid or ventricular haemorrhage or both for the prediction of DCI, acute hydrocephalus, and functional outcome at 3 months in a large aSAH population. We identified a 39% rate of DCI in our aSAH population, in agreement with studies using a modern definition of DCI [31]. As previously reported, the Fisher scale failed to predict vasospasm or DCI occurrence, with both poor sensitivity and poor specificity [6, 7, 9, 10]. We confirmed

that the Fisher scale could not predict any of the three outcome measures. We note that in our ICU population, 91% of all patients were classified Fisher grade 3–4, which may have confounded statistical analysis.

The Hijdra scale was the most effective scale for predicting DCI, with an ideal cut-off of 20/42 and excellent interobserver agreement. This scale has been studied mostly for its association with functional outcome and has been found to be superior to the Fisher scale [12, 32]. Dupont et al [33] also reported that a Hijdra score ≥ 23 was strongly associated with the occurrence of vasospasm, and our findings show a strong association of Hijdra score with DCI. The design of the grading system may explain these results. Because DCI development and outcome correlate with the amount of blood on CT scan [4, 5, 7, 9, 33, 34], grading every cistern and every ventricle likely assesses the overall bleeding with greater precision than other scales. Despite its apparent complexity, the Hijdra scale had a good reliability, and we found an excellent interobserver agreement for it [12, 35, 36]. Of interest, both sensitivity and specificity were increased in a WFNS 1–2 subpopulation. In fact, with an ideal cut-off of 18/42, the Hijdra scale had 88% sensitivity and 69% specificity for DCI prognosis (only 4/54 patients had DCI with a Hijdra scale score < 18/42). Associated with clinically predictive factors such as smoking, history of diabetes, and hypertension [31], the Hijdra scale could help physicians to better predict DCI occurrence and determine the most appropriate hospitalization unit for these aSAH patients.

Acute hydrocephalus is a frequent complication after brain aneurysm rupture [37–39]. In our ICU population, 53% patients needed an EVD. We found that the IVH score best predicted acute hydrocephalus requiring EVD. Moreover, this score stood out from the Graeb and Leroux scores by allowing for reliable estimation of intraventricular bleeding volume [17]. In a 2012 study, Hwang et al found that the IVH score could reliably predict poor neurological outcome, which was associated with an estimated IVH volume > 6 mL [40]. Recently, the interval to blood clearance in the basal cisterns and peripheral subarachnoid spaces has been associated with shunt dependency. In this study, patients with a shorter interval of blood clearance required a shorter duration of shunt use than other patients [41]. Thus, accurate evaluation of blood volume on CT scans using quantitative scales or automated computer blood quantification could be useful for aSAH management [42].

SAPS II was the best predictor of poor outcome at 3 and 6 months in our study. This score was generated from a cohort of medical and surgical ICU patients and was not intended to assess mortality in neurological patients. This expected finding illustrates the importance of clinical variables included in the SAPS II scale, particularly age and initial Glasgow Coma Scale score [23]. Indeed, the initial neurological assessment by means of the Glasgow Coma Scale or WFNS scale is a crucial determinant for neurological outcome and death [22, 29, 43, 44]. New grading scales using both clinical and radiological scores (SAFIR grading scale [45], Southwestern Severity Index [46]) have shown promising results but always use Fisher scale, which is not sufficiently reliable. Future composite scores should include the Hijdra scale to improve accuracy. Because of its complex and time-consuming nature, an automated approach to the Hijdra scale could be developed to facilitate clinical use [42].

The main limitation of this study arises from its retrospective nature with accordingly lower accuracy and lower completeness of the recorded data, compared to a prospectively collected cohort. Consequently, some degree of bias is inevitable. To avoid some of this inherent bias, the two observers analysing the CT scans were blinded to clinical outcome and DCI occurrence. Our cohort included neurological ICU patients. Consequently, the less severely ill patients, who probably had the lowest amounts of blood and lowest risk for DCI, were likely not included. Finally, the exclusion of patients with non-aneurysmal haemorrhage (peri-mesencephalic, traumatic, or arteriovenous malformation) biased the data toward a relatively high overall risk of DCI and poor outcome. Nevertheless, DCI occurred in 39% of patients, which is comparable to proportions in other recent studies [31].

Conclusion

Radiological grading of SAH is useful for predicting DCI risk. Among these scales, the Hijdra scale seems to be the most effective at predicting the occurrence of DCI. An automated computer quantification approach for this scale could facilitate its daily use. This evaluation associated with clinical predictive values could help physicians better use critical care resources for these patients.

Declarations

Ethical approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki and approved by the Ethics Committee (Comité d'éthique pour la recherche en Anesthésie-Réanimation - IRB 000102542019081), which waived the requirement for individual consent according to French law at the time of the study.

Consent for publication

Not applicable. No consent for publication was requested for this study in accordance to French law at the time of the study

Availability of supporting data

The anonymized datasets analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

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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Authors' contributions

Along with the first author (DC), PS and LV made substantial contributions to the conception and design, acquisition of data, and analysis and interpretation of data; TG, HD, OM, and NB were involved in drafting the manuscript and revising it critically for important intellectual content; SM and SB participated in designing and performing the statistical analyses; AA, DC, and LG were involved in data collection and preparation of the report. AR, HB, and ND assisted in the evaluation of the radiographic data. All authors read and approved the final manuscript.

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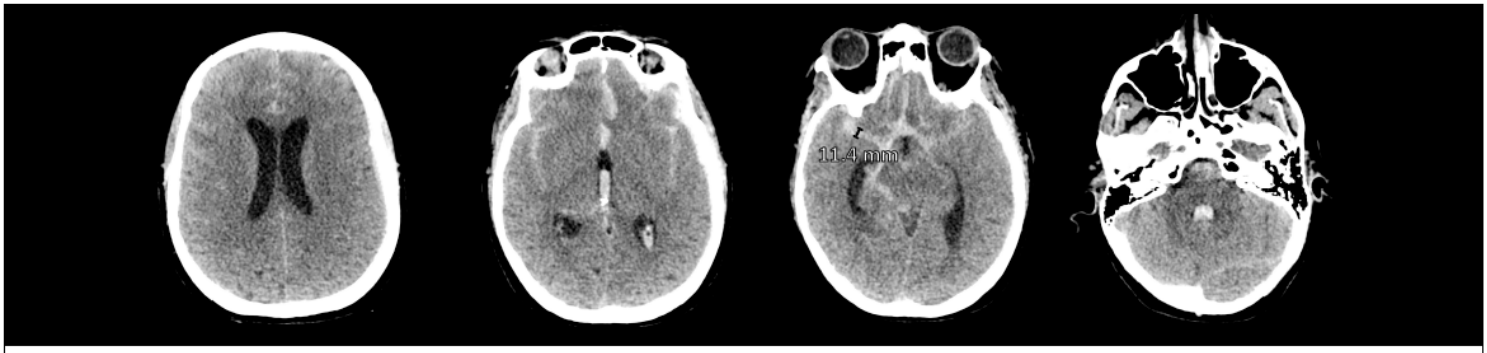
Figures



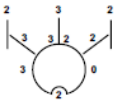
Grading systems	Fisher	modified Fisher	Claassen	BNI	Hijdra	Graeb	LeRoux	IVH
Result	4	4	3	4	28	4	8	2 (1.5ml)
Rational	SAH with IVH	Thick SAH with IVH	Thick SAH with no IVH in both lateral Ventricles	Right Sylvian fissure clot >10mm	 Subarachnoid: 22 Intraventricular: 6 Total Score: 28	Left ventricle: trace of blood (1) Right ventricle: no blood (0) Third ventricle : blood present, size normal (1) Fourth ventricle : filled with blood and expended (2)	Left ventricle: trace of blood (1) Right ventricle: no blood (0) Third ventricle : > 50% filled of blood (3) Fourth ventricle : Completely filled and expanded (4)	Left ventricle: small amount of layering (0) Right ventricle : no blood (0) Third ventricle : Partially or completely filled (1) Fourth ventricle : Completely filled and expanded (1) Hydrocephalus: Absent (0)

Figure 1

Illustration of the eight CT-scan based grading systems from patient 6 hours after subarachnoid haemorrhage from anterior communicating artery aneurysm.

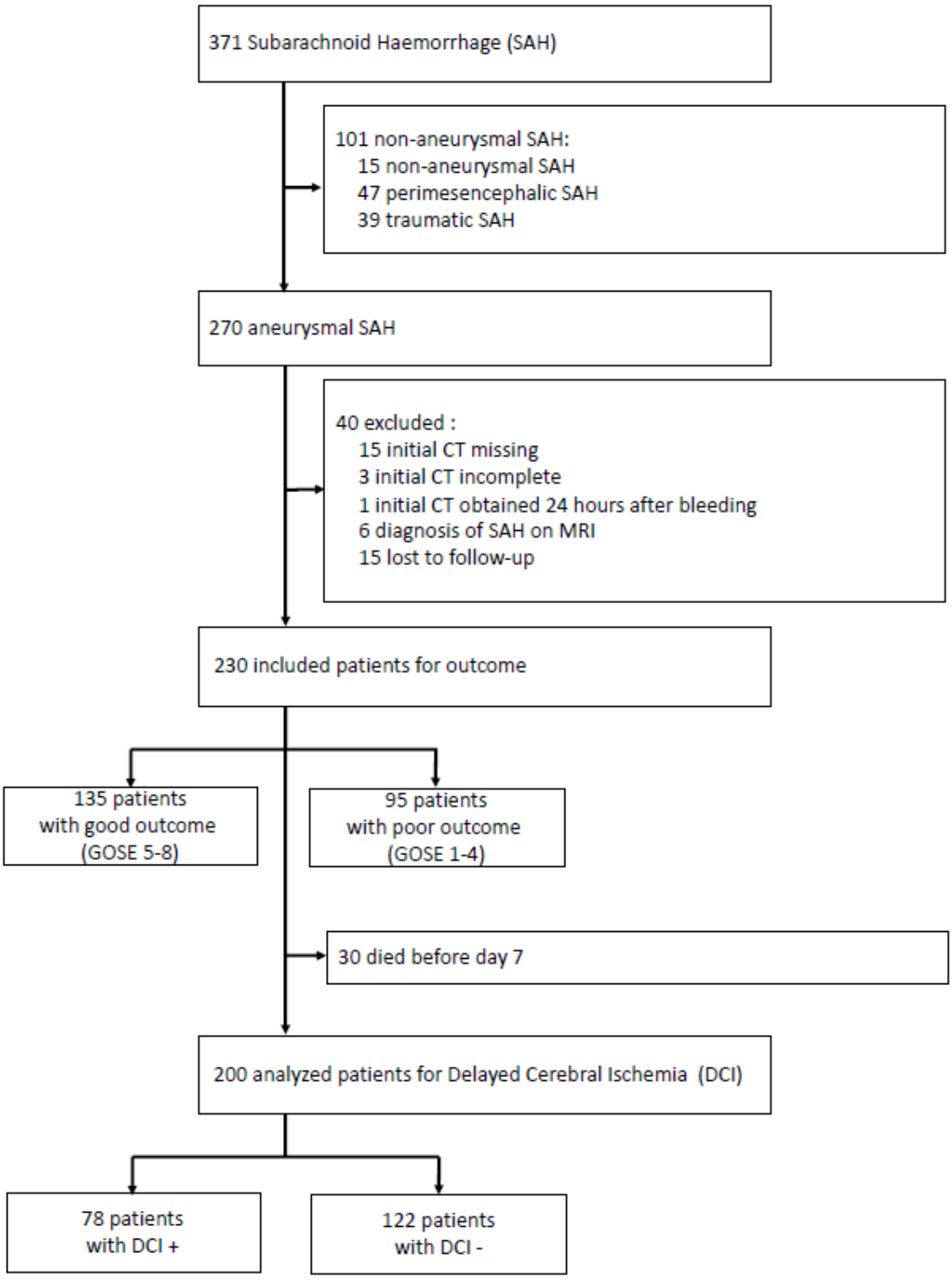


Figure 2

Flow of patients with subarachnoid haemorrhage (SAH) within this cohort. CT denotes computerized tomography; DCI, Delayed Cerebral Infarction; GOSE, Glasgow Outcome Scale Extended and MRI, Magnetic resonance imaging.

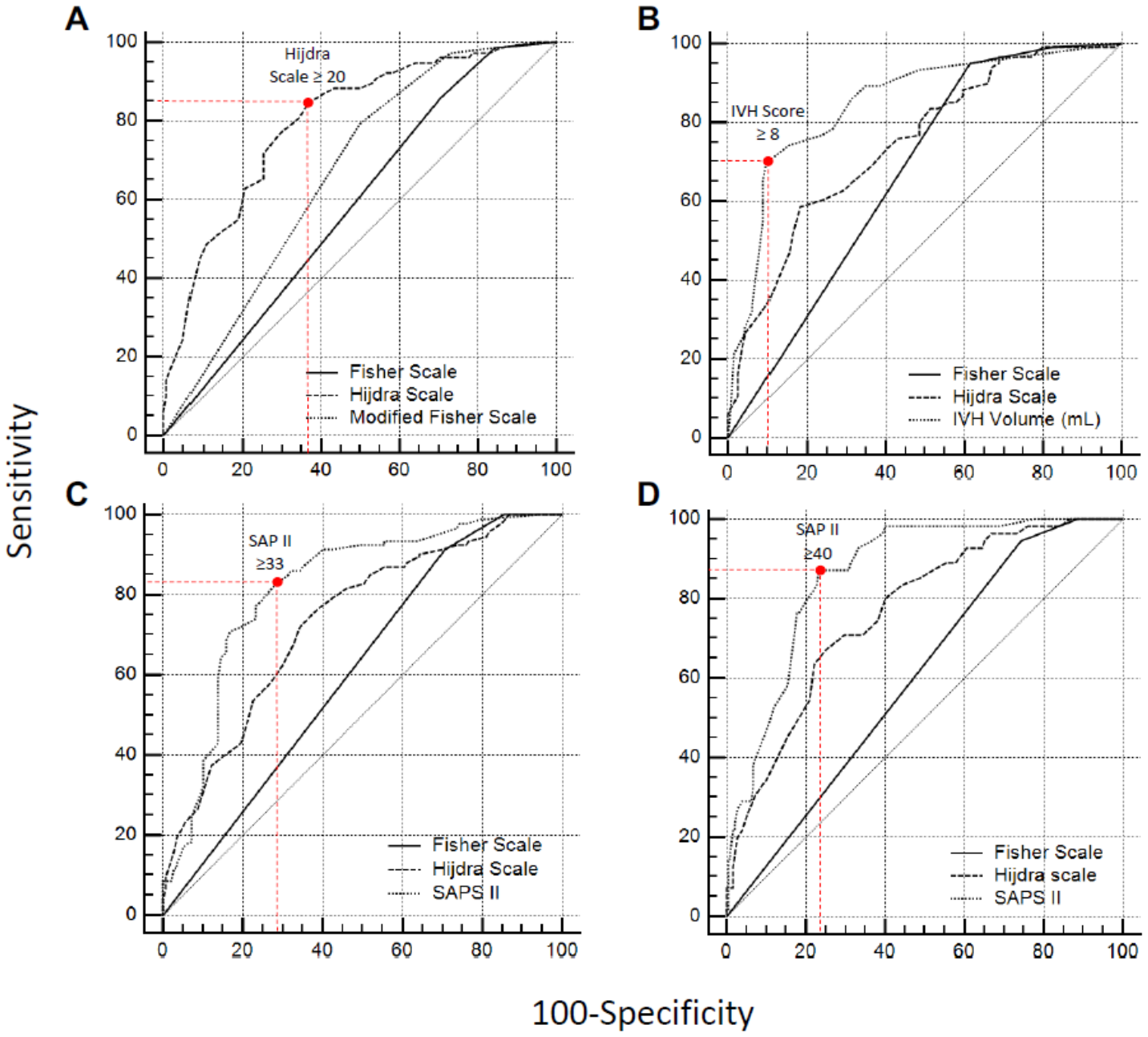


Figure 3

ROC curves for the different qualitative, semi-quantitative, and quantitative measures used for determining the development of delayed cerebral infarction (A), poor outcome (B) death (C) and early hydrocephalus requiring external ventricular drain (D).

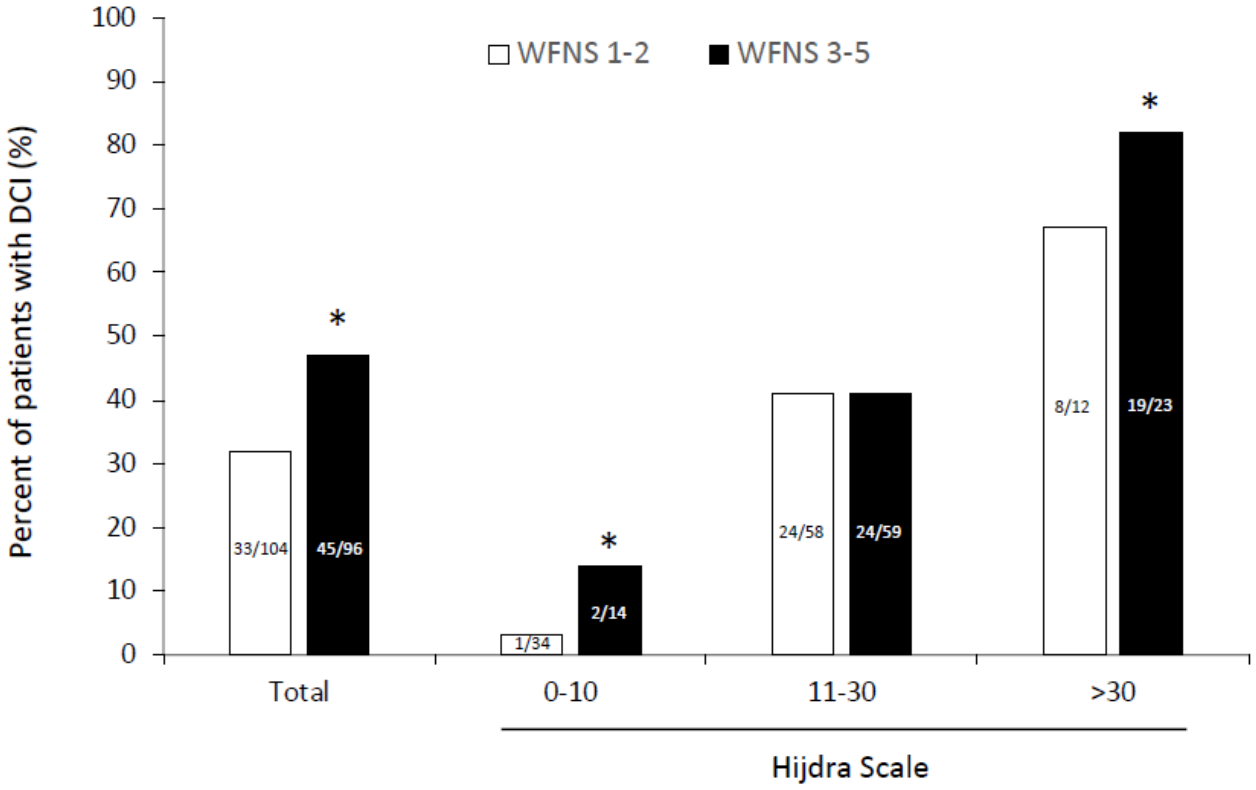


Figure 4

Occurrence of DCI in low-severity aSAH (WFNS 1-2, white bar) and high-severity aSAH (WFNS 3–5, black bar) for the total population and grouped by Hijdra score <10, 10–30, and >30. * $p < 0.05$, WFNS1-2 vs WFNS 3–5.

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