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Risk Factors and Preoperative Risk Scoring System for Shunt-Dependent Hydrocephalus Following Aneurysmal Subarachnoid Hemorrhage

Joo Hyun Kim, Jae Hoon Kim, Hee In Kang, Deok Ryeong Kim, Byung Gwan Moon, Joo Seung Kim

Department of Neurosurgery, Eulji University Eulji Hospital, Seoul, South Korea

Objective : Shunt-dependent hydrocephalus (SdHCP) is a well-known complication of aneurysmal subarachnoid hemorrhage (SAH). The risk factors for SdHCP have been widely investigated, but few risk scoring systems have been established to predict SdHCP. This study was performed to investigate the risk factors for SdHCP and devise a risk scoring system for use before aneurysm obliteration.

Methods : We reviewed the data of 301 consecutive patients who underwent aneurysm obliteration following SAH from September 2007 to December 2016. The exclusion criteria for this study were previous aneurysm obliteration, previous major cerebral infarction, the presence of a cavum septum pellucidum, a midline shift of >10 mm on initial computed tomography (CT), and in-hospital mortality. We finally recruited 254 patients and analyzed the following data according to the presence or absence of SdHCP : age, sex, history of hypertension and diabetes mellitus, Hunt-Hess grade, Fisher grade, aneurysm size and location, type of treatment, bicaudate index on initial CT, intraventricular hemorrhage, cerebrospinal fluid drainage, vasospasm, and modified Rankin scale score at discharge.

Results : In the multivariate analysis, acute HCP (bicaudate index of ≥0.2) (odds ratio [OR], 6.749; 95% confidence interval [CI], 2.843–16.021; p=0.000), Fisher grade of 4 (OR, 4.108; 95% CI, 1.044–16.169; p=0.043), and an age of ≥50 years (OR, 3.938; 95% CI, 1.375–11.275; p=0.011) were significantly associated with the occurrence of SdHCP. The risk scoring system using above parameters of acute HCP, Fisher grade, and age (AFA score) assigned 1 point to each (total score of 0–3 points). SdHCP occurred in 4.3% of patients with a score of 0, 8.5% with a score of 1, 25.5% with a score of 2, and 61.7% with a score of 3 (p=0.000). In the receiver operating characteristic curve analysis, the area under the curve (AUC) for the risk scoring system was 0.820 (p=0.080; 95% CI, 0.750–0.890). In the internal validation of the risk scoring system, the score reliably predicted SdHCP (AUC, 0.895; p=0.000; 95% CI, 0.847–0.943).

Conclusion : Our results suggest that the herein-described AFA score is a useful tool for predicting SdHCP before aneurysm obliteration. Prospective validation is needed.

Key Words : Aneurysm · Hydrocephalus · Subarachnoid hemorrhage · Ventriculoperitoneal shunt.

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• Address for reprints : **Jae Hoon Kim**
Department of Neurosurgery, Eulji University Eulji Hospital, 68 Hangeulbiseok-ro, Nowon-gu, Seoul 01830, Korea
Tel : +82-2-970-8268, Fax : +82-2-979-8268, E-mail : grimi2@eulji.ac.kr, ORCID : https://orcid.org/0000-0002-9179-8569

INTRODUCTION

The incidence of shunt-dependent hydrocephalus (SdHCP) after aneurysmal subarachnoid hemorrhage (SAH) ranges from 14% to 47%[1,2,4,12,14,17,20,23]. The risk factors for SdHCP have been widely investigated, and a recent meta-analysis demonstrated that age, Hunt-Hess grade at admission, Fisher grade, acute HCP or external ventricular drainage (EVD) challenge, in-hospital complications, intraventricular hemorrhage (IVH), rebleeding, and posterior circulation aneurysm were significantly correlated with the risk of SdHCP[18]. However, some factors have shown contradictory results, and this discrepancy may be attributed to the heterogeneity of study designs and populations.

Some investigators recently suggested the use of risk scoring systems for predicting SdHCP[4,9,12]. Although these scoring systems are systematic and validated, their parameters are heterogeneous and somewhat complex.

The aim of this study was to identify independent predictive factors for SdHCP in a large series and devise a simple and reliable scoring system for use before aneurysm obliteration to help early identification of patients who require permanent shunt and thus, decrease the length of hospital stay, EVD procedure, and associated complications[9,22].

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board (EMCIRB 17-109). We reviewed 301 consecutive patients who underwent aneurysm obliteration following SAH from September 2007 to December 2016. The exclusion criteria for this study were previous aneurysm obliteration, previous major cerebral infarction, the presence of a cavum septum pellucidum, midline shift of >10 mm on initial computed tomography (CT), and in-hospital mortality (Fig. 1). We finally recruited 254 patients.

We retrospectively analyzed the following data : age, sex, history of hypertension and diabetes mellitus, Hunt-Hess grade, Fisher grade, aneurysm size and location, type of treatment (clipping or coiling), bicaudate index (BCI) on initial CT scan, IVH, cerebrospinal fluid (CSF) drainage (EVD or lumbar drainage), vasospasm, modified Rankin scale (mRS) score at discharge, and SdHCP. Aneurysm size was categorized as <5 mm, 5 to 10 mm, and >10 mm. The BCI was defined as the ratio of the width of the frontal horns at the level of the caudate nucleus to the distance of the brain at the foramen of Monro[7]. We considered a BCI of ≥0.2 as acute HCP regardless of patient's clinical symptoms. Cerebral vasospasm was defined as the highest mean velocity of the middle cerebral artery of >150 cm/s or a Lindegaard ratio of >3 on transcranial Doppler ultrasonography. A favorable outcome was defined as a mRS score of 0 to 2. For interpretation purposes, we dichotomized other variables as follows : age at 50 years (<50 vs. ≥50 years), Hunt-Hess grade at 4 (grade 1–3 vs. 4–5), Fisher grade at 4 (grade 1–3 vs. 4), and aneurysm location as anterior (anterior cerebral artery, internal cerebral artery, and middle cerebral artery) vs. posterior (vertebrobasilar) circulation.

Statistical analysis

Continuous variables are presented as mean (with standard deviation) and range, and categorical variables are presented as number of cases. For comparison of baseline variables, the chi-square test and Fisher's exact test were used for categorical variables, and Student's t-test was used for continuous variables. The significant factors in the univariate analysis ($p<0.05$) were entered into a multivariate logistic regression analysis. A probability value of <0.05 was considered statistically significant. Receiver operating characteristic curve analysis was performed to validate the risk scoring system. The predictability of the scoring system was assessed by the value of the area under the curve (AUC).

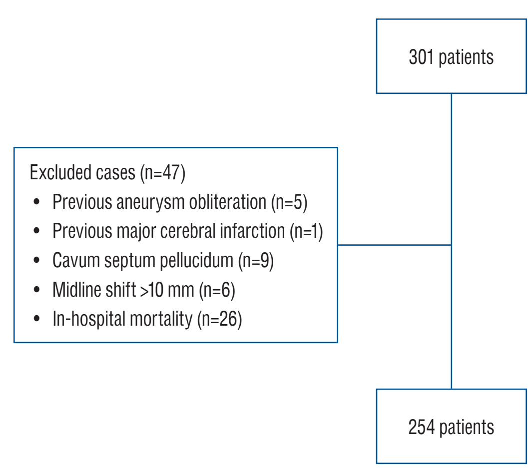

Fig. 1. Flow chart showing exclusion criteria of study population.

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Table 1. Analysis of factors between patients with and without SdHCP

Variable	SdHCP (n=47)	No SdHCP (n=207)	*p*-value
Male sex	15 (31.9)	59 (28.5)	0.642
Age (years)	63.7±10.3	53.4±12.0	0.000
≥50 years	42 (89.4)	122 (58.9)	0.000
Hypertension	21 (44.7)	64 (30.9)	0.071
Diabetes mellitus	10 (21.3)	143 (69.1)	0.013
Hunt-Hess grade			0.000
Grade 1, 2, 3	31 (66.0)	181 (87.4)	
Grade 4, 5	16 (34.0)	26 (12.6)	
Fisher grade			0.000
Grade 1, 2, 3	9 (19.1)	117 (56.5)	
Grade 4	38 (80.9)	90 (43.5)	
Location 1			0.651
ACA	20 (42.6)	79 (38.2)	
ICA	15 (31.9)	59 (28.5)	
MCA	8 (17.0)	53 (25.6)	
VBS	4 (8.5)	16 (7.7)	
Location 2			0.771
Anterior (ACA, ICA, MCA)	43 (91.5)	191 (92.3)	
Posterior (VBS)	4 (8.5)	16 (7.7)	
Size (mm)			0.001
<5	12 (25.5)	110 (53.1)	
5–10	30 (63.8)	78 (37.7)	
>10	5 (10.6)	19 (9.2)	
Treatment			0.517
Clipping	29 (61.7)	138 (66.7)	
Coiling	18 (38.3)	69 (33.3)	
BCI	0.22±0.05	0.16±0.04	0.000
Acute HCP (BCI ≥0.2)	35 (74.5)	50 (24.2)	0.000
IVH	34 (72.3)	70 (33.8)	0.000
CSF drainage	34 (72.3)	66 (31.9)	0.000
Vasospasm	6 (12.8)	19 (9 .2)	0.425
mRS score			0.000
Favorable	28 (59.6)	190 (91.8)	
Unfavorable	19 (40.4)	17 (8.2)	

Values are presented as mean±standard deviation or number (%). SdHCP : shunt-dependent hydrocephalus, ACA : anterior cerebral artery, ICA : internal carotid artery, MCA : middle cerebral artery, VBS : vertebrobasilar system, BCI : bicaudate index, HCP : hydrocephalus, IVH : intraventricular hemorrhage, CSF : cerebrospinal fluid, mRS : modified Rankin scale

RESULTS

We included 254 patients (180 women, 70.9%) with a mean age of 55.3±12.3 years (range, 22–90). A summary of the patients' demographic and clinical characteristics is shown in Table 1. SdHCP occurred in 47 patients (18.5%). Age of ≥50 years, diabetes mellitus, higher Hunt-Hess grade (4–5), Fisher grade 4, larger aneurysm, higher BCI, IVH, CSF drainage, and poorer mRS scores were significantly associated with SdHCP in the univariate analysis (Table 1). Acute HCP (BCI of ≥0.2), Fisher grade 4, and age of ≥50 years were significantly associated with the occurrence of SdHCP in the multivariate analysis (Table 2).

Risk scoring system

Based on the results of the multivariate logistic regression analysis, the risk scoring system, referred to as the "AFA score", consisted of the following parameters : acute HCP (BCI of ≥0.2) (1 point), Fisher grade 4 (1 point), and age of ≥50 years (1 point); thus, the total score ranged from 0 to 3 points (Table 3). SdHCP occurred in 4.3% of patients with a score of 0, 8.5% with a score of 1, 25.5% with a score of 2, and 61.7% with a score of 3 (p=0.000) (Table 4). In the receiver operating characteristic curve analysis, the AUC for the risk scoring sys-

Table 2. Multivariate analysis of factors related to SdHCP

Variable	OR	95% CI	*p*-value
Age of ≥50 years	3.938	1.375–11.275	0.011
Diabetes mellitus	1.931	0.688–5.425	0.212
Hunt-Hess grade 4 or 5	2.040	0.846–4.921	0.112
Fisher grade 4	4.108	1.044–16.169	0.043
Acute HCP (BCI ≥0.2)	6.749	2.843–16.021	0.000
IVH	1.539	0.411–5.763	0.522

SdHCP : shunt-dependent hydrocephalus, OR : odds ratio, CI : confidence interval, HCP : hydrocephalus, BCI : bicaudate index, IVH : intraventricular hemorrhage

Table 3. AFA risk scoring system for preoperative prediction of SdHCP

Parameter	OR	Score
Acute HCP (BCI ≥0.2)	6.749	1
Fisher grade 4	4.108	1
Age (age of ≥50 years)	3.938	1

SdHCP : shunt-dependent hydrocephalus, OR : odds ratio, HCP : hydrocephalus, BCI : bicaudate index tem was 0.820 (p=0.080; 95% confidence interval [CI], 0.750–0.890) (Fig. 2). We performed internal validation of the AFA score using another cohort (175 patients with aneurysmal SAH from January 2001 to August 2007). SdHCP occurred in 0.0% of patients with a score of 0, 2.9% with a score of 1, 34.3% with a score of 2, and 62.9% with a score of 3 (p=0.000) (Table 5). The AUC was 0.895 (p=0.000; 95% CI, 0.847–0.943) (Fig. 2).

DISCUSSION

In the current study, we found that acute HCP (BCI of ≥0.2), Fisher grade of 4, and an age of ≥50 years were independent risk factors on the development of SdHCP following aneurysmal SAH. Additionally, the AFA score reliably predicted the occurrence of SdHCP before aneurysm treatment.

Patients with aneurysmal SAH aged >50 years had a 4-fold higher rate of SdHCP compared with younger patients (odds ratio, 3.938; 95% CI, 1.375–11.275). This finding is consistent with those of recent studies[1,2,5,13,14,17,22,23]. Although each study used a different cut-off value for age, a recent meta-analysis found an increased risk of SdHCP in patients aged >50 years[21]. The precise mechanism is not fully understood, but

Table 4. Relationship between AFA score and SdHCP

AFA score	SdHCP	No SdHCP	*p*-value
0	2 (4.3)	46 (22.2)	0.000
1	4 (8.5)	80 (38.6)	
2	12 (25.5)	61 (29.5)	
3	29 (61.7)	20 (9.7)	
0–1	6 (12.8)	126 (60.9)	0.000
2–3	41 (87.2)	81 (39.1)	

Values are presented as number (%). SdHCP : shunt-dependent hydrocephalus

Table 5. Internal validation of relationship between AFA score and SdHCP (175 patients with aneurysmal subarachnoid hemorrhage from January 2001 to August 2007)

AFA score	SdHCP	No SdHCP	*p*-value
0	0 (0.0)	48 (34.3)	0.000
1	1 (2.9)	54 (38.6)	
2	12 (34.3)	25 (17.9)	
3	22 (62,9)	13 (9.3)	
0–1	1 (2.9)	102 (72.9)	0.000
2–3	34 (97.1)	38 (27.1)	

Values are presented as number (%). SdHCP : shunt-dependent hydrocephalus

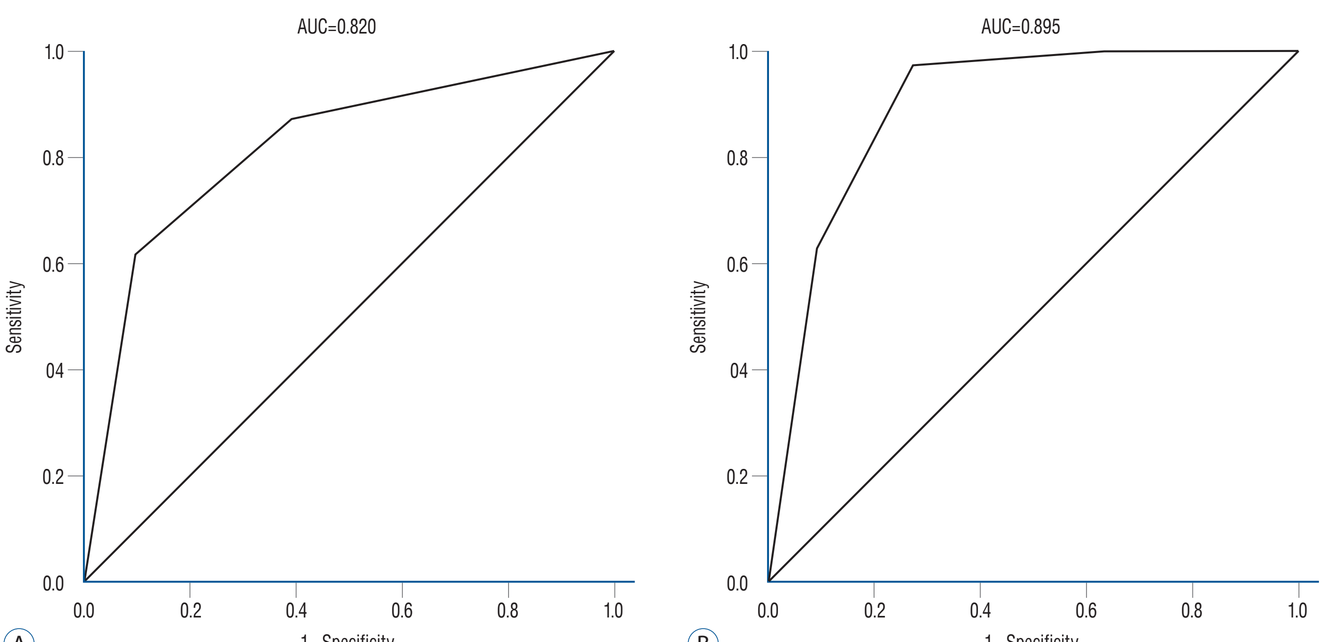

Fig. 2. The receiver operating characteristic curve of preoperative AFA scores predicting shunt-dependent hydrocephalus in study population (A) and previous cohort (B). AUC : the area under the curve.

aging may accelerate an increase in the CSF compartment due to brain atrophy and a reduction of CSF turnover due to accumulation of brain metabolites[10,16]. SdHCP was more frequently occurred in patients with a Fisher grade of 4 in our cohort. Many studies have shown that a higher Fisher grade (3 and 4) was a strong predictive factor for shunt dependency[1,12,22,23]. This finding can be explained by the fact that blood clots in the ventricular system or subarachnoid space disturb CSF circulation and impair CSF absorption at the arachnoid villi. Additionally, recent experiments have shown that thrombin and transforming growth factor-β1 released after SAH induce ventricular dilatation, ependymal cell damage, and subarachnoid meningeal fibrosis and play role in the development of HCP[8,11]. In our subgroup analysis, the presence of intracerebral hemorrhage was the only significant factor in the patients aged <50 years (data not shown). This result implies that the pathogenetic mechanism of SdHCP differs somewhat depending on age. The BCI is a practically useful tool for assessing linear ventricle size[6]. Although the BCI varies with age, many investigators have adapted this index to quantitatively assess HCP[3-5,15]. Accordingly, we defined HCP as a BCI of ≥0.2 and excluded patients with a cavum septum pellucidum to reduce the false-positive rate. Previous studies have demonstrated that patients with SdHCP show poorer clinical outcomes[1,4,17,23]. Consistent with these findings, SdHCP was significantly associated with unfavorable clinical outcomes in our series (40.4% vs. 8.2%, p=0.000).

We propose use of the herein-described preoperative risk scoring system based on acute HCP (1 point), Fisher grade of 4 (1 point), and an age of ≥50 years (1 point). This AFA scoring system reliably predicted SdHCP. We validated the AFA scoring system in another cohort (175 patients with aneurysmal SAH with the same inclusion criteria from January 2001 to August 2007). The AFA scoring system showed significant predictability in this cohort (AUC, 0.895; 95% CI, 0.847–0.943). Some investigators recently devised a scoring system to predict SdHCP after aneurysmal SAH[4,9,12]. The CHESS score is somewhat complex, and the definition of acute HCP is subjective[9]. The diagnosis of acute HCP was made according to generally acknowledged clinical and radiological criteria. However, it may be difficult to distinguish clinical deterioration due to SAH from that due to acute HCP. Moreover, there is no explanation of how early cerebral infarction is associated with SdHCP. Whether a posterior location of a ruptured aneurysm is a risk factor for SdHCP remains controversial. We found no significant association between the location of the ruptured aneurysm and SdHCP. Motiei-Langroudi et al.[12] suggested a scoring system consisting of EVD insertion, Hunt-Hess grade, and modified Fisher grade. However, the indication for EVD insertion could differ among institutions or attending neurosurgeons. In the SDASH scoring system, the authors used the Barrow Neurological Institute (BNI) to predict SdHCP[4,19]. The BNI was originally devised to predict cerebral vasospasm, like the Fisher grade. Although a previous study reported that the BNI was associated with the development of SdHCP, the BNI has not been used universally.

Our study has certain limitations apart from those inherent to retrospective studies. This was a single-center study, and the results must therefore be validated externally to prove their applicability in a prospectively collected cohort. The decision to perform a shunt procedure is not uniform among institutions and clinicians, possibly resulting in selection bias. In the method to assign a point to each predictor, we simply assigned 1 point to each predictor based on the OR, not the corresponding regression coefficient. This may lead to different overall scores, and thus decrease discriminative ability of the scoring system. Therefore, we validated the scoring system through the receiver operating characteristic curve analysis to overcome this drawback. Additionally, some patients could not undergo a shunt procedure because of their poor clinical condition or loss to follow-up.

CONCLUSION

The AFA risk scoring system is a simple and useful tool to assess the risk of SdHCP based on demographic and clinical data before aneurysm treatment. We have internally validated its usefulness. Additional external validation will be needed before this risk scoring system is universally adopted.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

INFORMED CONSENT

This type of study does not require informed consent.

AUTHOR CONTRIBUTIONS

Conceptualization : JHK, JHK, DRK
Data curation : JHK, JHK
Formal analysis : JHK, JHK
Methodology : JHK, JHK, BGM
Project administration : JHK, JHK
Visualization : JHK, JHK
Writing - original draft : JHK, JHK
Writing - review & editing : JHK, JHK, HIK, JSK

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