Shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage

- Post-traumatic hydrocephalus after decompressive craniectomy: a multidimensional analysis of clinical, radiological, and surgical risk factors
- Cerebrospinal fluid analysis and changes over time in patients with subarachnoid hemorrhage: a prospective observational study
- Serum uric acid is associated with shunt dependent hydrocephalus of aneurysmal subarachnoid hemorrhage patients
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Chronic communicating hydrocephalus following aneurysmal subarachnoid hemorrhage (aSAH), requiring permanent cerebrospinal fluid (CSF) diversion, typically via a ventriculoperitoneal (VP) shunt.

Clinical Features

- Headache
- Cognitive impairment
- Gait disturbance (magnetic gait)
- Urinary incontinence
- Symptoms often overlap with normal pressure hydrocephalus (NPH)

Incidence & Risk Factors

Incidence

- Occurs in ~15–30% of aSAH patients

Risk Factors

- Poor initial clinical grade (Hunt-Hess IV–V)

- Thick subarachnoid clot (Fisher grade III–IV)
- Intraventricular hemorrhage (IVH)
- Acute hydrocephalus requiring EVD
- Older age
- Posterior circulation aneurysm
- EVD-related infection

Pathophysiology

- Impaired CSF absorption due to fibrosis of arachnoid villi
- Obstruction of CSF pathways by blood products
- Inflammatory response and scarring in the subarachnoid space

Diagnosis

- CT/MRI showing ventricular enlargement (Evans index > 0.3)
- Clinical triad: gait disturbance, cognitive decline, urinary symptoms
- Failure to wean from EVD

Management

- *Temporary CSF Diversion: * **External Ventricular Drain (EVD)** * **Lumbar punctures or lumbar drains in selected cases** Permanent CSF Diversion: * **Ventriculoperitoneal (VP) shunt (preferably programmable valve)** Alternatives:**
- Endoscopic third ventriculostomy (ETV) rarely used in communicating hydrocephalus

Systematic review and meta-analysis

A systematic search was conducted using PubMed and Embase databases for studies pertaining to aSAH and SDHC. Articles were assessed by meta-analysis if the number of risk factors for SDHC was reported by >4 studies and could be extracted separately for patients who did or did not develop SDHC.

Results: Thirty-seven studies were included, comprising 12,667 patients with aSAH (SDHC 2214 vs. non-SDHC 10,453). In a primary analysis of 15 novel potential risk factors, 8 were identified to be significantly associated with increased prevalence of SDHC after aSAH, including high World Federation of Neurological Surgeons grades (odds ratio [OR], 2.43), hypertension (OR, 1.33), anterior cerebral artery (OR, 1.36), middle cerebral artery (OR, 0.65), and vertebrobasilar artery (2.21) involvement, decompressive craniectomy (OR, 3.27), delayed cerebral ischemia (OR, 1.65), and intracerebral hematoma (OR, 3.91).

Conclusions: Several new factors associated with increased odds of developing SDHC after aSAH were found to be significant. By providing evidence-based risk factors for shunt dependency, we describe an identifiable list of preoperative and postoperative prognosticators that may influence how

surgeons recognize, treat, and manage patients with aSAH at high risk for developing SDHC [1].

Prospective cohort studies

The relationships between osteopontin (OPN) expression and chronic shunt-dependent hydrocephalus (SDHC) have never been investigated. In 166 Aneurysmal Subarachnoid Hemorrhage patients (derivation and validation cohorts, 110 and 56, respectively), plasma OPN levels were serially measured at days 1-3, 4-6, 7-9, and 10-12 after aneurysmal obliteration. The OPN levels and clinical factors were compared between patients with and without subsequent development of chronic SDHC. Plasma OPN levels in the SDHC patients increased from days 1-3 to days 4-6 and remained high thereafter, while those in the non-SDHC patients peaked at days 4-6 and then decreased over time. Plasma OPN levels did not correlate with serum levels of C-reactive protein (CRP), a systemic inflammatory marker. Univariate analyses showed that age, modified Fisher scale, acute hydrocephalus, cerebrospinal fluid drainage, and OPN and CRP levels at days 10-12 were significantly different between patients with and without SDHC. Multivariate analyses revealed that higher plasma OPN levels at days 10-12 were an independent factor associated with the development of SDHC, in addition to the more frequent use of cerebrospinal fluid drainage and higher modified Fisher grade at admission. Plasma OPN levels at days 10-12 maintained similar discrimination power in the validation cohort and had good calibration on the Hosmer-Lemeshow goodness-of-fit test. Prolonged higher expression of OPN may contribute to the development of post-SAH SDHC, possibly by excessive repairing effects promoting fibrosis in the subarachnoid space [2].

Prognostic studies

ML models were trained for CHESS and SDASH and two combined individual feature sets with clinical, radiographic, and laboratory variables. Seven different algorithms were used including three types of generalized linear models (GLM) as well as a tree boosting (CatBoost) algorithm, a Naive Bayes (NB) classifier, and a multilayer perceptron (MLP) artificial neural net. The discrimination of the area under the curve (AUC) was classified ($0.7 \leq AUC < 0.8$, acceptable; $0.8 \leq AUC < 0.9$, excellent; $AUC \geq 0.9$, outstanding). Of the 292 patients included with aSAH, 28.8% (n = 84) developed SDHC. Non-ML-based prediction of SDHC produced an acceptable performance with AUC values of 0.77 (CHESS) and 0.78 (SDASH). Using combined feature sets with more complex variables included than those incorporated in the scores, the ML models NB and MLP reached excellent performances, with an AUC of 0.80, respectively. After adding the amount of CSF drained within the first 14 days as a late feature to ML-based prediction, excellent performances were reached in the MLP (AUC 0.81), NB (AUC 0.80), and tree boosting model (AUC 0.81). ML models may enable clinicians to reliably predict the risk of SDHC after aSAH based exclusively on admission data. Future ML models may help optimize the management of SDHC in aSAH by avoiding delays in clinical decision-making [3].

Retrospective observational cohort studies

Subarachnoid Hemorrhage Volume, intraventricular hemorrhage volume, intracerebral hemorrhage volume, and total hemorrhage (TH) were computed from brain CT scans utilizing AW Server analytical software. ROC curves and multivariate analyses were employed to determine the association between hemorrhage volumes and SDAHC. The study included 170 patients, of whom 111 (65.3%) were

women, with a mean age of 58.5 years (SD: 14.6). Fifty-five patients (32.4%) presented SDAHC. intraventricular hemorrhage volumes had an area under the ROC curve of 0.757 (95% CI: 0.674-0.839; p <0.001). An IVH volume > 2.7 cm³ showed a sensitivity of 70.9% and a specificity of 77.2% for predicting SDAHC, while TH volumes > 29.5 cm³ demonstrated a sensitivity of 69.1% and a specificity of 61.4%. Multivariate analysis revealed that IVH volumes > 2.7 cm³ (OR 5.373; 95% CI: 2.477-11.657), TH volumes > 29.5 cm³ (OR 2.232; 95% CI: 1.008-4.942), and a bicaudate index ≥0.2 were significantly associated with SDAHC, adjusting for confounders. In aSAH patients, semiautomatic measurement of hemorrhage volumes using specialized software is independently associated with SDAHC. This method could facilitate early prediction and timely intervention [4].

This is a well-conceived and clinically relevant study that contributes meaningfully to the literature on aSAH complications. While its methodological rigor is commendable, future studies should aim to validate and refine the thresholds in larger, multicentric cohorts, and integrate clinical, radiological, and biochemical markers into comprehensive SDAHC prediction tools.

The clinical and imaging data of aSAH patients who received interventional embolization in our hospital were retrospectively collected from March 2018 to August 2022. All patients underwent one-stop whole brain CT examination within 24 hours after symptom onset, and the qualitative and quantitative CTP parameters were obtained after post-processing. Follow-up was conducted once every 2 months by consulting electronic medical records or by telephone for 6 months. According to whether SDHC occurred or not, the patients were divided into SDHC group and non-SDHC group. The differences between the two groups were compared. Logistic regression model was used to analyze and determine the predictive factors of SDHC, and the SDHC predictive model was established. The effectiveness of the predictive model was evaluated by drawing the receiver operating characteristic (ROC) curve of the subjects. Results: A total of 414 patients were included, including 132 males and 282 females, aged (59±11) years. 17.6%(73/414) patients had SDHC. There were significant differences in the occurrence of acute hydrocephalus, the World Neurosurgical League Scale (WFNS), the Hunt-Hess scale, the modified Fisher score (mFS), and the qualitative and quantitative parameters of CTP between the two groups (both P<0.001). Multivariate logistic regression analysis showed that acute hydrocephalus (OR=8.621, 95%CI: 4.237-17.542),old age (OR=1.107, 95%CI: 1.068-1.148), high mFS and high Hunt-Hess classification (OR=3.740, 95%CI: 1.352-10.342) were the risk factors of SDHC in aSAH patients, and high mean cerebral blood flow (mCBF) (OR=0.931, 95%CI: 0.885-0.980) was a protective factor of SDHC.The area under ROC curve (AUC) of the prediction model constructed by these five variables was 0.923(95%CI: 0.89-0.95), with 84.5% sensitivity and 87.7% specificity. Conclusion: The mCBF and acute hydrocephalus, age, mFS and Hunt-Hess classification within 24 hours at admission can be used to predict SDHC for aSAH patients [5].

Retrospective cohort studies

Suzuki et al. retrospectively investigated cases of aSAH treated by coil embolization. Patients were divided into those with and without CLOCCs. Between-group differences were evaluated, including clinical outcomes and the characteristics of both the patients and the aneurysms. Patients were divided into those with and without SDCH to identify predictive factors of SDCH after aSAH focusing on CLOCCs.

This single-center study included 196 patients with aSAH. All patients received coil embolization between April 2013 and March 2020. CLOCCs were detected in 38 (19.4%) patients. In the group with CLOCCs, male sex, poor severity grade at onset, acute hydrocephalus, SDCH (all $P < 0.01$), and Fisher group 3 or 4 ($P = 0.04$) were significantly more common than in the group without CLOCCs. Diabetes and CLOCCs were significant predictors of SDCH after aSAH in multivariate analysis (diabetes: $P < 0.01$, odds ratio [OR]: 6.73, 95% confidence interval [CI]: 1.61-28.09; CLOCCs: $P < 0.01$, OR: 6.86, 95% CI: 2.87-16.38).

CLOCCs and SDCH were common in patients with poor-grade aSAH, and CLOCCs were independent predictors of SDCH after aSAH. Meticulous follow-up is necessary to detect SDCH after aSAH, especially in patients with poor-grade aSAH and CLOCCs [6].

The purpose of the study was to compare the impact of early (< 21 days after aSAH) versus late (≥ 21 days after aSAH) VPS placement on the functional clinical outcome. We retrospectively analyzed data from 82 patients with VPS placement after aSAH enrolled in our institutional database between 2011 and 2021. We compared two groups, early VPS placement (< 21 days after aSAH) versus late VPS placement (≥ 21 days after aSAH) in terms of demographics, SAH grading, radiological parameters, externalized cerebrospinal fluid diversions, DCI, VPS variables, and functional outcome. We identified 53 patients with early and 29 patients with late VPS implantation. Baseline variables, such as the modified Rankin Scale (mRS), the World Federation of Neurological Surgeons Scale, the Glasgow Coma Scale, and the Fisher grade were not significantly different between the groups. Postoperatively, the mRS ($p = 0.0037$), the Glasgow Outcome Scale ($p = 0.0037$), and the extended Glasgow Outcome Scale ($p = 0.0032$) showed significantly better functional results in patients with early cerebrospinal fluid diversion. The rate of DCI did not differ significantly between the groups ($p = 0.53$). There was no difference in the rate of VPS placement-associated complications ($p = 0.44$) or overall mortality ($p = 0.39$). Early shunt implantation, within 21 days after aSAH and therefore during the timeframe of possible DCI, might not be harmful in patients developing HC after aSAH [7].

A total of 1533 aSAH patients from the population-based Eastern Finland Saccular Intracranial Aneurysm Database (Kuopio, Finland) were used in a recursive partitioning analysis to identify risk factors for shunting after aSAH. The risk model was built and internally validated in random split cohorts. External validation was conducted on 946 aSAH patients from the Southwestern Tertiary Aneurysm Registry (Dallas, TX) and tested using receiver-operating characteristic curves.

Results: Of all patients alive ≥14 days, 17.7% required permanent cerebrospinal fluid diversion. The recursive partitioning analysis defined 6 groups with successively increased risk for shunting. These groups also successively risk stratified functional outcomes at 12 months, shunt complications, and time-to-shunt rates. The area under the curve-receiver-operating characteristic curve for the exploratory sample and internal validation sample was 0.82 and 0.78, respectively, with an external validation of 0.68.

Shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage is associated with higher morbidity and mortality, and prediction modeling of shunt dependency is feasible with clinically useful yields. It is important to identify and understand the factors that increase the risk of shunting and to eliminate or mitigate the reversible factors. The aSAH-PARAS Consortium (Aneurysmal Subarachnoid Hemorrhage Patients' Risk Assessment for Shunting) has been initiated to pool the collective insights and resources to address key questions in post-aSAH shunt dependency to inform

future aSAH treatment guidelines [8].

Observational retrospective analytic studies

An observational retrospective analytic study of the patients with spontaneous SAH admitted to Miguel Servet University Hospital between 2017 and 2022. Patients' clinical and radiological characteristics, type of treatment, diagnoses and treatment of hydrocephalus, complications of ventriculoperitoneal shunts, and mortality are some of the data achieved in this study. A descriptive study of these variables has been done and, subsequently, the most relevant variables have been statistically analyzed to identify patients with an increasing risk of shunting for hydrocephalus. This study was authorized by the Ethics Committee before its elaboration.

Results: A total of 359 patients with spontaneous SAH were admitted to Miguel Servet University Hospital between 2017 and 2022, with an intrahospital death rate of 25.3%. 66.3% of the total of patients with SAH were due to intracranial aneurysm rupture (n = 238). 45.3% of the patients with aneurysmal SAH required an external ventricular drain (EVD) to treat acute hydrocephalus. 11.7% (n = 28) developed a shunt-dependent hydrocephalus. Statistical significance was found between shunt-dependent hydrocephalus and the following: high score in modified Fisher scale and placement of EVD. The mean interval from EVD to ventriculoperitoneal shunt placement was 26.1 days. The mean rate of reoperation of patients after shunt was 17.7%, mostly due to infection.

The most significant risk factor for shunt-dependent hydrocephalus after aneurysmal subarachnoid hemorrhage was high Fisher scale and previous need for external ventricular drainage. Shunt infections are the main cause of shunt reoperation. Early shunt placement in selected patients might reduce the rate of infectious complications [9].

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