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ORIGINAL ARTICLE

# Long-term Outcomes and Risk Factors Related to Hydrocephalus After Intracerebral Hemorrhage

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## Abstract

Hydrocephalus after intracerebral hemorrhage (ICH) is a common and treatable complication. However, the long-term outcomes and factors for predicting hydrocephalus have seldom been studied. The goal of this study was to determine the long-term outcomes and analyze the risk factors of hydrocephalus after ICH. A consecutive series of 1342 patients with ICH were reviewed from 2010 to 2016 to identify significant risk factors for hydrocephalus. Patients with a first-ever ICH without any prior diagnosis of hydrocephalus after ICH were followed up for survival status and cause of death. Risk factors for hydrocephalus were evaluated by using logistic regression analysis. Out of a total of 1342 ICH patients, 120 patients (8.9%) had hydrocephalus. The risk factors for hydrocephalus (≤ 3 days) were infratentorial hemorrhage ($p = 0.000$), extension to ventricles ($p = 0.000$), greater ICH volume ($p = 0.09$), and hematoma expansion ($p = 0.01$). Extension to ventricles ($p = 0.022$) was the only independent risk factor for hydrocephalus (4–13 days), while extension to ventricles ($p = 0.028$), decompressive craniotomy ($p = 0.032$), and intracranial infection ($p = 0.001$) were independent predictors of hydrocephalus (≥ 14 days). Patients were followed up for a median of 5.2 years (IQR 3.3–7.3 years). Estimated all-cause mortality was significantly higher in the ICH patients with hydrocephalus than that without hydrocephalus (HR 3.22, 95% CI 2.42–4.28; $p = 0.000$). Fifty-nine (49.2%) died and 40 (33.3%) had a favorable outcome in patients with hydrocephalus. Of all deaths, 30.5% were from ICH and 64.4% from infection. Hydrocephalus is a frequent complication of ICH and most commonly occurs at the onset of ICH. Patients with hydrocephalus show relatively higher mortality. ClinicalTrials.gov Identifier: NCT02135783 (May 7, 2014)

**Keywords** Hydrocephalus · Risk factors · Long-term outcome · Intracerebral hemorrhage

## Introduction

Hydrocephalus occurs up to 50% of patients with intraventricular hemorrhage (IVH), which is secondary to intracerebral hemorrhage (ICH) [1, 2]. Recent studies have suggested that hydrocephalus is a predictor of poor prognosis after ICH [2–6]. Both human and animal studies on hydrocephalus after IVH/ICH are rare [7]. Although a few researchers have reported the therapeutic effect and prognosis of hydrocephalus after ICH with small patient populations [8–13], the long-term outcomes, the prevention, and the association with other complications still remain uncertain. The goal of this study is to assess the risk factors and determine the long-term outcomes of hydrocephalus after ICH.

## Materials and Methods

### Patients

We identified all patients with ICH between January 2010 and December 2016 from the Department of Neurosurgery in the Southwest Hospital of the Third Military Medical University (Army Medical University). A long-term follow-up of ICH patients was performed. Ethics approval was obtained from the Ethics Committee of the Southwest Hospital of Third

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Military Medical University. Waiver of informed consent was granted for the retrospective cohort.

The patients diagnosed with acute ICH by computed tomography (CT) were included in the study. Patients were eligible for enrollment if they were 18 years of age or older and first-ever ICH. Patients with secondary causes, such as underlying aneurysm, vascular malformation, tumor, head trauma, or hemorrhagic transformation of ischemic infarcts, were excluded. Patients who had hydrocephalus before ICH were also excluded from the study. Any severe pre-existing physical or mental disability or severe comorbidity that might interfere with the assessment of outcome was also excluded.

Hydrocephalus was determined both radiographic evidence and progressive clinical manifestations of hydrocephalus within 1 year after first-ever ICH [14]. The criteria of hydrocephalus on CT or magnetic resonance imaging (MRI) images were as follows: (1) an Evans index (the largest width of the frontal horns of the lateral ventricles/the internal diameter of the skull at the same level) more than 0.3; (2) the enlargement of the anterior horns of the lateral ventricles, temporal horns and third ventricle, and periventricular interstitial edema in the presence of normal or absent sulci [15]. The clinical characteristics of hydrocephalus included neurobehavioral (e.g., inappropriate behavior and depressed mood) and cognitive (e.g., inability to plan or make a decision, memory, or language disturbances) disorders in conscious patients and deterioration of consciousness in the comatose patients [14, 16]. A ventriculoatrial shunt was considered in patients with progressive ventricular dilation and clinical deterioration.

### Data Processing

For each patients, information on demographic data (age, sex, smoking history, drinking history), medical history data (hypertension, diabetes mellitus, coronary artery disease, history of stroke), and clinical data at admission (Glasgow Coma Scale score, IVH score [17], systolic blood pressure, diastolic blood pressure); imaging data (ICH volumes and IVH volumes [measured on CT using the ABC/2 [18]], hematoma location [supratentorial and infratentorial], extension to ventricles, hematoma expansion [more than 6 mL or 33% growth compared with the initial ICH volume within 24 h of symptom onset [19, 20]], dilatation of each ventricles of hydrocephalus) were collected; decompressive craniotomy (according to the intracranial pressure (ICP) when the ICP exceeded 20 mmHg by using a ICP monitoring device [Codman, Johnson and Johnson Medical Ltd., Raynham, MA] inserted into the brain parenchyma or cerebral ventricles), hematoma evacuation, rate of clot removal, thrombolysis, extraventricular drainage (EVD), lumbar drainage, ventriculoatrial shunt composed the surgical data. Leucocyte, hemoglobin, platelet, and blood glucose composed the laboratory data. Treatment-related data (time of hydrocephalus ictus, in-hospital outcome, and complications [gastrointestinal bleeding, pneumonia, ischemic stroke, intracranial infection]) were also collected. All CT scans were evaluated by an experienced investigator who was blinded to patients' clinical and biochemical data.

### Follow-up

Survival status and cause of death were followed until May 31, 2019. Follow-up was performed by face-to-face interview or telephone call. Cause of death data are classified according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10) and registered in the Cause of Death Registry [20, 21]. The underlying causes of death in this study were categorized into the following groups: (1) cerebrovascular disease (corresponding to ICD-10, I60-69; subdivided into death related to index ICH, new ICH, and ischemic stroke); (2) infection; and (3) other causes of death (for example, renal failure, dementia, and gastrointestinal bleeding). The outcome was measured by modified Rankin scale (mRS). Unfavorable outcome was defined as mRS grades 4–6 (mRS 4 = moderately severe disability; mRS 6 = dead) [18].

### Statistical Analysis

Data analysis was performed using the SPSS software for Windows (version 13.0, Inc., Chicago, IL). Data were presented as mean (standard deviation [SD]) or counts (percentages). Quantitative variables were presented as mean ± SD and compared using Student's $t$ test or nonparametric test, whereas categorical variables were expressed as counts with percentages and compared using the $\chi^2$ test or continuity correction test. Significant variables ($p < 0.05$) were entered into the multivariable analysis via the binary logistic regression model of risk factors for hydrocephalus. Survival curves were estimated by the Kaplan-Meier survivor function and compared through log-rank test. Estimated all-cause mortality was tested with Cox proportional hazard regression models. Risk factors for poor outcome within follow-up were tested with Cox proportional hazard regression models, and the variables that had a significant ($p < 0.05$) association in the univariable analysis were included in the multivariable analysis. A $p < 0.05$ indicated statistically significant.

## Results

### Characteristics of Patients

A total of 1342 patients with first-ever ICH were initially enrolled. Eight patients were lost to follow-up. During 1 year after ICH, 120 (8.9%) developed hydrocephalus and the inter-rater agreement was 0.922 ($p = 0.000$) for the assessing of

hydrocephalus between two experienced investigators. Among 455 patients with IVH secondary to ICH, hydrocephalus occurred in 22.0% (100 of 455 patients). Dilatation of lateral ventricles, third ventricles, and fourth ventricles was 100%, 58.3%, and 30.0%, respectively. Three patients of hydrocephalus with high opening pressure and one patient with normal opening pressure underwent a ventriculoperitoneal shunt. Clinical improvement was seen in 3 cases and 1 case revealed no recovery of clinical signs because of occlusion at the distal catheter. Hydrocephalus appeared within 24 h in 63 (52.5%), within 3 days in 80 (66.7%), 4 days to 13 days in 14 (11.7%), and more than 14 days in 26 (21.6%) (Fig. 1). The baseline characteristics of these patients are shown in Table 1. There was no difference between the patients with hydrocephalus and those without hydrocephalus with respect to age, sex, previous diseases, and lifestyle factors.

## Predictors of Hydrocephalus After ICH

Univariate and multivariate logistic regression analyses were used to identify independent predictors of hydrocephalus (Table 1 and Table 2). The independent risk factors for hydrocephalus (≤ 3 days) in the multivariable analysis were infratentorial hemorrhage ($p = 0.000$), extension to ventricles ($p = 0.000$), greater ICH volume ($p = 0.009$), and hematoma expansion ($p = 0.010$). Extension to ventricles ($p = 0.022$) was the only independent risk factor for hydrocephalus (4–13 days), while extension to ventricles ($p = 0.028$), decompressive craniotomy ($p = 0.032$), and intracranial infection ($p = 0.001$) were independent predictors of hydrocephalus (≥ 14 days).

## Long-term Outcome of Hydrocephalus After ICH

In hospital, there were 20 deaths (16.7%) and 94 (78.3%) patients of poor outcome for ICH with hydrocephalus. Thirty-four patients (2.8%) died and poor outcome occurred in 580 (47.5%) patients without hydrocephalus in hospital. There was significant difference between the patients with hydrocephalus and those without hydrocephalus of death ($p = 0.000$) and poor outcome ($p = 0.000$). Among all patients after ICH, 61 (50.8%) patients with hydrocephalus and 962 (78.7%) patients without hydrocephalus survived followed up for a median of 5.2 years (IQR 3.3–7.3 years). Rates of mortality and disability in hydrocephalus of the patients with ICH at discharge and follow-up are shown in Fig. 2. Overall survival for ICH patients is shown in Fig. 3. Estimated all-cause mortality was significantly higher in the ICH patients with hydrocephalus than that without hydrocephalus (HR 3.22, 95% CI 2.42–4.28; $p = 0.000$).

## Predictors for Long-term Poor Outcome of ICH

Cox regression analysis showed that higher age ($p = 0.000$), diabetes mellitus ($p = 0.000$), higher systolic BP ($p = 0.014$), greater total ICH volume ($p = 0.000$), extension to ventricles ($p = 0.002$), pneumonia ($p = 0.000$), ischemic stroke ($p = 0.007$), and gastrointestinal bleeding ($p = 0.005$) are independent predictors for poor outcome during follow-up (Table 3). Hydrocephalus (HR 1.446, 95% CI 1.118 to 1.869, $p = 0.005$) was found to be a significant predictor for poor outcome after ICH.

## Cause of Death in Patients with Hydrocephalus After ICH

The cumulative numbers of observed deaths during follow-up hydrocephalus after ICH were the following: 18 (30.5%) due to ICH, 38 (64.4%) due to infection (pneumonia and intracranial infection), 2 (3.4%) due to ischemic stroke, 1 (1.7%) due to other causes (dementia). All-cause and cause-specific mortalities (*n* [%]) in patients for hydrocephalus after intracerebral hemorrhage are shown in Table 4.

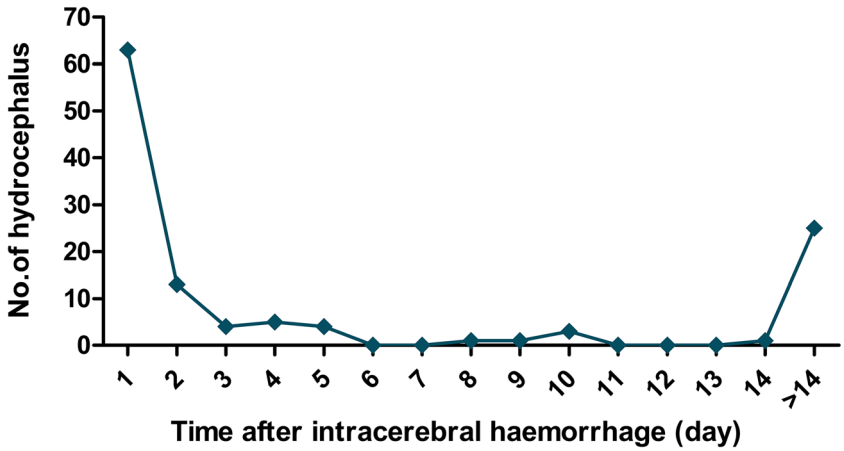


**Fig. 1** The timing of developing hydrocephalus in the patients with intracerebral hemorrhage. The time was within 1 day, within 3 days, 4 days to 13 days, and more than 14 days in 52.5%, 66.7%, 11.7%, and 21.6% of the patients with hydrocephalus after ICH, respectively

**Table 1** The baseline characteristics of the patients with hydrocephalus after ICH

| Variables | No hydrocephalus ($n$ = 1222) | Hydrocephalus | | | | $p_1$ | $p_2$ | $p_3$ | $p_4$ |
|---|---|---|---|---|---|---|---|---|---|
| | | Total ($n$ = 120) | ≤ 3 days ($n$ = 80) | 4–13 days ($n$ = 14) | ≥ 14 days ($n$ = 26) | | | | |
| Age (years, mean ± SD) | 59 ± 12 | 59 ± 12 | 61 ± 12 | 58 ± 13 | 52 ± 12 | 0.680 | 0.035 | 0.749 | 0.009 |
| Male ($n$ (%)) | 863 (70.6) | 85 (70.8) | 51 (63.8) | 14 (78.6) | 23 (88.5) | 0.961 | 0.193 | 0.723 | 0.120 |
| Medical history ($n$ (%)) | | | | | | | | | |
| Hypertension | 826 (67.6) | 82 (68.3) | 55 (68.8) | 9 (64.3) | 18 (69.2) | 0.869 | 0.83 | 1.000 | 0.860 |
| Diabetes mellitus | 72 (5.9) | 11 (9.2) | 8 (10.0) | - | 3 (11.5) | 0.155 | 0.214 | 0.717 | 0.434 |
| Coronary artery disease | 35 (2.9) | 7 (5.8) | 6 (7.5) | - | 1 (3.8) | 0.132 | 0.049 | 1.000 | 1.000 |
| History of stroke | 87 (7.1) | 12 (10.0) | 9 (11.3) | 1 (7.1) | 2 (7.7) | 0.249 | 0.171 | 1.000 | 1.000 |
| Lifestyle factors (n (%)) | | | | | | | | | |
| Smoking | 473 (38.7) | 47 (39.2) | 28 (35.0) | 6 (42.9) | 13 (50.0) | 0.921 | 0.509 | 0.751 | 0.243 |
| Drinking | 470 (38.5) | 48 (40.0) | 32 (40.0) | 5 (35.7) | 11 (42.3) | 0.741 | 0.784 | 0.834 | 0.69 |
| Clinical features | | | | | | | | | |
| Temperature (°C, mean ± SD) | 36.6 ± 0.4 | 36.6 ± 0.4 | 36.7 ± 0.4 | 36.6 ± 0.3 | 36.6 ± 0.4 | 0.999 | 0.726 | 0.764 | 0.772 |
| Systolic BP (mmHg, mean ± SD) | 166 ± 27 | 173 ± 28 | 172 ± 29 | 179 ± 32 | 172 ± 22 | 0.015 | 0.073 | 0.075 | 0.279 |
| Diastolic BP (mmHg, mean ± SD) | 94 ± 16 | 94 ± 18 | 92 ± 19 | 98 ± 19 | 98 ± 13 | 0.977 | 0.303 | 0.353 | 0.209 |
| GCS score ($n$ (%)) | | | | | | | | | |
| 3–8 | 179 (14.6) | 55 (45.8) | 41 (51.2) | 4 (28.6) | 10 (38.5) | 0.000 | 0.000 | 0.186 | 0.001 |
| 9–12 | 246 (20.1) | 26 (21.7) | 15 (18.8) | 4 (28.6) | 7 (26.9) | | | | |
| 13–15 | 797 (65.3) | 39 (32.5) | 24 (30.0) | 6 (42.8) | 9 (34.6) | | | | |
| IVH score ($n$ (%)) | | | | | | | | | |
| 0–7 | 1092 (89.4) | 60 (50.0) | 32 (40.0) | 9 (64.3) | 19 (73.1) | 0.000 | 0.000 | 0.010 | 0.021 |
| 8–23 | 130 (10.6) | 50 (50.0) | 48 (60.0) | 5 (35.7) | 7 (26.9) | | | | |
| Radiological data | | | | | | | | | |
| Left ($n$ (%)) | 621 (50.8) | 621 (50.9) | 37 (46.3) | 8 (57.1) | 13 (50.0) | 0.603 | 0.429 | 0.638 | 0.934 |
| Location ($n$ (%)) | | | | | | | | | |
| Supratentorial | 1188 (97.2) | 93 (77.5) | 55 (68.8) | 12 (85.7) | 26 (100.0) | 0.000 | 0.000 | 0.081 | 0.800 |
| Infratentorial | 34 (2.8) | 27 (22.5) | 25 (31.2) | 2 (14.3) | - | | | | |
| IVH volume (mL, mean ± SD) | 1.7 ± 4.7 | 9.2 ± 11.4 | 11.1 ± 12.5 | 6.3 ± 8.1 | 4.7 ± 7.4 | 0.000 | 0.000 | 0.000 | 0.049 |
| Total volume (mL, mean ± SD) | 26.3 ± 23.7 | 38.7 ± 26.0 | 36.1 ± 24.2 | 35.3 ± 30.0 | 48.5 ± 28.1 | 0.000 | 0.000 | 0.156 | 0.000 |
| Extension to ventricles ($n$ (%)) | 355 (29.1) | 100 (83.3) | 71 (88.6) | 13 (92.9) | 16 (61.5) | 0.000 | 0.000 | 0.000 | 0.000 |
| Hematoma expansion ($n$ (%)) | 66 (5.4) | 20 (16.7) | 12 (15.0) | 3 (21.4) | 5 (19.2) | 0.000 | 0.001 | 0.044 | 0.005 |
| Laboratory data | | | | | | | | | |
| Leucocyte ($10^9$/L, mean ± SD) | 9.2 ± 3.7 | 11.5 ± 4.7 | 11.8 ± 4.7 | 10.6 ± 3.1 | 11.2 ± 4.1 | 0.000 | 0.000 | 0.165 | 0.006 |
| Hemoglobin (g/L, mean ± SD) | 137 ± 19 | 141 ± 20 | 140 ± 21 | 134 ± 14 | 149 ± 18 | 0.024 | 0.173 | 0.57 | 0.001 |
| Platelet ($10^9$/L, mean ± SD) | 180 ± 67 | 181 ± 660 | 179 ± 63 | 165 ± 45 | 192 ± 56 | 0.926 | 0.957 | 0.405 | 0.377 |
| Blood glucose (mmol/L, mean ± SD) | 7.6 ± 2.9 | 8.3 ± 3.1 | 8.7 ± 3.4 | 7.0 ± 1.8 | 7.9 ± 2.8 | 0.006 | 0.001 | 0.498 | 0.552 |
| Treatment-related data | | | | | | | | | |
| Surgery ($n$ (%)) | 316 (25.9) | 99 (82.5) | 67 (83.8) | 11 (78.6) | 21 (80.8) | 0.000 | 0.000 | 0.000 | 0.000 |
| DC ($n$ (%)) | 198 (16.2) | 44 (36.7) | 22 (27.5) | 5 (35.7) | 17 (65.4) | 0.000 | 0.009 | 0.110 | 0.000 |
| Hematoma evacuation ($n$ (%)) | 262 (21.4) | 50 (41.7) | 29 (36.3) | 4 (28.6) | 17 (65.4) | 0.000 | 0.002 | 0.726 | 0.000 |
| Craniotomy ($n$ (%)) | 236 (90.1) | 47 (94.0) | 29 (100.0) | 4 (100.0) | 14 (82.4) | 0.542 | 0.151 | 1.000 | 0.548 |
| MIS ($n$ (%)) | 26 (9.9) | 3 (6.0) | - | - | 3 (17.6) | | | | |
| Rate of clot removal ($n$ (%)) | | | | | | | | | |
| ≥ 90% | 147 (46.5) | 34 (34.3) | 19 (28.4) | 5 (45.4) | 10 (47.6) | 0.002 | 0.000 | 0.331 | 0.960 |
| 75–89% | 129 (40.8) | 38 (37.4) | 27 (40.3) | 3 (27.3) | 8 (38.1) | | | | |
| < 75% | 40 (12.7) | 27 (27.3) | 21 (31.3) | 3 (27.3) | 3 (14.3) | | | | |

**Table 1** (continued)

| Variables | No hydrocephalus | Hydrocephalus | | | | $p_1$ | $p_2$ | $p_3$ | $p_4$ |
|---|---|---|---|---|---|---|---|---|---|
| | ($n$ = 1222) | Total ($n$ = 120) | ≤3 days ($n$ = 80) | 4–13 days ($n$ = 14) | ≥14 days ($n$ = 26) | | | | |
| Urokinase/rt-pa ($n$ (%)) | 262 (21.4) | 12 (10.0) | 7 (8.8) | 2 (14.3) | 3 (11.5) | 0.000 | 0.000 | 0.003 | 0.000 |
| EVD ($n$ (%)) | 108 (8.8) | 83 (69.2) | 62 (77.5) | 10 (71.4) | 11 (42.3) | 0.000 | 0.000 | 0.000 | 0.000 |
| Lumbar drainage ($n$ (%)) | 73 (6.0) | 46 (38.3) | 32 (40.0) | 7 (50.0) | 7 (16.9) | 0.000 | 0.000 | 0.000 | 0.000 |
| Ventriculoperitoneal shunt ($n$ (%)) | - | 4 (3.3) | 1 (1.3) | 1 (7.1) | 2 (7.7) | 0.000 | 0.068 | 0.000 | 0.000 |
| Complications ($n$ (%)) | | | | | | | | | |
| Pneumonia | 549 (44.6) | 105 (87.5) | 72 (90.0) | 12 (85.7) | 21 (80.8) | 0.000 | 0.000 | 0.002 | 0.000 |
| Gastrointestinal bleeding | 55 (4.5) | 21 (17.5) | 15 (18.8) | 1 (7.1) | 5 (19.2) | 0.000 | 0.000 | 1.000 | 0.003 |
| Ischemic stroke | 37 (3.0) | 8 (6.7) | 5 (6.3) | 2 (14.3) | 1 (2.8) | 0.065 | 0.210 | 0.104 | 1.000 |
| Intracranial infection | 19(1.6) | 19 (15.8) | 12 (15.0) | 2 (14.3) | 5 (19.2) | 0.000 | 0.000 | 0.009 | 0.000 |

$p_1$, hydrocephalus (≤3 days) vs. no hydrocephalus; $p_2$, hydrocephalus (4–13 days) vs. no hydrocephalus; $p_3$, hydrocephalus (≥14 days) vs. no hydrocephalus; *ICH*, intracerebral hemorrhage; *SD*, standard deviation; *BP*, blood pressure; *GCS*, Glasgow Coma Scale; *IVH*, intraventricular hemorrhage; *SAH*, subarachnoid hemorrhage; *DC*, decompressive craniotomy; *EVD*, extraventricular drainage

## Discussion

Hydrocephalus is associated with ICH, especially IVH secondary to ICH [1]. Research from Bhattathiri and colleagues has shown that the likelihood of positive outcome is decreased from 15.1 to 11.5% because of the presence of hydrocephalus in a subanalysis of the STICH trial [4]. Although increasing studies have reported the incidence rate of posttraumatic hydrocephalus, varying from 0.7 to 29% [22–25], up to 50% of patients with IVH secondary to ICH may develop hydrocephalus [2]. The incidence of hydrocephalus after ICH was seldom addressed. Of the 1342 patients with ICH in this study, hydrocephalus occurred in 8.9% of patients after ICH and 22.0% of patients with IVH secondary to ICH. The incidence of hydrocephalus with IVH secondary to ICH is lower than that of the previous study [1]. Agreements on diagnostic method and criteria for hydrocephalus are still not achieved to date [22]. The diagnosis of hydrocephalus in the present research was based on patients' clinical and imaging data.

Hydrocephalus after ICH occurs in about two-thirds of patients mainly within 3 days. Hematoma mass effect/IVH may be related to early obstructive hydrocephalus. However, the time course for ictus of communicating hydrocephalus due to traumatic brain injury and/or subarachnoid hemorrhage (SAH) is from 2 weeks to 1 month [16]. Extension of hemorrhage into the ventricles can prevent normal CSF flow and, with mass effects of blood clot, lead to acute obstructive hydrocephalus in hydrocephalus after IVH secondary to ICH [3–5]. Surgery, such as the insertion of EVD, can be effective when the condition is severe [1, 26]. But, about one-fifth of hydrocephalus occured more than 14 days. Persistent iron overload from intracerebral hematoma and intracerebral infection from invasive operation after ICH/IVH may contribute to the occurrence of hydrocephalus [7]. Ventriculitis, surgical complications, mass effect due to edema, recurrent ICH, or fibrosis of the ventricles maybe also relate to late hydrocephalus.

The risk factors for hydrocephalus (≤3 days) in the multivariable analysis were infratentorial hemorrhage, extension to ventricles, greater ICH volume, and hematoma expansion. Extension to ventricles was the only independent risk factor for hydrocephalus (4–13 days), while extension to ventricles, decompressive craniotomy, and intracranial infection were

**Table 2** Predictors of hydrocephalus after ICH

| Variable | Odds ratio | 95% CI | $p$ |
|---|---|---|---|
| Hydrocephalus (≤3 days) | | | |
| Location (infratentorial) | 30.019 | 13.543, 66.539 | 0.000 |
| Total ICH volume | 1.013 | 1.003, 1.023 | 0.009 |
| Extension to ventricles | 15.637 | 7.433, 32.981 | 0.000 |
| Hematoma expansion | 2.831 | 1.284, 6.245 | 0.010 |
| Hydrocephalus (4–13 days) | | | |
| Extension to ventricles | 12.692 | 1.442, 111.723 | 0.022 |
| Hydrocephalus (≥14 days) | | | |
| Extension to ventricles | 2.706 | 1.115, 6.565 | 0.028 |
| Decompressive craniotomy | 4.204 | 1.135, 15.571 | 0.032 |
| Intracranial infection | 7.917 | 2.253, 27.819 | 0.001 |

*ICH*, intracerebral hemorrhage

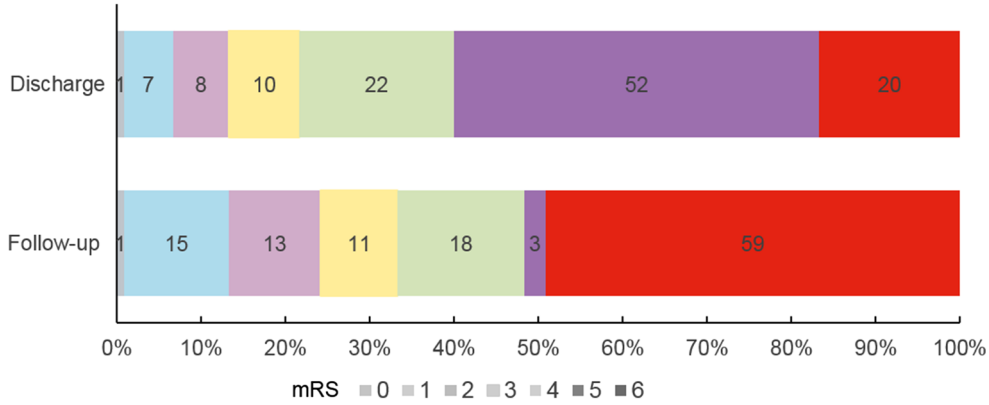


**Fig. 2** mRS score at discharge and follow-up after hydrocephalus in the patients with intracerebral hemorrhage. mRS scores range from 0 (no disability) to 6 (death). 21.7% (26) at discharge and 33.3% (40) at follow-up had an mRS score of 3 or less. 16.7% (20) at discharge and 49.2% (59) at follow-up had an mRS score of 6

independent predictors of hydrocephalus (≥ 14 days). Many of the risk factors are related to the blood clot which lead to obstruction to normal CSF flow. There was no correlation between the development of hydrocephalus and sex and age. Previous studies have also reported that intraventricular hemorrhage, thickness, distribution of SAH, IVH volume, and Graeb score can be used for predicting hydrocephalus after ICH [4, 9–12, 27], which is similar with our study in the early hydrocephalus, not late hydrocephalus. A greater total hematoma volume was an independent predictor for acute hydrocephalus, not late hydrocephalus. The removal of hematoma which lead to obstruction to normal CSF flow may be a reason. However, our results also show that there is no correlation between rate of clot removal and subsequent hydrocephalus ($p = 0.539$). Maybe, there is no benefit from more clot removal because of ventriculitis, surgical complications, and decompressive craniotomy. Decompressive craniotomy ($p = 0.032$) and intracranial infection ($p = 0.001$) were independent predictors of late hydrocephalus. In the previous study, decompressive craniotomy also seemed to be strongly related to the development of hydrocephalus in previous studies [22, 23]. Decompressive craniotomy is an effective approach to save life. But, a large decompressive craniotomy might aggravate ventricular expansion and reduce the CSF absorption by lower intracranial pressure [23, 28].

In long-term follow-up of study, we recognize the occurrence of late hydrocephalus. Twenty-two (18.2%) patients appeared hydrocephalus after ICH at 1 month later. The mortality was 16.7% at hospital discharge and 49.2% during follow-up. In previous study, 56.4% (679) of patients (1204) died after ICH/IVH [10–12]; the mortality rate was the same as hydrocephalus after ICH [29–31]. However, the mortality of hydrocephalus after IVH/ICH in infants is lower than that in adult [32], 34% and 48.8%, respectively. The cause related to patients death was similar between ICH induced hydrocephalus and ICH, and major causes of death during follow-up were ICH and infection [29].

This study still has some limitations. A major limitation of our work is a retrospective, nonrandomized, and single center study, which may produce information bias because of the unclear data collection. Second, we cannot rule out the additional variables which may influence the outcome of

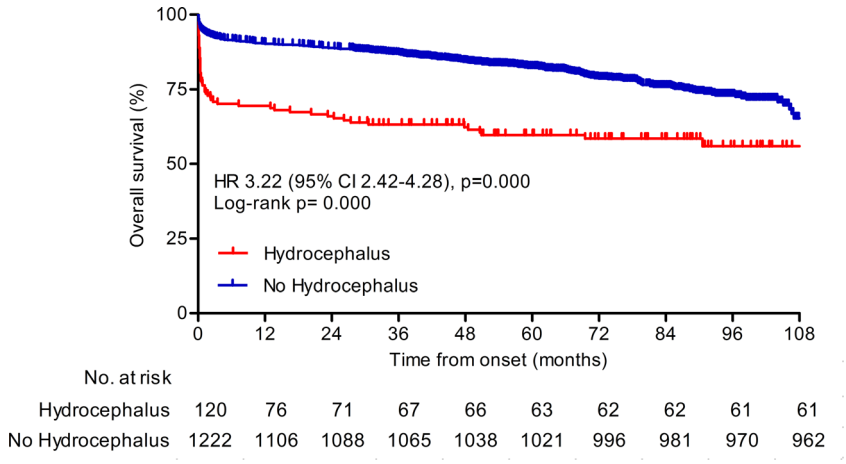


**Fig. 3** Overall survival

**Table 3** Predictors of poor outcome in patients with ICH in long-term follow-up

| Variable | Odds ratio | 95% CI | *p* |
|---|---|---|---|
| Age (years) | 1.030 | 1.022, 1.037 | 0.000 |
| Diabetes mellitus | 1.837 | 1.360, 2.482 | 0.000 |
| Systolic BP | 1.004 | 1.001, 1.007 | 0.014 |
| Total ICH volume | 1.012 | 1.009, 1.015 | 0.000 |
| Extension to ventricles | 1.324 | 1.106, 1.584 | 0.002 |
| Pneumonia | 1.999 | 1.632, 2.448 | 0.000 |
| Gastrointestinal bleeding | 1.535 | 1.136, 2.0735 | 0.005 |
| Ischemic stroke | 1.611 | 1.136, 2.2.285 | 0.007 |
| Hydrocephalus | 1.446 | 1.118, 1.869 | 0.005 |

*ICH*, intracerebral hemorrhage; *BP*, blood pressure

hydrocephalus after ICH, such as iron [7]. One study showed that intracerebral hematoma contributed to persistent brain iron accumulation and aggravated hydrocephalus after ICH/IVH. Finally, the information of surgery is incomplete. Therefore, more clinical researches are needed to explore the effectiveness of treatment for ICH.

## Summary

Hydrocephalus is a frequent complication of ICH and most commonly occurs at the onset of ICH. Patients with hydrocephalus show relatively higher mortality and disability. Surgery, such as extraventricular drainage, lumbar drainage, and ventriculoatrial shut, may decrease the risk of hydrocephalus. Major causes of death during follow-up were ICH and infection.

**Table 4** All-cause and cause-specific mortality (*n* [%]) in patients for hydrocephalus after ICH

| | During hospital period | Follow-up (median, 5.2 years) |
|---|---|---|
| All-cause mortality | 20 (100.0) | 39 (100.0) |
| ICH | 7 (35.0) | 8 (20.5) |
| New ICH | 0 (0.0) | 3 (7.7) |
| Ischemic stroke | 0 (0.0) | 2 (5.1) |
| Pneumonia | 10 (50.0) | 22 (56.4) |
| Intracranial infection | 3 (15.0) | 3 (7.7) |
| Other | 0 (0.0) | 1 (2.6) |

*ICH*, intracerebral hemorrhage

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**Data Availability** Please contact with the corresponding author.

## Compliance with Ethical Standards

**Disclaimer** All inferences, opinions, and conclusions drawn in this publication are those of the authors and do not reflect the opinions or policies of the data steward(s).

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Ethics Approval** This study adheres to the principles of the Declaration of Helsinki. The protocol was approved by the Ethics Committee of the Southwest Hospital of Third Military Medical University, China.

**Consent to Participate** Obtained.

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**Patient Consent** Obtained.

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