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ORIGINAL WORK

# Clinical, Imaging Characteristics and Outcome of Intracerebral Hemorrhage Caused by Structural Vascular Lesions

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## Abstract

**Background:** The objective of this study was to investigate the clinical, imaging, and outcome characteristics of intracerebral hemorrhage (ICH) caused by structural vascular lesions.

**Methods:** We retrospectively analyzed data from a prospective observational cohort study of patients with spontaneous ICH admitted to the First Affiliated Hospital of Chongqing Medical University between May 2016 and April 2021. Good outcome was defined as modified Rankin Scale score of 0–3 at 3 months. The clinical and imaging characteristics were compared between primary ICH and ICH caused by structural vascular lesions. Multivariable logistic regression analysis was performed to test the associations of etiology with clinical outcome.

**Results:** All patients enrolled in this study were Asian. Compared with patients with primary ICH, those with structural vascular lesions were younger (48 vs. 62 years, $P<0.001$), had a lower incidence of hypertension (26.4% vs. 81.7%, $P<0.001$) and diabetes (7.4% vs. 16.2%, $P=0.003$), and had mostly lobar hemorrhages (49.1% vs. 22.8%). ICH from structural vascular lesions had smaller baseline hematoma volume (8.4 ml vs. 13.8 ml, $P=0.010$), had lower mortality rate at 30 days and 3 months (5.8% vs. 12.0%, $P=0.020$; 6.7% vs. 14.8%, $P=0.007$), and are associated with better functional outcome at 3 months (88% vs.70.3%, $P<0.001$).

**Conclusions:** Compared with primary ICH, ICH due to vascular lesions has smaller hematoma volume and less severe neurological deficit at presentation and better functional outcomes.

**Keywords:** Intracerebral hemorrhage, Structural vascular lesion, Hematoma, Outcome

## Introduction

Intracerebral hemorrhage (ICH) is a devastating type of stroke characterized by hemorrhage in the brain parenchyma [1]. ICH accounts for 10–15% of all strokes in the United States [2, 3], but is more prevalent in China [4, 5]. ICH can be caused by different etiologies [6, 7]. The Structural lesion, Medication, Amyloid angiopathy, Systemic/other disease, Hypertension, Undetermined (SMASH-U) [8, 9] is a feasible and easy-to-use etiological classification with an excellent interrater agreement, which can rapidly categorize ICH into six subtypes according to medical history, laboratory tests, and imaging studies.

The clinical, imaging, and prognosis have been extensively studied in patients with primary ICH without a demonstrated structural or traumatic cause [10]; however, analyses of secondary ICH associated with vascular lesions are sparse. Emerging studies suggested that ICH due to structural vascular lesion have better functional outcomes and lower mortality [9, 11, 12], but the specific mechanism and hematoma characteristics are poorly

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understood. The main purpose of this study was to compare the clinical, imaging, and prognosis of primary ICH and ICH associated with structural vascular lesion, so as to better understand the clinical and imaging features of ICH with different etiologies.

## Methods

### Standard Protocol Approvals, Registrations, and Patient Consents

This study was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University. Informed consent was obtained from all participants or their legal representatives.

### Patient Selection

We retrospectively analyzed data from a prospective observational cohort study of consecutive patients presenting with ICH at the First Affiliated Hospital of Chongqing Medical University between May 2016 and April 2021. Patients were eligible for our study if they were diagnosed with spontaneous ICH and had completed computed tomography (CT) examination. All patients were classified etiologically according to the SMUSH-U method [8], as described in Fig. 1. We included in this analysis those with ICH from a structural vascular lesion and those with primary ICH. Patients with ICH due to secondary causes (e.g., anticoagulants, systemic diseases) were excluded.

### Data Collection

The demographic and clinical data including age, sex, the status of smoking and alcohol, past medical history and drug use, the admission blood pressure (BP), and blood test results were obtained. The admission Glasgow Coma Scale (GCS) score and the admission National Institute of Health stroke scale (NIHSS) score were prospectively collected. All CT, CT angiography, or magnetic resonance imaging (MRI) examinations were independently reviewed by two trained neurologists who were blinded to clinical data and outcome. The hematoma volume was calculated by the semiautomated, computer-assisted volumetric analysis (Analyze 12.0, Mayo Clinic, Rochester, MN) as described [13, 14]. The primary outcome was assessed using modified Rankin Scale (mRS) score at 3 months after discharge. Good outcome was defined as an mRS score of 0–3 [15]. Functional independence was defined as an mRS score of 0–2 [16]. In addition, 30-day and 3-month mortality rates were recorded.

### Statistical Analysis

Statistical analyses were performed using SPSS (version 25.0, IBM Corp, Armonk, NY). Continuous variables were expressed as medians with interquartile ranges due to the nonnormal distribution. Categorical variables were provided as percentages (%). The nearest neighbor propensity score matching (caliper = 0.02, ratio = 2) was used to reduce selection bias by matching patients with primary ICH and those with structural vascular lesions. Confounding factors, including age, sex, current smoking, alcohol consumption, hypertension, systolic BP (mm Hg), diastolic BP (mm Hg), diabetes, coronary heart disease, antiplatelet, and statin, were chosen for matching. The propensity score matching was conducted by R software. The baseline demographic, clinical, and imaging characteristics were compared between primary ICH and vascular lesion group, using Kruscal Whallis H tests or $\chi^2$ tests, as appropriate. We used multivariable logistic regression analysis to investigate factors associated with good outcome and functional independence at 3 months after discharge. All $P$ values presented are two-sided, and a $P$ value of 0.05 or less is considered statistically significant.

## Results

Between May 2016 and April 2021, a total of 1,515 patients with spontaneous ICH who had complete imaging data were included in our database at the First Affiliated Hospital of Chongqing Medical University. Of these, 1,318 (87%) were primary ICH and 163 (10.76%) were diagnosed as ICH due to structural vascular lesion. Of 163 patients diagnosed with ICH due to vascular lesions, 73 (44.79%) were arteriovenous malformation (AVM), 38 (23.31%) were cavernous angioma, 19 (11.66%) were cerebral aneurysm, 19 (11.66%) were moyamoya disease, 8 (4.91%) were venous malformations, and 6 (3.68%) were arteriovenous fistula.

Compared with patients with primary ICH, those with structural vascular lesions were younger (48 vs. 62 years, $P < 0.001$), less likely to smoke (33.7% vs. 43.1%, $P = 0.022$) and consume alcohol (19.0% vs. 30.7%, $P = 0.001$), had lower incidence of hypertension (26.4% vs. 81.7%, $P < 0.001$) and diabetes (7.4% vs. 16.2%, $P = 0.003$), and were more likely to have seizures (9.2% vs. 3.0%, $P < 0.001$). Notably, patients with ICH who had vascular lesions were more likely to have a prior history of ICH events (16.6% vs. 7.2%, $P < 0.001$) and the blood pressure levels were significantly lower than those with primary ICH (systolic BP 131.5 mm Hg vs. 169 mm Hg, $P < 0.001$; diastolic BP 80 mm Hg vs. 96 mm Hg, $P < 0.001$). The baseline hematoma volume was significantly smaller in patients with ICH who had structural vascular lesions than those with primary ICH (8.4 ml vs. 13.8 ml, $P = 0.010$), but there were no differences in the prevalence of intraventricular hemorrhage (IVH) (37.0% vs. 33.6%, $P = 0.389$) and IVH volume (2.41 ml vs. 2.14 ml, $P = 0.281$).

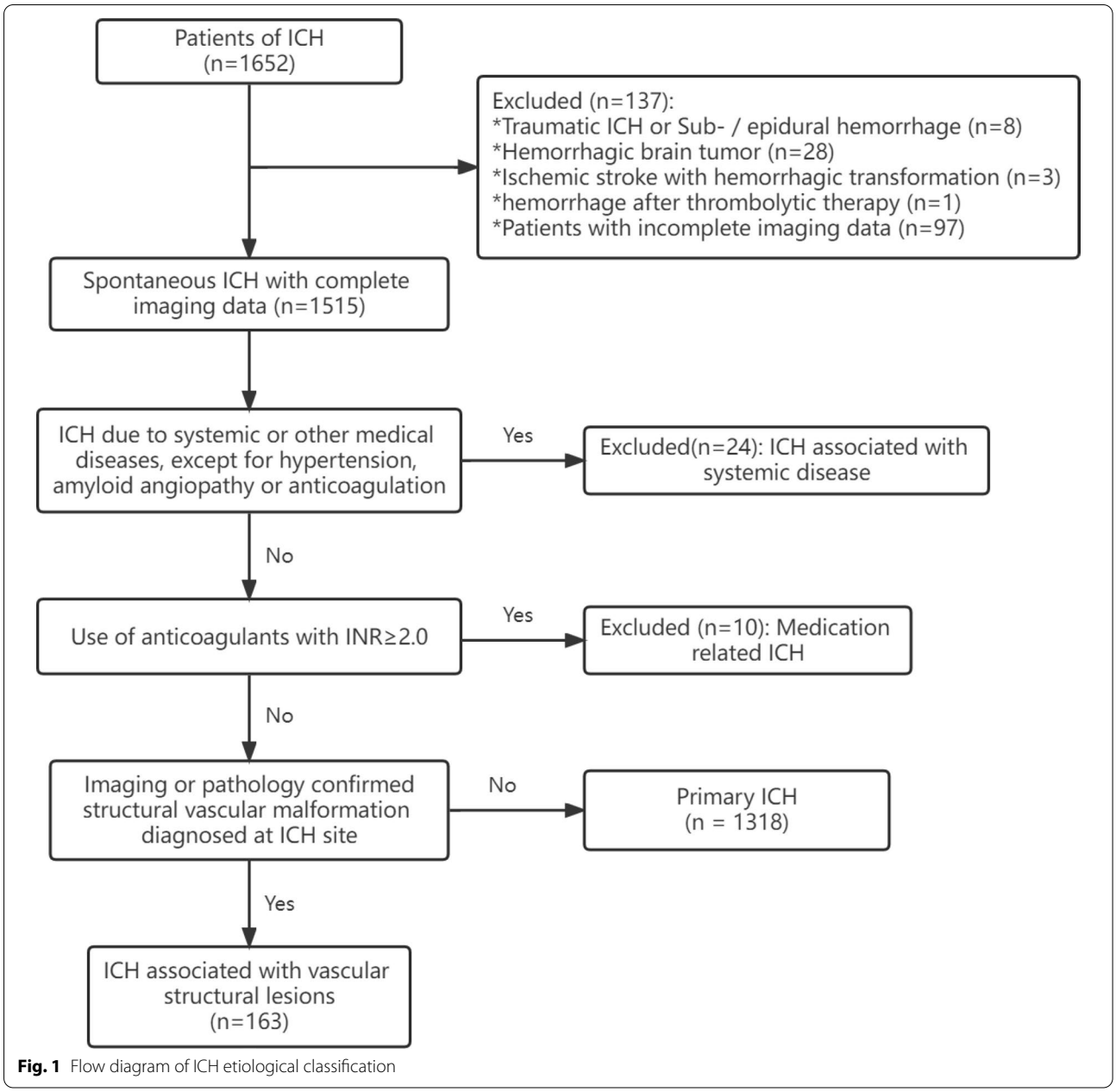


**Fig. 1** Flow diagram of ICH etiological classification

Patients with ICH who had vascular lesions were more prone to have a longer median time from symptom onset to hospital admission (24 h vs. 6.5 h, $P<0.001$) compared with patients with primary ICH. However, there were no differences in the incidence of wake-up ICH (5.5% vs. 7.4%, $P=0.390$). Furthermore, ICH from structural vascular lesions had higher admission GCS (14 vs. 13, $P=0.009$), lower admission NIHSS (3 vs. 12, $P<0.001$), and lower mortality rates at 30 days (5.8% vs. 12.0%, $P=0.020$) and 3 months (6.7% vs. 14.8%, $P=0.007$). The proportion of patients who had good outcome (mRS 0–3) were significantly more in structural vascular lesions than primary ICH (88.0% vs. 70.3%, $P<0.001$).

The most common bleeding site for primary ICH is basal ganglia (45.8%), followed by cerebral lobes (22.8%) and thalamus (16.0%) (Table 1). However, lobar hemorrhage (49.1%) is the most common type of bleeding for patients with vascular structural lesions, followed by basal ganglia (15.3%) and then brain stem (12.3%). Compared with primary ICH, cerebellar or primary IVH were more common in vascular structure lesions (11.7% vs. 6.5%, 4.9% vs. 1.6%, $P<0.001$).

**Table 1 Characteristics of patients with primary ICH and those with structural vascular lesions before and after propensity score matching**

| Variables | Before matching | | | After matching | | |
|---|---|---|---|---|---|---|
| | Primary ICH ($n=1318$) | vascular lesion ($n=163$) | *P* value | Primary ICH ($n=177$) | vascular lesion ($n=104$) | *P* value |
| Race | Asian | | | Asian | | |
| Age | 62 (50–70) | 48 (29–54) | < 0.001 | 50 (39–64) | 51 (46.5–63) | 0.051 |
| Male sex | 914 (69.3) | 90 (55.2) | < 0.001 | 104 (58.8) | 59 (56.7) | 0.740 |
| Onset-to-admission time (h) | 6.5 (3–24) | 24 (5–96) | < 0.001 | 5.5 (3–14) | 10.54 (4–60) | 0.011 |
| Wake-up ICH | 97 (7.4) | 9 (5.5) | 0.390 | 13 (7.3) | 6 (5.8) | 0.612 |
| Current smoking | 568 (43.1) | 55 (33.7) | 0.022 | 68 (38.4) | 40 (38.5) | 0.994 |
| Alcohol consumption | 405 (30.7) | 31 (19.0) | 0.001 | 36 (20.3) | 23 (22.1) | 0.724 |
| Hypertension | 1077 (81.7) | 43 (26.4) | < 0.001 | 80 (45.2) | 43 (41.3) | 0.530 |
| Systolic BP (mm Hg) | 169 (151–190) | 131.5 (121–151) | < 0.001 | 142 (131–169) | 142.5 (125–163.5) | 0.382 |
| Diastolic BP (mm Hg) | 96 (83–110) | 80 (70–89) | < 0.001 | 81 (72–102) | 85.5 (76.5–100) | 0.852 |
| Diabetes | 213 (16.2) | 12 (7.4) | 0.003 | 19 (10.7) | 10 (9.6) | 0.766 |
| Coronary heart disease | 69 (5.2) | 3 (1.8) | 0.057 | 8 (4.5) | 3 (2.9) | 0.495 |
| Antiplatelet | 59 (4.5) | 4 (2.5) | 0.227 | 6 (3.4) | 4 (3.8) | 0.842 |
| Statin | 44 (3.3) | 2 (1.2) | 0.143 | 4 (2.3) | 2 (1.9) | 0.850 |
| Previous Stroke | 205 (15.6) | 32 (19.6) | 0.18 | 23 (13.0) | 25 (24.0) | 0.018 |
| Previous ICH | 95 (7.2) | 27 (16.6) | < 0.001 | 11 (6.2) | 20 (19.2) | 0.001 |
| Thrombocytes (E9/L) | 181 (140–225) | 192 (166–231) | 0.025 | 183 (141–224) | 182.5 (162–230.5) | 0.245 |
| Seizures | 40 (3.0) | 15 (9.2) | < 0.001 | 6 (3.4) | 8 (7.7) | 0.109 |
| Bleeding site (central-point method) | | | < 0.001 | | | < 0.001 |
| Basal ganglia | 603 (45.8) | 25 (15.3) | | 80 (45.2) | 20 (19.2) | |
| Thalamus | 211 (16.0) | 11 (6.7) | | 16 (9.0) | 4 (3.8) | |
| Lobar | 301 (22.8) | 80 (49.1) | | 48 (27.1) | 47 (45.2) | |
| Brainstem | 96 (7.3) | 20 (12.3) | | 11 (6.2) | 14 (13.5) | |
| Cerebellar | 86 (6.5) | 19 (11.7) | | 15 (8.5) | 13 (12.5) | |
| Primary IVH | 21 (1.6) | 8 (4.9) | | 7 (4.0) | 6 (5.8) | |
| ICH volume (mL) | 13.8 (5.3–37.2) | 8.4 (2.7–24.3) | 0.010 | 15.3 (5.28–37.32) | 5.64 (2.0–15.72) | 0.004 |
| Existing IVH* | 443/1,317 (33.6) | 60/162 (37.0) | 0.389 | 50/177 (28.2) | 35/103 (34.0) | 0.314 |
| IVH volume (mL) | 2.14 (0–10.15) | 2.41 (0.27–12.97) | 0.281 | 1.89 (0–10.47) | 2.70 (0–15.88) | 0.487 |
| Admission GCS | 13 (8–15) | 14 (9–15) | 0.009 | 12 (7–15) | 14 (8.5–15) | 0.350 |
| Admission NIHSS | 12 (4–26) | 3 (1–17) | < 0.001 | 12 (3–35) | 3 (1–16.5) | < 0.001 |
| Mortality at 30 days[a] | 151/1256 (12.0) | 9/156 (5.8) | 0.020 | 16/165 (9.7) | 6/101 (5.9) | 0.280 |
| good outcome at 3 months[a] | 869/1237 (70.3) | 132/150 (88.0) | < 0.001 | 124/162 (76.5) | 86/98 (87.8) | 0.026 |
| Functional independence at 3 months[a] | 734/1232 (59.6) | 125/150 (83.3) | < 0.001 | 102/162 (63.0) | 80/98 (81.6) | 0.001 |
| Mortality at 3 months[a] | 183/1238 (14.8) | 10/150 (6.7) | 0.007 | 17/162 (10.5) | 7/98 (7.1) | 0.366 |

All values are median (interquartile range) or *n* (%)

*BP* blood pressure, *ICH* intracerebral hemorrhage, *IVH* intraventricular hemorrhage, *GCS* Glasgow Coma Scale, *NIHSS* National Institutes of Health Stroke Scale

[a] There are missing values in this item, and the exact data are listed in the table

Significant covariates from univariate analyses with $P<0.1$ and other variables chosen for their potential clinical relevance (etiology, age, sex, hypertension, diabetes, previous ICH, admission GCS, ICH volume, and IVH volume) were included in multivariable models. We found that ICH from vascular structure lesions was associated with good outcome (odds ratio [OR] 4.460; 95% confidence interval [CI] 1.724–11.536, $P=0.002$; Table 2) and more likely to be functionally independent (OR 6.893; 95% CI 2.677–17.746, $P<0.001$; Table 2) at 3 months.

**Table 2 Multivariable regression analysis of factors associated with good outcome (mRS 0–3) and functional independence (mRS 0–2) at 3 months before propensity score matching**

| Variables | Good outcome (mRS 0–3) | | Functional independence (mRS 0–2) | |
|---|---|---|---|---|
| | OR (95% CI) | *P* value | OR (95% CI) | *P* value |
| Vascular lesion[a] | 4.460 (1.724–11.536) | 0.002 | 6.893 (2.677–17.746) | < 0.001 |
| Age (per year) | 0.958 (0.942–0.974) | < 0.001 | 0.964 (0.949–0.980) | < 0.001 |
| Male sex | 0.809 (0.507–1.291) | 0.374 | 0.940 (0.595–1.484) | 0.790 |
| Hypertension | 1.576 (0.889–2.795) | 0.120 | 1.253 (0.711–2.210) | 0.435 |
| Diabetes | 1.052 (0.585–1.891) | 0.865 | 1.016 (0.565–1.827) | 0.959 |
| Previous ICH | 0.373 (0.171–0.812) | 0.013 | 0.308 (0.135–0.704) | 0.005 |
| Admission GCS | 1.401 (1.305–1.505) | < 0.001 | 1.411 (1.302–1.530) | < 0.001 |
| ICH volume (ml) | 0.982 (0.973–0.992) | < 0.001 | 0.972 (0.960–0.984) | < 0.001 |
| IVH volume (ml) | 0.980 (0.962–0.999) | 0.038 | 0.983 (0.963–1.004) | 0.108 |

*GCS* Glasgow Coma Scale, *ICH* intracerebral hemorrhage, *IVH* intraventricular hemorrhage

[a] Compared with primary ICH

To further verify the association between ICH etiology and outcomes, we created a cohort with a comparable baseline using the nearest neighbor propensity score matching method (1:2). After propensity score matching, we included 177 and 104 patients with primary ICH and structural vascular lesions, respectively (Table 1). We also found that ICH from vascular structure lesions was associated with good outcome (OR 8.418; 95% CI 2.090–33.901, $P = 0.003$; Table 3) and more likely to be functionally independent (OR 25.220; 95% CI 4.202–151.358, $P < 0.001$; Table 3) at 3 months.

## Discussion

This observational study found that ICH due to structural vascular lesions may have a distinct clinical phenotype as compared with primary ICH. ICH due to structural vascular lesions were associated with a higher rate of functional independence and a lower 3-month mortality than primary ICH.

In our study, about half of the patients with ICH due to structural vascular lesions had bleeding sites in cerebral lobes, whereas more than half of the patients with primary ICH had a basal ganglia or thalamus hematoma. A possible explanation would be that hypertensive ICH predominantly affects deep brain structures such as basal ganglia and thalamus, whereas secondary ICH caused by AVM arteriovenous malformation usually occurs in cerebral lobes [17]. Unlike deep ICH, which was associated with poor functional outcome [18, 19], ICH due to vascular lesions are mostly lobar hemorrhages that is associated with better functional outcome.

We found that ICH due to structural vascular lesions had relatively smaller hematomas than primary ICH. The reasons for this may be related to lower BP [20, 21] and venous or capillary bleeding [3, 22, 23]. Consistent with

**Table 3 Multivariable regression analysis of factors associated with good outcome (mRS 0–3) and functional independence (mRS 0–2) at 3 months after propensity score matching**

| Variables | Good outcome (mRS 0–3) | | Functional independence (mRS 0–2) | |
|---|---|---|---|---|
| | OR (95% CI) | *P* value | OR (95% CI) | *P* value |
| Vascular lesion[a] | 8.418 (2.090–33.901) | 0.003 | 25.220 (4.202–151.358) | < 0.001 |
| Age (per year) | 0.961 (0.921–1.002) | 0.064 | 0.975 (0.934–1.018) | 0.253 |
| Male sex | 0.755 (0.234–2.432) | 0.638 | 1.338 (0.362–4.952) | 0.663 |
| Hypertension | 1.771 (0.567–5.531) | 0.325 | 1.787 (0.492–6.493) | 0.378 |
| Diabetes | 1.024 (0.155–6.761) | 0.980 | 3.380 (0.349–32.753) | 0.293 |
| Previous ICH | 0.081 (0.012–0.543) | 0.010 | 0.083 (0.010–0.721) | 0.024 |
| Admission GCS | 1.391 (1.152–1.680) | 0.001 | 1.589 (1.222–2.066) | 0.001 |
| ICH volume (ml) | 0.991 (0.967–1.015) | 0.457 | 0.972 (0.938–1.007) | 0.114 |
| IVH volume (ml) | 0.990 (0.952–1.030) | 0.619 | 0.987 (0.942–1.034) | 0.584 |

*CI* confidence interval, *GCS* Glasgow Coma Scale, *ICH* intracerebral hemorrhage, *IVH* intraventricular hemorrhage, *mRS* modified Rankin Scale, *OR* odds ratio

[a] Compared with primary ICH

previous reports, we found that patients with ICH due to structural vascular lesions were younger and had lower admission NIHSS, and higher admission GCS [24–26].

Furthermore, it was interesting to observe that the time from symptom onset to hospitalization was significantly longer in patients with ICH due to vascular lesions than primary ICH. A possible explanation would be that ICH due to vascular lesions had less severe neurological deficits and the hematomas were mostly located within the nidus or in the venous side with sparing the healthy brain parenchyma [24, 27]. In addition, we noticed that patients with ICH due to structural vascular lesions were more likely to have epileptic symptoms, probably because of the lobar location of the hemorrhage, which may increase the chances of cortical irritation with gliosis, leading to epileptic seizures [28].

Our findings highlight that etiological classification of ICH is important for individualized risk stratification, management, and outcome prediction. SMASH-U and H-ATOMIC are representatives of the etiologic classifications of ICH that have been proposed and shown high interrater reliability [9]. Unlike the H-ATOMIC classification, which is relatively complex and time-consuming [29], the SMUSH-U classification is an easy-to-use system that can be quickly used by experienced emergency physicians or neurologists to classify etiologies and has been widely used in clinical practice. In previous reports, most studies focused on primary ICH. Data are sparse on the etiology and spectrum of secondary ICH, especially ICH due to structural vascular lesions. In our study, we have investigated the clinical and imaging characteristics of different types of hematomas according to the SMASH-U classification. Our findings have shed light on the etiological constituents of ICH. We found that the most common cause of ICH due to structural lesions was AVM, followed by cavernous angioma, cerebral aneurysm, and moyamoya disease. Intracranial aneurysms occur in approximately 2–5% in the general population [30] and are more common than brain AVMs [31]. Because a ruptured aneurysm typically presents with subarachnoid hemorrhage [32], ICH due to ruptured intracranial aneurysm is less common than ICH secondary to AVM. We found that ICH due to cavernous angioma is not uncommon in patients with ICH who had vascular lesions, suggesting that brain MRI might be useful in elucidating the underlying cause of ICH.

## Limitations

Our study has several limitations. First, this is a single-center study, and the natural history of ICH in this population may not be representative of other populations. Second, not all patients received a brain MRI scan in the cohort, which may underestimate the real prevalence of ICH due to structural lesions. Third, the sample size of some subtypes of vascular lesions is relatively small, so all kinds of vascular structural lesions were analyzed uniformly.

## Conclusions

Our study concluded that the patients with ICH due to vascular lesions have smaller hematoma volume and less severe neurological deficit at presentation and better functional outcomes than those with primary ICH. It is of great significance to complete multimodal imaging examination to identify secondary ICH associated with vascular lesions.

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**Author contributions**

QL, X-FW: study concept and design. X-FW, LD, X-NL, Z-QL, Z-JW, XH, M-JP, CC and L-BZ: acquisition of data. X-FW: statistical analysis. Analysis and interpretation of data: all authors. X-FW: drafting of the manuscript. QL, X-FW: critical revision of the manuscript for important intellectual content. QL: obtained funding. QL: study supervision. The authors approved the final manuscript.

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**Conflicts of interest**

The authors declare no competing interests.

**Ethical Approval/Informed Consent**

The Ethics Committee of the First Affiliated Hospital of Chongqing Medical University approved the study protocol.

## Publisher's Note



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