Short-term surgical outcomes of spontaneous intracerebral hemorrhage in China from 2019 to 2021: a retrospective cohort study

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The Lancet Regional Health - Western Pacific 2023;39: 100870

Published Online xxx
https://doi.org/10.1016/j.lanwpc.2023.100870

Summary

Background China has the highest prevalence of spontaneous intracerebral hemorrhage (sICH) worldwide. To date, no national-level report has revealed sICH surgical performance. We aimed to investigate the current status and short-term outcomes of patients who underwent surgical treatment for sICH between 2019 and 2021.

Methods Data from 7451 patients undergoing sICH surgical treatment in China between 2019 and 2021, including demographic information, disease severity, surgical treatments for sICH, complications, and follow-up information, were retrieved from the Bigdata Observatory Platform for Stroke of China. Propensity score matching (PSM) was applied to balance the baseline characteristics. The surgical treatment performance on 3-month mortality and functional outcome were then explored by regression analysis. The influence of stroke center level and region on surgical performance was then explored.

Findings The numbers of sICH patients undergoing open craniotomy (OC), cranial puncture (CP), decompressive craniectomy (DC) and endoscopic evacuation (EE) were 2404 (32.3%), 3030 (40.7%), 1700 (22.8%) and 317 (4.3%), respectively. The 3-month mortality rate was 20.2%. Among the surviving patients, the 3-month poor functional prognosis (mRS 3–5) rate was 46.5%. After PSM, regression analysis showed that DC was associated with a higher mortality risk (OR = 1.31, 95% CI 1.06–1.61) than OC. CP was associated with a lower risk of poor mRS scores than OC (OR = 0.84, 95% CI 0.70–1.01), especially in stroke prevention centers and specific regions.

Interpretation Outcome improvements in Chinese sICH patients undergoing surgical treatment are worth expecting. Inconsistent surgical performance, especially functional outcome, affected by inhomogeneity of the hospital should be addressed.

Funding This work was supported by the Beijing Hospitals Authority Youth Programme (QML20230804), the National Natural Science Foundation of China (81701796, 82030037, 81871009), Capital Health Research and Development of Special Fund (2020-2Z-2019), Science and Technology Innovation 2030-Major Project (2021ZD0201801), and the Translational and Application Project of Brain-inspired and Network Neuroscience on Brain Disorders (11000022T000000444685).

Abbreviations: sICH, spontaneous intracerebral hemorrhage; MIS, minimal invasive surgery; OC, open craniotomy; CP, cranial puncture; DC, decompressive craniectomy; EE, endoscopic evacuation; DALY, disability-adjusted life year; CSPPC, The China Stroke Prevention Project Committee; mRS, modified Rankin Scale; GCS, Glasgow Coma Scale; SBP, systolic blood pressure; RCT, randomized controlled trial; PSM, propensity score matching

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Keywords: Intracerebral hemorrhage; Short-term outcomes; Open craniotomy; Cranial puncture; Decompressive craniectomy; Endoscopic evacuation; Propensity score matching

Research in Context

Evidence before this study

In China, current clinical practice manifested that open craniotomy (OC), cranial puncture (CP) combined with urokinase infusion, decompressive craniectomy (DC) with hematoma evacuation and endoscopic evacuation (EE) are the four major kinds of surgical treatments for sICH. However, the heterogeneous quality of sICH care has been observed. We searched PubMed, Web of science, and Google Scholar on May 4, 2022, for studies published in English describing the surgical outcomes of ICH in China, using the search terms ("surgery" OR "craniotomy" OR "decompressive" OR "evacuation" OR "endoscopic" OR "drainage" OR "cranial puncture" OR "stereotactic") AND "spontaneous intracerebral hemorrhage" AND "outcome" AND "China". We identified no national-level data reports the current surgical practices and outcomes of sICH patients in the real-world.

Added value of this study

In our nationwide study, we described a landscape of comprehensive and heterogeneous sICH surgical treatment outcomes in China. To our knowledge, this is the first and the latest observational report revealing the nationwide population-based performance of mainstream sICH surgical treatments. The number of ICH patients who underwent OC, CP, DC, and EE was 2404 (32.3%), 3030 (40.7%), 1700 (22.8%) and 317 (4.3%), respectively. The 3-month mortality rate was 20.2%. Among the surviving patients, the 3-month poor functional prognosis (mRS score 3–5) rate was 46.5%. After PSM, regression analysis showed that DC was associated with a higher mortality risk (OR = 1.31, 95% CI 1.06–1.61) than OC. CP was associated with a lower risk of poor mRS scores than OC (OR = 0.84, 95% CI 0.70–1.01), especially in stroke prevention centers and specific regions.

Implications of all the available evidence

Outcome improvements in Chinese sICH patients undergoing surgical treatment are worth expecting. Inconsistent surgical performance, especially functional outcome, affected by inhomogeneity of the hospital should be addressed. Apart from diligently exploring better surgical strategies, decision-makers should also engage with the capacity building of healthcare professionals as well as platform construction in China, which is a critical procedure to promote research on sICH care and prevention and further guide the allocation of healthcare resources in the future.

Introduction

China has the highest prevalence of stroke worldwide. According to the results from the Global Burden of Disease Study in 2019, stroke is the leading cause of disability-adjusted life years (DALYs) in China, and the number of DALYs reached 45 million.[1] As the deadliest form of acute stroke, intracerebral hemorrhage (ICH) contributed 25 million DALYs in China in 2019, has an early mortality rate of approximately 30%–40% and has shown no reduction in incidence over recent decades.[1,2] Spontaneous intracerebral hemorrhage (sICH), which is not caused by head trauma and does not have a visualized structural cause, is the most prevalent subtype of hemorrhagic stroke.[1,2] The increased prevalence is expected due to the growth proportion of aging adults, the surging usage of antithrombotic therapies and inadequate stroke management, which makes sICH a heavy burden on the Chinese health system.[3]

Surgical treatment is recognized as a promising strategy to improve sICH prognosis by preventing hematoma expansion and mitigating secondary injury.[4] To date, the well-known challenges in matching surgical treatments to appropriate patients have not been completely resolved. Although the STICH trials I and II showed no overall benefit of open craniotomy (OC) over standard medical treatment,[5,6] minimally invasive evacuation techniques produced promising results, while the MISTIE III trial demonstrated that, compared to medical management, minimal invasive surgery (MIS) did not improve 1-year functional outcome.[4,7] In China, current clinical practice has shown that OC, cranial puncture (CP) combined with urokinase infusion, decompressive craniectomy (DC) with hematoma evacuation and endoscopic evacuation (EE) are the four major kinds of surgical treatments for sICH. However, a heterogeneous quality of sICH care has been observed,[8] partly attributed to the capability of healthcare services to vary across a vast territory of China. To date, no national-level data have reported the current surgical practices and outcomes of sICH patients in the real world, which limits the promotion research of sICH care and prevention, as well as the allocation guidance of healthcare resources in the future.

The China Stroke Prevention Project Committee (CSPPC) was established in April 2011 by the Ministry of Health of China with the goals of setting standards, minimizing variation, and improving quality in China.[9,10] Under the guidance of CSPPC, the construction of two-level stroke centers, i.e., advanced stroke centers and stroke prevention centers began in July 2015. A direct report system named the Bigdata Observatory platform for Stroke of China (BOSC)[8,9] was responsible for monitoring and recording data of stroke patients from stroke centers, providing a valuable opportunity to investigate the current status and short-term outcomes of patients undergoing surgical treatment for sICH in China. By elucidating this information, we aim to provide insights and support the development of healthcare strategies at a national level.

Methods

Data source

We retrospectively retrieved Chinese sICH nationwide data from the BOSC. Demographic information, diagnosis, disease severity, treatment, complications, and 3-month follow-up information between 2019 and 2021 were collected. This study was approved by the institutional review board of Capital Medical University Xuanwu Hospital. Approval was received from the medical ethics committee to report the data on the BOSC without requiring individual informed consent.

Study design and participants

We identified 8615 patients undergoing sICH surgical treatment in 2019–2021 from the BOSC (Fig. 1). After excluding patients with incomplete admission information (n = 1164), 7451 remained for analyses of baseline characteristics and in-hospital outcomes. We further excluded patients without 3-month follow-up information (n = 1261), leaving a sample of 6190 participants (including 263 patients who died in the hospital). To balance the baseline characteristics, propensity score matching (PSM) was repeated 3 times to match OC patients with those receiving surgical treatment with CP, DC, and EE. The surgical treatment performance on 3-month mortality and functional outcome were explored by regression analysis. Interaction effects between four surgical treatments and stroke center level or region were then assessed. We also performed subgroup analysis of stroke center and region on short-term surgical outcomes. Detailed information is presented in the Supplemental Study Protocol.

Measurements and key variables

The variables that were included were as follows: demographic information including sex and age; preoperative information including blood pressure, modified Rankin Scale (mRS) score, Glasgow Coma Scale (GCS) score, ICH volume and ICH site; surgery and postoperative information including surgical treatment, postoperative complications, in-hospital outcomes, and 3-month outcome; and hospital information including region and stroke center. Blood pressure was stratified into normal, grade I, grade II, and grade III according to the Chinese diagnostic standard.[11] The mRS score was dichotomized as poor outcome (mRS 3–5) and favorable outcome (mRS 0–2). The GCS score was stratified into normal consciousness (15), mild coma (12–14), moderate coma (9–11), and severe coma (≤8). ICH volume was stratified into small volume (≤30 mL), medium volume (30–60 mL), and large volume (>60 mL).

Outcomes

The primary outcome was 3-month mortality after surgery. The secondary outcome was the 3-month functional outcome, which was evaluated as a poor outcome (mRS 3–5) or a favorable outcome (mRS 0–2).

Propensity score matching

Propensity of treatment was estimated using a multivariable logistic regression model with baseline age, sex, mRS score on admission, GCS score on admission, ICH volume, ICH site, and hypertension grade. To increase matching precision, patients were matched in a variable matching ratio (5:1–1:1) by nearest neighbor matching using the optimal caliper (0.1 standard deviations of the propensity score). A single patient could be used multiple times in one analysis and across analyses. To account for this, replacement was permitted in these matching models. The R package Marchlt (4.5.2) was applied.

Statistical analysis

The data of continuous variables were described by means and standard deviations (SDs) or medians (interquartile ranges), and categorical variables were represented as numbers and percentages (N, %). Differences between groups were based on the Wilcoxon test for continuous variables and the chi-square test for categorical variables. Post hoc Bonferroni adjustments were applied to compare statistical significance among the different treatments. We performed Hosmer–Lemeshow tests on all regression models to value model assumptions. The results with a two-sided $P < 0.05$ were considered statistically significant. Statistical analyses were performed by SPSS (version 17.0) and R software (version 4.2.3).

Bias

Selection bias may arise from the exclusion of patients with incomplete follow-up information for outcome analysis. We compared the baseline characteristics of the patients with incomplete follow-up information with those of the included population (Supplementary Table S1). To estimate the surgical effect, we performed PSM and controlled for potential confounders to reduce potential bias.

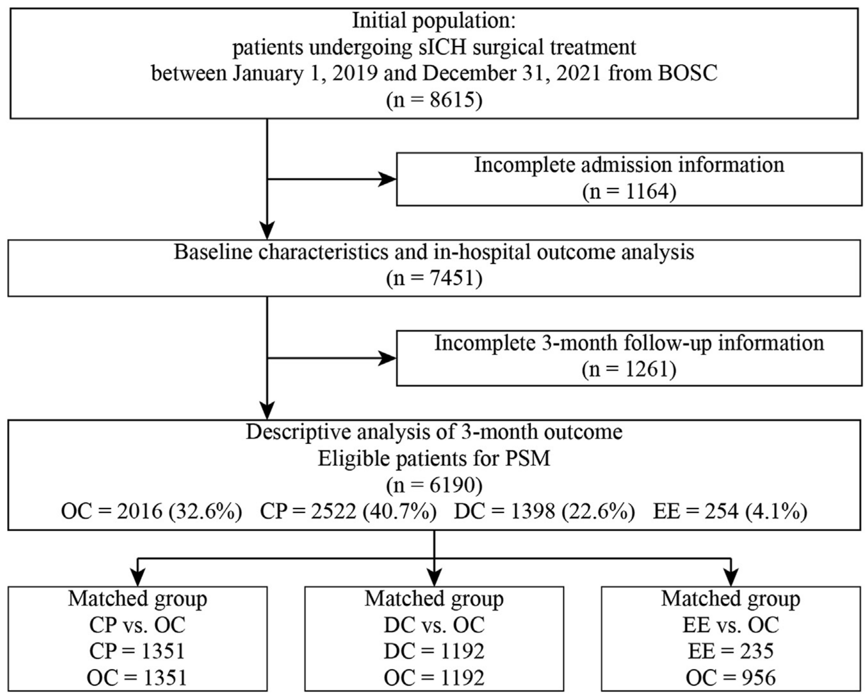

Fig. 1: Study flowchart.

Role of the funding source
The funders did not participate throughout the study design, study conduct, interpretation, or manuscript writing.

Results

Clinical characteristics and surgical treatment
The baseline characteristics of 7451 patients are presented in Table 1. The number of ICH patients who underwent OC, CP, DC, and EE was 2404 (32.3%), 3030 (40.7%), 1700 (22.8%) and 317 (4.3%), respectively. An intergroup imbalance was observed among the different surgical treatments. Compared with the OC group, the CP group comprised older age patients, a higher proportion of preoperative GCS scores of 15, and smaller ICH volume; patients in the DC group had lower preoperative GCS scores, larger ICH volume, and a higher proportion of patients with grade III hypertension; and patients in the EE group had smaller ICH volume, and a higher proportion of cases reported by stroke prevention centers (Supplementary Table S2). Apart from the above unevenly distributed groups regarding disease severity and stroke center, among the four surgical treatments, different surgical treatment preferences were manifested across seven geographical regions of mainland China (Fig. 2).

Outcome assessment
After excluding individuals without 3-month follow-up information, 6190 patients remained (including 263 patients who died in the hospital) and were analyzed for short-term outcome assessment. The 3-month mortality rate was 20.2% (1248/6190 patients). Significant differences were found in the 3-month mortality rate among the four surgical treatments (Table 2). For in-hospital outcomes, significant differences were observed among the four surgical treatments in GCS score at discharge, complications, and mortality (Supplementary Fig. S1). The baseline characteristics comparison and independent risk factor exploration of patients in terms of 3-month mortality to survival are shown in Supplementary Tables S3 and S5.

In the surviving 4942 patients, the 3-month poor functional outcome (mRS 3–5) rate was 46.5% (2298/4942 patients). Significant differences were found in the 3-month functional outcome among the four surgical treatments (Table 2). The 3-month mRS score distribution is presented in Supplementary Fig. S2. The baseline characteristics comparison and independent risk factor exploration of patients in terms of 3-month good functional outcome to poor functional outcome are shown in Supplementary Tables S4 and S5.

Propensity score matching (PSM)
To reduce inconsistent baseline information, we performed propensity matching before assessment of the surgical treatment effect. A total of 6190 patients with 3-month outcome information were prepared for PSM. The propensity score of treatment was estimated with baseline age, sex, mRS score on

Characteristics	Value
Age (range), y	
<45	828 (11.1)
45–70	5434 (72.9)
>70	1189 (16.0)
Sex	
Male	5019 (67.4)
Female	2432 (32.6)
Age, y	58.55 ± 11.75
SBP, mmHg	171.43 ± 28.82
DBP, mmHg	98.10 ± 17.98
Hypertension classification	
Normal	732 (9.8)
Grade I	1502 (20.2)
Grade II	1919 (25.8)
Grade III	3298 (44.3)
Preop mRS score	2.94 ± 2.03
Preop mRS score classification	
Favorable	2845 (38.2)
Poor	4606 (61.8)
Preop GCS score	8.88 ± 3.63
Preop GCS score classification (range)	
15	598 (8.0)
12–14	1574 (21.1)
9–11	1566 (21.0)
3–8	3713 (49.8)
ICH volume, mL	41.94 ± 23.86
ICH volume classification (range), mL	
≤30	2937 (39.4)
30–60	3406 (45.7)
>60	1108 (14.9)
ICH site	
Basal ganglia	4287 (57.5)
Supratentorial lobe	1249 (16.8)
Cerebellum	424 (5.7)
Brainstem	101 (1.4)
Ventricle(s)	1293 (17.4)
Multiple sites	97 (1.3)
Surgical techniques	
OC	2404 (32.3)
CP	3030 (40.7)
DC	1700 (22.8)
EE	317 (4.3)
Stroke center	
Advanced stroke centers	5585 (75.0)
Stroke prevention centers	1866 (25.0)

Data are presented as median ± standard deviation for continuous variables or number (%) for categorical variables.

Table 1: **Summary of patient demographics and clinical characteristics before surgery (N = 7451).**

admission, GCS score on admission, ICH volume, ICH site, and hypertension grade. Considering that different distributions of surgical treatments were observed in stroke centers and regions that may influence the assessment of surgical treatment, we kept these two confounders unmatched for further analysis. The matching process then matched 2702 patients in the CP vs. OC group, 2384 patients in the DC vs. OC group, and 1191 patients in the EE vs. OC group (Fig. 1). After matching, there were few differences within each group (Table 3 and Supplementary Tables S6–S9).

Regression analysis of outcome assessment

To explore the surgical effect, we fitted three statistical models controlling for different variable groups: none were added to Model 1; PSM covariates were added to Model 2; and PSM covariates, stroke center and region were added to Model 3. Model 1 and model 2 showed no difference in outcome assessment in each group, which indicated that PSM successfully balanced the baseline characteristics (Fig. 3). The Hosmer–Lemeshow test results of all the models were $P > 0.05$.

Generally, after eliminating influence from stroke center and region, no significant surgical effect difference was found in Model 3 between OC and CP, DC, EE, except DC showed a significantly higher mortality risk than OC (OR = 1.31, 95% CI 1.06–1.61). However, the surgical effect of CP on both mortality and functional outcome was influenced by stroke center and region when comparing Model 2 with Model 3. For example, adjustment for stroke center and region changed the significant CP risk of mortality to nonsignificant (Model 2: OR = 1.29, 95% CI 1.04–1.59 vs. Model 3: OR = 1.22, 95% CI 0.97–1.52). Similarly, the effect of CP on functional outcome was also influenced by stroke center and region. These results suggested the existence of a complex relationship between different surgical treatment effects and stroke centers or regions.

Regression analysis of outcome assessment by stroke center level

To explore how stroke center influences surgical effect, interaction effects between stroke center and surgical treatment were first explored (Table 4). Then, subgroup analyses of advanced stroke centers and stroke prevention centers were performed (Table 5).

Both stroke center level alone and the interaction between stroke center and surgical treatment showed no association with mortality. In the subgroup analysis, nearly no surgical treatment was associated with mortality assessment, except for DC, which showed a risk of mortality compared with OC in advanced stroke centers (OR = 1.31, 95% CI 1.02–1.68).

However, things changed when we investigated the surgical effect on functional outcome. Stroke prevention centers can independently predict a risk of worse functional outcome in the CP and DC groups (CP: OR = 1.79, 95% CI 1.30–2.45; DC: OR = 1.51, 95% CI

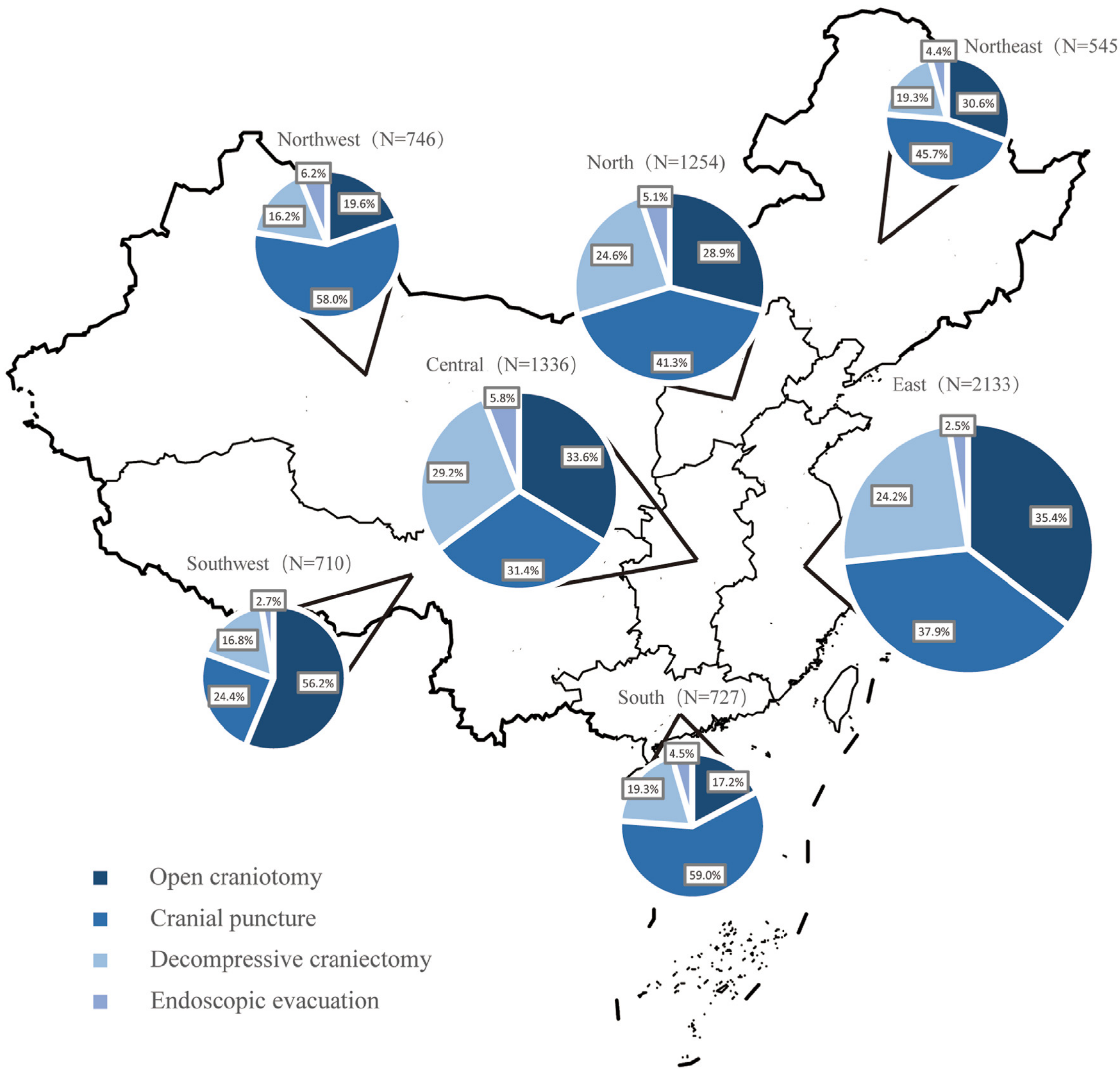

Fig. 2: The distribution of the four surgical treatments in seven geographical regions of mainland China.

	Total	OC	CP	DC	EE	P
3-month follow-up patients	6190	2016	2522	1398	254	
Mortality	1248 (20.2)	343 (17.0)	467 (18.5)	379 (27.1)	59 (23.2)	<0.001
3-month surviving patients	4942	1673	2055	1019	195	
Poor mRS score (3–5)	2298 (46.5)	819 (49.0)	846 (41.2)	539 (52.9)	94 (48.2)	<0.001

Mortality and poor mRS score (3–5) are presented as numbers (%) based on 3-month follow-up patients and 3-month surviving patients, respectively.

***Table 2:* Mortality and functional outcomes among each surgical treatment at the 3-month follow-up.**

1.07–2.14). Meanwhile, stroke center level was associated with worse functional outcome by interacting with surgical treatments such as CP and DC. In the subgroup analysis, CP was associated with good functional outcome compared with OC in stroke prevention centers (OR = 0.54, 95% CI 0.35–0.85).

Regression analysis of outcome assessment by region

To explore how region influences surgical effect, interaction effects between region and surgical treatment were first explored (Table 4). Then, subgroup analyses of different regions were performed (Table 5).

	OC and CP			OC and DC			OC and EE		
	OC (N, %), (N = 1351)	CP (N, %), (N = 1351)	*P*	OC (N, %), (N = 1192)	DC (N, %), (N = 1192)	*P*	OC (N, %), (N = 956)	EE (N, %), (N = 235)	*P*
Age (range), y			0.19			0.97			0.71
<45	154 (11.4)	126 (9.3)		131 (11.0)	129 (10.8)		101 (10.6)	29 (12.3)	
45–70	981 (72.6)	996 (73.7)		903 (75.8)	901 (75.6)		724 (75.7)	173 (73.6)	
>70	216 (16.0)	229 (17.0)		158 (13.3)	162 (13.6)		131 (13.7)	33 (14.0)	
Sex			0.77			0.97			0.74
Male	919 (68.0)	911 (67.4)		797 (66.9)	795 (66.7)		664 (69.5)	160 (68.1)	
Female	432 (32.0)	440 (32.6)		395 (33.1)	397 (33.3)		292 (30.5)	75 (31.9)	
Hypertension classification			0.55			0.90			0.99
Normal	138 (10.2)	131 (9.7)		135 (11.3)	132 (11.1)		86 (9.0)	21 (8.9)	
Grade I	294 (21.8)	267 (19.8)		230 (19.3)	219 (18.4)		186 (19.5)	46 (19.6)	
Grade II	363 (26.9)	374 (27.7)		279 (23.4)	276 (23.2)		215 (22.5)	54 (23.0)	
Grade III	556 (41.2)	579 (42.9)		548 (46.0)	565 (47.4)		469 (49.1)	114 (48.5)	
Preop mRS score classification			0.29			0.41			0.69
Favorable	563 (41.7)	535 (39.6)		405 (34.0)	425 (35.7)		346 (36.2)	89 (37.9)	
Poor	788 (58.3)	816 (60.4)		787 (66.0)	767 (64.3)		610 (63.8)	146 (62.1)	
Preop GCS score classification (range)			0.74			0.84			0.65
15	114 (8.4)	107 (7.9)		59 (4.9)	66 (5.5)		43 (4.5)	15 (6.4)	
12–14	321 (23.8)	314 (23.2)		181 (15.2)	180 (15.1)		233 (24.4)	53 (22.6)	
9–11	347 (25.7)	332 (24.6)		86 (15.6)	196 (16.4)		233 (24.4)	57 (24.3)	
3–8	570 (42.2)	598 (44.3)		766 (64.3)	750 (62.9)		447 (46.8)	110 (46.8)	
ICH volume classification (range), mL			0.60			0.24			0.08
0–30	493 (36.5)	469 (34.7)		307 (25.8)	276 (23.2)		308 (32.2)	94 (40.0)	
30–60	731 (54.1)	747 (55.3)		612 (51.3)	617 (51.8)		521 (54.5)	112 (47.7)	
>60	127 (9.4)	135 (10.0)		273 (22.9)	299 (25.1)		127 (13.3)	29 (12.3)	
ICH site			0.63			0.80			0.16
Basal ganglia	769 (56.9)	802 (59.4)		720 (60.4)	701 (58.8)		623 (65.2)	140 (59.6)	
Supratentorial lobe	239 (17.7)	223 (16.5)		198 (16.6)	219 (18.4)		112 (11.7)	22 (9.4)	
Cerebellum	86 (6.4)	73 (5.43)		96 (8.1)	86 (7.2)		31 (3.2)	8 (3.4)	
Brainstem	23 (1.7)	29 (2.1)		6 (0.5)	5 (0.4)		14 (1.5)	3 (1.3)	
Ventricle(s)	215 (15.9)	203 (15.0)		157 (13.2)	163 (13.7)		166 (17.4)	59 (25.1)	
Multiple sites	19 (1.4)	21 (1.6)		15 (1.3)	18 (1.5)		10 (1.0)	3 (1.3)	
Stroke center			0.99			<0.001			<0.001
Advanced stroke centers	1060 (78.5)	1061 (78.5)		934 (78.4)	839 (70.4)		770 (80.5)	163 (69.4)	
Stroke prevention centers	291 (21.5)	290 (21.5)		258 (21.6)	353 (29.6)		186 (19.5)	72 (30.6)	
Region			<0.001			<0.001			<0.001
Northwest	86 (8.4)	190 (14.1)		83 (7.0)	76 (6.4)		43 (4.5)	30 (12.8)	
Southwest	217 (16.1)	79 (5.8)		189 (15.9)	90 (7.6)		158 (16.5)	10 (4.3)	
North	213 (15.8)	258 (19.1)		216 (18.1)	220 (18.5)		174 (18.2)	54 (23.0)	
Northeast	85 (6.3)	123 (9.1)		76 (6.4)	82 (6.9)		75 (7.8)	19 (8.1)	
Central	269 (19.9)	200 (14.8)		211 (17.7)	264 (22.1)		175 (18.3)	57 (24.3)	
South	59 (4.4)	174 (12.9)		49 (4.1)	72 (6.0)		35 (3.7)	25 (10.6)	
East	422 (31.2)	327 (24.2)		368 (30.9)	388 (32.6)		296 (31.0)	40 (17.0)	

Data are presented as numbers (%) for categorical variables. *P* values for differences between groups were based on the chi-square test for categorical variables.

***Table 3:* Baseline characteristics of the matched patient groups.**

For mortality outcome assessment, region alone was associated with higher mortality risk, while no interaction effect on mortality between region and surgical treatment was observed. In the region subgroup analysis, generally, no association was found between surgical treatment and mortality except for DC, which was associated with a high mortality rate compared with OC in the central China region (OR = 1.89, 95% CI 1.16–3.07).

For functional outcome assessment, similarly, region alone was associated with poor mRS scores. However,

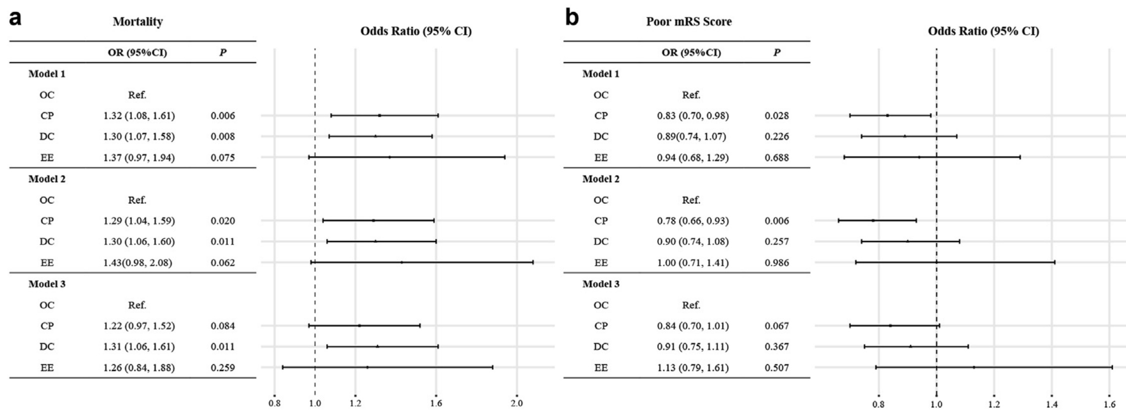

Fig. 3: Logistic regression assessing surgical effect on 3-month outcome assessment. Model 1 unadjusted; Model 2 adjusted for age and sex; and Model 3 adjusted for age, sex, mRS score on admission, GCS score on admission, ICH volume, ICH site, blood pressure and stroke center. a: Logistic regression analysis of 3-month mortality. b: Logistic regression analysis of the 3-month functional outcome.

	CP		DC		EE	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Stroke center for mortality						
Advanced stroke center	Ref.		Ref.		Ref.	
Stroke prevention center	1.41 (0.97, 2.04)	0.07	1.24 (0.87, 1.76)	0.23	1.22 (0.78, 1.90)	0.38
Surgery	1.02 (0.52, 2.00)	0.93	1.27 (0.68, 2.38)	0.45	0.74 (0.23, 2.38)	0.61
Stroke center × surgery	1.14 (0.69, 1.88)	0.60	1.02 (0.64, 1.62)	0.93	1.50 (0.65, 3.42)	0.34
Stroke center for poor functional outcome						
Advanced stroke center	Ref.		Ref.		Ref.	
Stroke prevention center	1.79 (1.30, 2.45)	<0.001	1.51 (1.07, 2.14)	0.017	1.22 (0.78, 1.90)	0.21
Surgery	1.76 (0.99, 3.11)	0.06	1.48 (0.81, 2.69)	0.19	1.35 (0.47, 3.90)	0.57
Stroke center × surgery	0.54 (0.34, 0.85)	0.008	0.68 (0.43, 1.07)	0.093	0.86 (0.39, 1.91)	0.72
Region for mortality						
Northwest	Ref.		Ref.		Ref.	
Southwest	0.68 (0.41, 1.11)	0.11	0.55 (0.34, 0.89)	0.01	0.70 (0.32, 1.52)	0.37
North	0.46 (0.30, 0.71)	<0.001	0.34 (0.22, 0.53)	<0.001	0.40 (0.19, 0.83)	0.01
Northeast	0.83 (0.49, 1.41)	0.50	0.61 (0.35, 1.05)	0.08	1.12 (0.48, 2.57)	0.79
Central	0.41 (0.25, 0.68)	<0.001	0.47 (0.29, 0.75)	0.001	0.60 (0.28, 1.28)	0.19
South	0.57 (0.31, 1.05)	0.07	0.69 (0.38, 1.25)	0.22	0.75 (0.28, 1.97)	0.56
East	0.50 (0.29, 0.85)	0.01	0.44 (0.26, 0.72)	0.001	0.46 (0.22, 0.97)	0.04
Surgery	1.11 (0.65, 1.87)	0.70	1.28 (0.77, 2.12)	0.33	1.78 (0.67, 4.67)	0.24
Region × surgery	1.02 (0.92, 1.14)	0.70	1.00 (0.91, 1.11)	0.94	0.92 (0.74, 1.14)	0.45
Region for poor functional outcome						
Northwest	Ref.		Ref.		Ref.	
Southwest	2.51 (1.57, 3.99)	<0.001	1.59 (0.94, 2.69)	0.081	4.18 (1.87, 9.28)	<0.001
North	1.64 (1.10, 2.45)	0.014	0.95 (0.59, 1.52)	0.82	2.18 (1.04, 4.54)	0.036
Northeast	1.33 (0.81, 2.16)	0.25	1.06 (0.59, 1.87)	0.85	2.05 (0.87, 4.76)	0.091
Central	2.28 (1.44, 3.59)	<0.001	1.58 (0.95, 2.60)	0.072	4.27 (1.97, 9.20)	<0.001
South	1.63 (0.93, 2.83)	0.083	0.80 (0.41, 1.55)	0.51	1.72 (0.65, 4.51)	0.27
East	1.79 (1.10, 2.89)	0.018	1.27 (0.75, 2.15)	0.37	2.84 (1.32, 6.11)	0.0070
Surgery	2.62 (1.63, 4.20)	<0.001	1.39 (0.84, 2.30)	0.20	1.98 (0.78, 5.00)	0.15
Region × surgery	0.78 (0.71, 0.86)	<0.001	0.92 (0.83, 1.01)	0.076	0.88 (0.73, 1.07)	0.20

***Table 4:* Interaction effect of surgical treatment × stroke center and surgical treatment × region on outcome assessment.**

	CP		DC		EE	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Stroke center subgroup analysis						
3-month mortality						
Advanced stroke center	1.16 (0.89, 1.52)	0.27	1.31 (1.02, 1.68)	0.035	1.20 (0.73, 1.97)	0.48
Stroke prevention center	1.28 (0.81, 2.04)	0.29	1.36 (0.91, 2.02)	0.14	1.71 (0.78, 3.79)	0.18
3-month poor mRS score						
Advanced stroke center	0.93 (0.76, 1.15)	0.51	0.99 (0.79, 1.24)	0.95	1.15 (0.76, 1.73)	0.51
Stroke prevention center	0.54 (0.35, 0.85)	0.007	0.71 (0.47, 1.07)	0.099	NA	NA
Region subgroup analysis						
3-month mortality						
Northwest	0.80 (0.40, 1.60)	0.52	1.57 (0.75, 3.30)	0.24	3.78 (0.88, 16.36)	0.075
Southwest	1.69 (0.73, 3.95)	0.22	1.32 (0.66, 2.62)	0.43	3.52 (0.55, 22.62)	0.19
North	1.21 (0.68, 2.15)	0.51	1.25 (0.72, 2.15)	0.43	1.72 (0.62, 4.76)	0.29
Northeast	0.93 (0.40, 2.13)	0.86	0.89 (0.35, 2.27)	0.81	0.28 (0.04, 1.89)	0.19
Central	1.24 (0.71, 2.18)	0.45	1.89 (1.16, 3.07)	0.010	2.05 (0.88, 4.79)	0.097
South	NA	NA	0.97 (0.38, 2.46)	0.94	NA	NA
East	1.23 (0.78, 1.95)	0.37	1.32 (0.89, 1.96)	0.17	0.88 (0.26, 2.94)	0.84
3-month poor mRS score						
Northwest	2.79 (1.21, 6.46)	0.016	3.39 (1.18, 9.72)	0.023	NA	NA
Southwest	0.43 (0.20, 0.94	0.035	0.35 (0.16, 0.75)	0.007	3.27 (0.34, 31.02)	0.30
North	2.36 (1,49, 3,73)	<0.001	1.08 (0.69, 0.75)	0.74	2.61 (1.20, 5.66)	0.015
Northeast	1.00 (0.45, 2.20)	0.99	3.77 (1.53, 9.25)	0.004	NA	NA
Central	0.44 (0.28, 0.68)	<0.001	1.09 (0.70, 1.71)	0.70	0.86 (0.39, 1.87)	0.70
South	1.28 (0.51, 3.12)	0.59	0.56 (0.18, 1.80)	0.33	NA	NA
East	0.42 (0.29, 0.62)	<0.001	0.71 (0.50, 1.00)	0.053	0.57 (0.25, 1.26)	0.16

NA refers to an insufficient sample size to fit the regression model on outcome assessment.

Table 5: **Subgroup analysis of surgical treatments on outcome assessment.**

an interaction effect on functional outcome between region and surgical treatment was observed in the CP group. Complex relationships were observed in functional outcome exploration. Compared with OC, CP was associated with good functional outcomes in Southwest, Central, and Eastern China but associated with poor functional outcomes in Northwest and Northern China. Compared with OC, DC was associated with good functional outcome in southwest China but associated with poor functional outcome in northwest and northern China. EE was associated with poor functional outcome in northern China.

Discussion

The surgical treatment effect on sICH outcome remains controversial. In our study, we investigated the current status and short-term outcome of sICH patients undergoing surgical treatment in China. To our knowledge, this is the first and the latest observational report revealing the nationwide population-based performance of mainstream sICH surgical treatments. We found that the 3-month mortality rate was 20.2%. In the surviving patients, the 3-month poor functional prognosis (mRS 3–5) rate was 46.5%. PSM analysis was performed to further explore the outcome effect among surgical treatments. Generally, compared with OC, CP, DC, and EE showed no difference in mortality and functional outcome, except DC showed a significantly higher mortality risk than OC (OR = 1.31, 95% CI 1.06–1.61). Stroke center level and region can influence the surgical outcome independently or by interaction with surgical treatment. Intriguingly, in stroke prevention centers and specific regions, such as Southwest, Central, and Eastern China, CP served as a protective factor for functional outcome compared with OC. In contrast, in Northwest and Northeast China, CP was associated with poor functional outcomes compared with OC. Our investigation described a landscape of comprehensive and heterogeneous sICH surgical treatment outcomes in China.

Current surgical treatment outcomes in China

In our study with 6190 sICH patients nationwide, we estimated that sICH patients underwent surgical treatments with a 3-month mortality rate of 20.2%. In surviving patients, a 3-month poor functional prognosis (mRS 3–5) rate of 46.5% was estimated.

For patients who underwent OC, the 3-month mortality rate was 17.0%, while the 3-month poor functional prognosis (mRS 3–5) rate was 49.0% in surviving patients. We compared our findings with data from 297 patients from STICH II in the early surgery group (98% of all cases were OC), which showed a 6-month mortality rate of 18% and a 6-month poor functional prognosis (mRS 3–5) rate of 45.2% in surviving patients.[5] A gap was discovered between the outcome performance of OC practices in China and records from international RCTs, considering that a longer follow-up time may lead to an accumulation of poor prognosis patients.

For patients who underwent CP, the 3-month mortality rate was 18.5%, while the 3-month poor functional prognosis (mRS 3–5) rate was 41.2% in surviving patients. We compared our findings with data from 250 patients from MISTIE III in the MIS group.[7] The 6-month mortality rate was 15.0%. In surviving patients, the 12-month poor functional prognosis (mRS 3–5) rate was 77.1%. We cannot conclude the difference between CP practice in China and international evidence due to the difference in follow-up time of outcome measurement. Further studies on 6-month outcomes in Chinese sICH patients are being planned to better communicate with international evidence and provide an in-depth understanding of current surgical performance in China.

General surgical effect on sICH outcome

The advantages and disadvantages of different sICH surgical treatments are the most concerning problems among neurosurgeons. Our nationwide large observational study showed that compared with OC, CP, DC, and EE showed no significant difference in surgical effect on mortality and functional outcome, except DC showed a significantly higher mortality risk (OR = 1.31, 95% CI 1.06–1.61). These real-world results are unexpected and somehow incompatible with other results that CP may contribute to functional improvement and that DC holds lifesaving benefits when compared to OC.[2] The unobserved advantages of CP may be explained by hidden effects from other influencing factors, which will be discussed in the next section.

Our study debated DC as a lifesaving procedure in sICH treatment. Although DC is often associated with clinical deterioration and elevated ICP refractory to medical management, our results were obtained after PSM balancing these above selection biases. The observed DC mortality risk is still unclear. Limited studies have focused on the beneficial effects of DC on functional outcomes. In a small RCT investigating DC added with expansive duraplasty to hematoma evacuation compared to ICH evacuation, researchers reported that a better outcome was seen only in a selected group of patients.[12] Whether DC improves functional outcomes more effectively than OC is still debated.[13–16]

Surgical effect by stroke centers and regions

Although MIS has shown potential functional benefits in the surgical management of ICH, the level of evidence is lower.[7,17,18] In our study, inconsistent surgical performance can be observed across different stroke centers and regions for specific surgical treatments. An observed complex role of CP on surgical outcome reflects this conclusion. CP was associated with good functional outcome compared with OC only in stroke prevention centers. Compared with OC, CP was associated with good functional outcomes in Southwest, Central, and Eastern China but associated with poor functional outcomes in Northwest and Northern China. The reason could be complex. One possible answer is that local health care capacity plays an important role in surgical outcome,[19] which was reflected by our findings that significant differences in surgical treatment preferences exist across seven geographical regions of China. Additionally, stroke centers are unevenly distributed in mainland China.[3] Better performance of CP was associated with good functional outcome compared with OC in stroke prevention centers, which could be explained by the fact that CP is easier for doctors to master. Another possible answer is the variation in the surgical technique for CP. In China, CP combined with urokinase infusion is a common surgical method for the treatment of sICH, which is usually performed by one of the following surgical techniques: surface anatomical landmark-based free-hand surgery, frame-based stereotactic surgery, frameless navigational surgery, and robotic surgery. The influence of different CP techniques should be further investigated. MIS interventions require surgeon and center skill and experience as the basis for recommendations.[2]

The subgroup analysis in our study revealed that for specific stroke centers and regions, surgical treatment mainly affected functional outcomes rather than mortality. For example, CP as an MIS procedure had no influence on the mortality rate compared with OC in any region and stroke center subgroup analysis, which was consistent with the results of other small RCTs[20–23] indicating the lack of a mortality benefit of MIS over OC.[2] It may also suggest that functional outcome improvement, as the most challenging pursuit in sICH treatment, can be reasonably improved by homogenization of stroke management.

Surgical effect of EE

Endoscopic evacuation (EE) is classified as an MIS procedure. Previous meta-analyses of smaller clinical trials and observational studies observed decreased mortality comparing EE with OC.[17,24] However, it is arbitrary to conclude that EE performed better or worse than OC based on the results of our real-world study, where no advantage of EE over OC was found in either decreasing mortality or improving the functional outcome. This may be attributed to the limited sample size of EE to discover the difference, indicating insufficient popularization. Only 317 (4.3%) EE cases were reported in 7451 total sICH surgically treated patients. Meanwhile, the wider confidence interval of the EE effect on outcome demonstrated that a heterogeneous performance existed in the EE technique itself, which also contributed to the difficulties in determining the effect of EE.

This may be explained by the learning curve of neuroendoscopic surgery being long and shallow.[25] EE is recommended by the AHA 2022 guideline with a 2b class of evidence for improving functional outcome. We are looking forward to the upcoming conclusion of RCTs, i.e., ENRICH (NCT02880878), MIRROR (NCT04494295), EVACUATE (NCT04434807), and especially NESICH (NCT05539859) from China to further guide EE practice. The future promotion of EE and homogenization training provide an extra opportunity to enhance surgical treatment outcomes in China.

CSPPC's advances in promoting the capacity building of healthcare professionals and platform construction

In our study, accurate estimation of mortality and functional prognosis in nationwide surgically treated sICH patients and understanding of inconsistent surgical performance affected by the inhomogeneity of hospitals should be attributed to the years of endeavor of CSPPC as an organization at the national level. Established in 2011 by the Ministry of Health,[19] CSPPC is strongly committed to promoting the homogenization of stroke prevention and management and technical capabilities to advance the prevention and treatment of stroke in China. The CSPPC has now established a stroke center network connected with the national population and health science data-sharing platform, provided certification for different levels of stroke care, and supervised stroke treatment. CSPPC engages both the capacity building of healthcare professionals and platform construction to promote future improvement of sICH treatment in China.

Limitations

This study had several limitations. First, our studies could not provide a comparison of surgical treatment to standard medical treatment. This inaccessibility to nonsurgical treatment patients limited the interpretability of our results. Second, since BOSC only collected data from certified stroke centers that provide better sICH management than average, our data represented a higher surgical management quality in current China, which may lead to an optimistic estimation of the current surgical performance and a slight impact on generalizability. A more general nationwide investigation is necessary and urgent to gain insight into this heavy burden related to people's livelihood. Third, given its observational design, the study is insufficient to ascribe specific outcomes to corresponding surgical treatments. Although PSM was performed and confounders were controlled to reduce bias, other undocumented factors, such as surgical timing and hematoma clearance rate, may also influence the prognosis of sICH patients.[4,7] It is difficult to evaluate the magnitude and direction of bias caused by this deficiency. Meanwhile, 3-month outcomes were mainly discussed in our study. However, as a longer follow-up time may lead to an accumulation of poor prognosis patients, further studies with longer follow-up time is required to provide an in-depth understanding of the current surgical performance in China. Last but not least, due to the nature of the available data, we were unable to follow up with the exact time of death for the patients in our study. As a result, we were unable to obtain the necessary information for conducting a comprehensive time-to-event analysis.

Conclusion

Between 2019 and 2021 in China, the 3-month mortality rate of sICH surgical patients was 20.2%. In the surviving patients, the 3-month poor functional prognosis (mRS 3–5) rate was 46.5%. However, region and stroke center level also affected surgical outcome, especially functional outcome. Apart from diligently exploring better surgical strategies, decision-makers should also engage with the capacity building of healthcare professionals as well as platform construction in China, which is a critical procedure to promote research on sICH care and prevention and further guide the allocation of healthcare resources in the future.

Contributors

Ye Li conceived the study, developed the research design and wrote the first draft of the manuscript. Hongyi Yang performed the statistical analyses and wrote the first draft of the manuscript. Lei Cao and Penghu Wei contributed to the design of the research. Yuhong Liu and Xue Wang performed the statistical analyses. Tao Wang and Xuesong Bai collected the data. Guoguang Zhao, Yongzhi Shan and Longde Wang planned the study, secured the funding, and managed the research as the principal investigators. Liqun Jiao and Hongqi Zhang developed the research design and critically revised the manuscript. All authors contributed to and approved the final manuscript.

Data sharing statement

The authors confirm that the data supporting the findings of this study are available within the article and its Supplementary material. Derived data supporting the findings of this study are available from the corresponding author upon request.

Editorial note

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Declaration of interests

The authors report no competing interests.

Acknowledgements

We would like to thank Ruoru Wu for her advice on revising the statistical analysis and interpreting the results and we thank all the hospitals reporting data to the Bigdata Observatory platform for Stroke of China.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2023.100870.

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