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RESEARCH

Posterior fossa ischemic infarction: single-center retrospective review of non-surgical and surgical cases

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Abstract
Cerebellar ischemic stroke (CIS) is a morbid neurological event, with potentially fatal consequences. There is currently no objective standard of care regarding when surgical procedures are required for this entity. We retrospectively reviewed 763 patients with CIS, 247 patients of which had a stroke larger than 1 cm in greatest dimension on cranial imaging. In this subgroup, 11% of patients received ventriculostomy, 12% suboccipital craniectomy, and 9% mechanical endovascular thrombectomy. Various clinical and radiographic variables were examined for relationship to surgical procedures, 30-day mortality rate, and modified Rankin scores. The smallest volume of stroke requiring a surgical procedure was 15.5 mL^3 (BrainLab Software). Patients receiving surgical procedures had a higher incidence of multi-territory infarctions, hydrocephalus, cistern compression, 4th ventricular compression, as well as younger age, lower admission GCS, higher admission NIHSS, and higher 30-day mortality/disability. Patients deemed to require surgical procedures for CIS have a higher expected morbidity and mortality than those not requiring surgery. Various clinical and radiographic variables, including stroke volume, can be used to guide selection of patients requiring surgery.

Keywords Posterior fossa · Infarction · Ischemic stroke · Cerebellar · Hydrocephalus · Craniectomy

Introduction

Posterior fossa infarction is a rare yet potentially lethal neurological event. Comprising < 5% of strokes, the most common symptoms are vertigo, nausea, vomiting, and gait instability—leading to a variety of potential misdiagnoses. Strokes can involve the brainstem alone or cerebellum (cerebellar ischemic stroke, CIS). Early computed tomography (CT) imaging may not display blatant signs of infarction, and clinical decline can be precipitous due to potential cerebellar edema, brainstem compression, acute obstructive hydrocephalus, and tonsillar herniation through the foramen magnum [1]. Hydrocephalus can occur as a result of cerebellar edema in 10–25% of posterior fossa strokes [2]. In the event that a patient becomes comatose or loses brainstem responses, the estimated mortality rate can be as high as 85% [1, 2]. Etiologies of CIS most commonly include embolism, large vessel atherosclerotic disease, or arterial dissection from a variety of precipitating events. Large-vessel disease/embolism, specifically PICA (posterior inferior cerebellar artery), was the most common etiology, at greater than 2/3 of cases [3–5]. Up to 50% of these strokes are limited to the brainstem alone, and approximately 50% show insult in multiple posterior circulation vascular territories [6].

Medical treatment of CIS includes airway protection if the patient is obtunded, permissive hypertension for intracranial perfusion, osmotic therapy for resultant cerebellar edema, control of hyperglycemia and febrile states, antiplatelet and/or anticoagulant medications, and investigation into stroke etiology. Level of consciousness has been proposed to be a strong indicator of prognosis in CIS [7]. Age has also been noted to have relation to outcome [8, 9].

At times, CIS leads to mechanical compression of brain structures and elevated intracranial pressure. If this clinical decline occurs, the typical time-frame after stroke onset is ~ 48–96 h [2, 7, 10]. In this circumstance, multiple surgical procedures may be offered to address compression: ventriculostomy, suboccipital craniectomy, tonsillar/cerebellar resection, or combinations of the above. Neurological decline

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from posterior fossa edema can be acute and dramatic; thus, surgical intervention is typically performed on an urgent basis. In referencing the 2014 American Heart Association/American Stroke Association "Recommendations for the Management of Cerebral and Cerebellar Infarction with Swelling," the optimum surgical procedure for treatment is not known, nor is the ideal time to perform said procedure [11]. Though the literature has a lack of specificity on recommendations for type of surgical intervention in CIS, multiple studies have attempted to identify correlations between clinical and radiographic characteristics [4, 5, 7, 12]. Despite these investigations, no well-established guidelines on these factors and their relation to surgical intervention and outcomes exist. We present a single-center retrospective review of determine factors which predict need for surgical interventions, as well as clinical outcome following stroke.

Materials and methods

The study was performed in line with the principles of the Declaration of Helsinki, and approval was granted by the Peoria Institutional Review Board.

Patient population

We performed a retrospective review study of adult patients admitted from 2011 to 2021 at Saint Francis Medical Center with diagnosis of CIS and available clinical and radiographic data from inpatient hospitalization. Exclusion criteria included patients < 18 years of age, patients with primary diagnosis of hemorrhagic stroke, stroke secondary to vascular malformation pathology or treatment (aneurysm, arteriovenous malformations, fistulae), and patients with suspicion for posterior fossa neoplasm as noted by the neuroradiologist. A total of 247 met the inclusion criteria and were included in analysis. For this type of study, formal consent was not required. Local institutional review board approval was obtained. Figure 1 depicts the patient selection process.

Patient care and surgical decision-making

Upon suspected diagnosis of CIS, the stroke neurology team evaluated the patient and used the National Institutes of Health Stroke Scale (NIHSS) to assess stroke severity. The stroke physician determined if referral for mechanical thrombectomy was needed. If deemed necessary, the neurosurgical service was consulted to evaluate the patient for surgical decompression. The decision to perform surgical decompression or insert ventriculostomy was made by the attending neurosurgeon on call. Eight separate neurosurgeons performed procedures throughout the study period. After discharge from the hospital, patients routinely followed up with the stroke neurology office. Throughout the follow-up period, dependency and functional status were assessed with modified Rankin score (mRS) by personnel in the stroke neurology clinic.

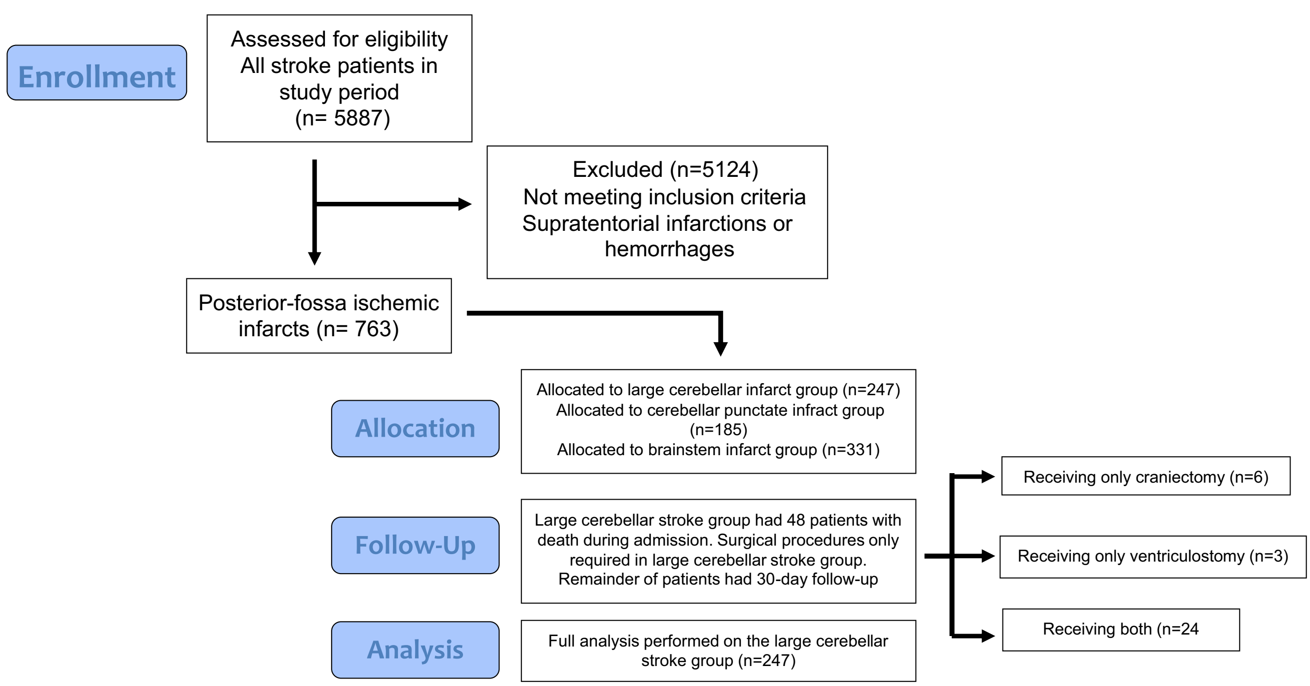

Fig. 1 Flowchart showing patient selection in study

Surgical procedures

If a surgical procedure was deemed necessary, it was performed by the neurosurgical team on call. All craniectomy procedures were performed in a Mayfield head-holder in a prone position with general endotracheal anesthesia with suboccipital craniectomy down to the foramen magnum with dural opening. Cerebellar resection is not typically performed at our institution for stroke. Ventriculostomy was typically performed at the bedside in the intensive care unit under IV sedation following craniectomy, or in the operating room if time allowed. A right frontal transcortical approach was utilized for all ventriculostomy procedures.

Image analysis

During data collection, all images were reviewed by neurosurgery physicians on the study team in a blinded manner. Image files and attending neuroradiology reports were personally reviewed by a physician involved in the study who did not have concurrent access to other patient data while evaluating the image. Images included non-contrast computed tomography (CT) scans, CT angiography, and magnetic resonance (MR) images of the brain. Not all patients had each type of image. After initial screening to determine if isolated brainstem or cerebellar infarctions were present, images with cerebellar infarctions were evaluated using BrainLab (version 4.3, Brainlab, Germany) software for additional volume data calculation. The "ABC/2" volume-estimation formula was also applied to each cerebellar stroke [13, 14]. If available, MRI was used to calculate stroke volume as the preferred study. If MRI was not performed, the CT scan just prior to procedural intervention was used to calculate radiographic variables.

Imaging findings evaluated in our study are defined below and were considered to be present when either the attending neuroradiologist dictated the finding in their imaging report, or when the neurosurgery physician reviewing images considered the finding to be present (Fig. 2).

Hydrocephalus was defined as dilation of the cerebral ventricles out of proportion to atrophy expected for age, with presence of related mass effect. Compression of the 4th ventricle was defined as asymmetric luminal shape or shift due to posterior fossa mass effect adjacent to the ventricle. Compression of the basilar cisterns was defined as narrowing of the cerebrospinal fluid spaces around the ponto-mesencephalic and tentorial incisural spaces, with presence of related mass effect in the posterior fossa. Posterior fossa atrophy was defined as decreased thickness of the cerebellar folia and increased appearance of CSF spaces on midline sagittal imaging of the brain.

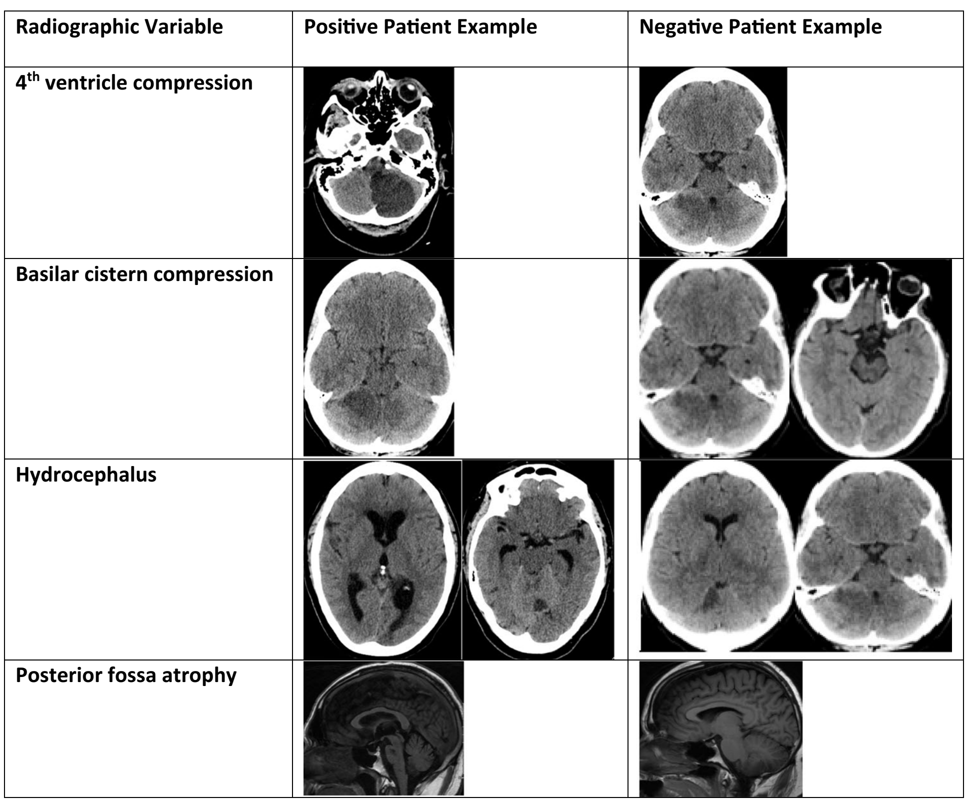

Fig. 2 Examples of radiographic findings assessed in study

Data analysis

Descriptive statistics included mean and standard deviation for continuous variables and frequency and proportion for categorical variables. For continuous variables and categorical variables, *t*-test and chi-square test were conducted, respectively.

For two variables with missing values, multiple imputation method was employed to fill out missing values using available values and other covariates. For infarct volume (10 volumes in patients who received no procedural intervention for their strokes were unable to be calculated due to errors with Brainlab software) and smoking (1 value unable to be identified in medical record), ten imputed values were obtained for each missing data point. The mean value of imputed values was used for any missing data points.

We conducted univariate and multivariable statistical analyses using logistic regression model. Primary outcomes included performance of ventriculostomy, craniectomy, and endovascular thrombectomy procedures. Secondary outcomes included discharge to home, discharge to skilled nursing care, mortality at 30 days, modified Rankin scale at 30 days, mortality at 90 days, and withdrawal of care. Covariates included age, gender, admission Glasgow coma score (GCS), admission National Institutes of Health Stroke Scale (NIHSS), infarct volume as measured by BrainLab software (iPlan version 4.3, Brainlab, Germany), smoking history, atrial fibrillation, hypertension, diabetes, chronic obstructive pulmonary diseases, chronic kidney disease, congestive heart failure, vascular territory, ventricular compression, basilar cistern compression, hydrocephalus, tonsillar herniation, and posterior fossa atrophy. The *p*-value less than or equal to 0.05 was considered to have statistical significance. All analyses were conducted using STATA 16 software (StataCorp., College Station, TX).

Results

Our initial record review of CIS diagnoses over almost a 10-year period yielded 763 patients. Of these, 247 strokes were considered "large" cerebellar strokes (widest diameter of stroke on axial radiographic imaging being > 1 cm). This group represented 32.4% of all patients. In the large cerebellar stroke group, 27 patients required ventriculostomy (11% of group), 30 required suboccipital craniectomy (12.1% of group), and 22 received endovascular mechanical thrombectomy (8.9% of group). Five of the 22 patients undergoing endovascular procedure did not receive mechanical thrombectomy due to apparent resolution of thrombus by the time angiography began. All but three patients receiving mechanical thrombectomy exhibited TICI 3 reperfusion. In the large cerebellar stroke group overall, 156 were male and 91 were female. A total of 48/247 (19.4%) patients in the large cerebellar stroke group had care withdrawn during their hospital stay by decision of medical power-of-attorney. Twelve of these patients required surgical procedures for CIS, and all were considered to have died as a result of their stroke (36.3% of all patients requiring surgical procedures). The remaining 36 patients who had withdrawal of care did not require surgical procedures for CIS. The "small" cerebellar stroke group was comprised of patients with widest diameter of stroke on axial radiographic imaging being ≤ 1 cm; this group included 185 patients (24.2% of all patients). No patients with "small" cerebellar strokes required ventriculostomy or suboccipital craniectomy; the overall 30-day mortality rate in this group was 31.9% (none considered to be direct effect of stroke). There were 331 isolated brainstem strokes, which represented 43.4% of all posterior fossa ischemic strokes. The 30-day mortality rate in this population was 22.3%. No patient with an isolated brainstem stroke required ventriculostomy or craniectomy.

In patients undergoing surgical procedures, there were three patients who received isolated ventriculostomy without craniectomy, and six patients who underwent isolated craniectomy without ventriculostomy. The average Brainlab-calculated volumes of ischemic stroke in patients receiving ventriculostomy, craniectomy, and thrombectomy were 58.0 mL^3, 56.8 mL^3, and 26.7 mL^3 respectively. The smallest Brainlab volumes of stroke receiving ventriculostomy, craniectomy, and thrombectomy were 25.5 mL^3, 15.5 mL^3, and 1.5 mL^3 respectively. Of patients receiving craniectomy, the average diameter of craniectomy in widest direction was 6.5 cm, with average diameter at foramen magnum being 2.5 cm. The average height of occipital bone removed in craniectomy patients was 5.0 cm. Of patients requiring ventriculostomy, the average time of insertion was 88.8 h after last known normal time. The average time for performing suboccipital craniectomy was 61.4 h after last known normal. During the first 24, 48, and 72 h of ICP monitoring, the average ICP recording was 9 mmHg, 11 mmHg, and 11 mmHg, respectively. Average number of hours after last known normal until endovascular thrombectomy was 31.1. No statistical comparison could be made between ICP measurements between procedure groups due to small number of total patients requiring ventriculostomy. It was not possible to compare ICP measurements before or after suboccipital craniectomy due to sample size.

For additional descriptive statistics arranged by primary outcomes, please see Tables 1, 2, and 3.

Patients receiving ventriculostomy had a higher incidence of multiple radiographic variables of interest (multi-territory infarction, hydrocephalus, cistern compression, 4th

Table 1 Descriptive statistics for patients receiving ventriculostomy. *AICA*, anterior inferior cerebellar artery; *CHF*, congestive heart failure; *CI*, confidence interval; *cistern*, basilar cisterns; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GCS*, Glasgow coma score; *GOS*, Glasgow outcome score; *MRS*, modified Rankin score; *NIHSS*, National Institutes of Health Stroke Scale; *PICA*, posterior inferior cerebellar artery; *SCA*, superior cerebellar artery; *Std. Dev*, standard deviation

Variables	Ventriculostomy		No ventriculostomy		*p* value
	Mean	Std. Dev	Mean	Std. Dev	
Age	57.1	14.9	66.1	15.4	**0.005**
Admission GCS	12.7	2.9	13.6	3.0	0.130
Admission NIHSS	8.7	10.0	6.3	9.1	0.197
Brainlab infarct volume	59.9	28.9	19.6	21.3	**< 0.001**
ABC/2 infarct volume	62.6	34.4	18.5	21.4	**< 0.001**
GOS 30 days	3.6	1.4	2.6	1.5	**< 0.001**
NIHSS at discharge	7.6	7.6	4.0	6.3	0.170
MRS at discharge	4.3	1.8	2.8	1.9	**< 0.001**
MRS 30 days	4.3	1.9	2.9	1.9	**0.001**
Variables	Ventriculostomy		No ventriculostomy		*p* value
	Number (%)		Number (%)		
Female	8 (29.6)		82 (37.8)		0.407
Smoking	14 (51.9)		115 (53)		0.911
Atrial fibrillation	8 (29.6)		50 (23)		0.448
Hypertension	22 (81.5)		156 (71.9)		0.290
Diabetes	11 (40.7)		73 (33.6)		0.464
COPD	7 (25.9)		31 (14.3)		0.116
CKD	4 (14.8)		23 (10.6)		0.510
CHF	7 (25.9)		27 (12.4)		0.056
SCA infarct	3 (11.1)		54 (24.9)		0.111
AICA infarct	1 (3.7)		15 (6.9)		0.525
PICA infarct	10 (37)		113 (52.1)		0.141
Multiple-territory infarct	13 (48.2)		35 (16.1)		**< 0.001**
4th ventricular compression	26 (96.3)		64 (29.5)		**< 0.001**
Hydrocephalus	20 (74.1)		6 (2.8)		**< 0.001**
Cistern compression	22 (81.5)		8 (3.7)		**< 0.001**
Posterior fossa atrophy	2 (7.4)		95 (43.8)		**< 0.001**
Discharge to home	0 (0)		104 (47.9)		**< 0.001**
Discharge to skilled nursing	17 (63)		89 (41)		**0.030**
30-day mortality	12 (44.4)		37 (17.1)		**0.001**
90-day mortality	12 (44.4)		41 (18.9)		**0.002**
Withdrawal of care	11 (40.7)		37 (17.1)		**0.003**

Bold values are P less than of equal to 0.05, the level that was considered statistically-significant in the text

ventricular compression, calculated stroke volume), as well as a younger age, higher 30-day mortality, higher MRS at 30 days, and higher rate of withdrawal of care than those who did not receive ventriculostomy (Table 1).

Patients receiving craniectomy had a higher incidence of multiple radiographic variables of interest (multi-territory infarction, hydrocephalus, cistern compression, 4th ventricular compression, calculated stroke volume), as well as a younger age, lower admission GCS, higher admission NIHSS, higher 30-day mortality, higher MRS at 30 days, and higher rate of withdrawal of care than those who did not receive craniectomy (Table 2).

Patients who received mechanical thrombectomy had a lower incidence of PICA-territory infarctions, a lower admission GCS, a higher admission NIHSS, a higher 30-day mortality, higher MRS at 30 days, and higher rate of withdrawal of care than those who did not receive mechanical thrombectomy (Table 3).

In multivariate analysis, younger age, lower admission NIHSS, presence of cistern compression, and hydrocephalus were predictive of ventriculostomy procedure. Only hydrocephalus was predicted of craniectomy in multivariate analysis. Younger age, lower admission GCS, non-smoking status, diagnosis of COPD, and presence of posterior fossa atrophy showed significance for predicting patients receiving mechanical thrombectomy.

Patients with a higher 30-day mortality had lower admission GCS, higher admission NIHSS, higher incidence of diabetes, and lower incidence of isolated PICA-territory infarctions. Patients with a higher MRS at 30 days had a

Table 2 Descriptive statistics for patients receiving craniectomy. *AICA*, anterior inferior cerebellar artery; *CHF*, congestive heart failure; *CI*, confidence interval; *cistern*, basilar cisterns; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GCS*, Glasgow coma score; *GOS*, Glasgow outcome score; *MRS*, modified Rankin score; *NIHSS*, National Institutes of Health Stroke Scale; *PICA*, posterior inferior cerebellar artery; *SCA*, superior cerebellar artery; *Std. Dev*, standard deviation

Variables	Craniectomy		No craniectomy		*p* value
	Mean	Std. Dev	Mean	Std. Dev	
Age	57.2	14.1	66.3	15.5	**0.003**
Admission GCS	12.3	3.3	13.7	2.9	**0.024**
Admission NIHSS	10.2	10.7	6.1	8.9	**0.022**
Brainlab infarct volume	56.6	30.4	19.5	21.2	**< 0.001**
ABC/2 infarct volume	57.7	34.2	18.6	21.9	**< 0.001**
GOS 30 days	3.8	1.1	2.5	1.5	**< 0.001**
NIHSS at discharge	7.4	9.2	3.9	6.0	**0.023**
MRS at discharge	4.5	1.6	2.8	1.9	**< 0.001**
MRS 30 days	4.5	1.5	2.8	1.9	**< 0.001**
Variables	Craniectomy		No craniectomy		*p* value
	Number (%)		Number (%)		
Female	9 (30)		81 (37.9)		0.404
Smoking	13 (43.3)		116 (54.2)		0.264
Atrial fibrillation	9 (30)		49 (22.9)		0.392
Hypertension	22 (73.3)		156 (72.9)		0.960
Diabetes	11 (36.7)		73 (34.1)		0.783
COPD	8 (26.7)		30 (14)		0.074
CKD	4 (13.3)		23 (10.8)		0.672
CHF	7 (23.3)		27 (12.6)		0.112
SCA infarct	4 (13.3)		53 (24.8)		0.166
AICA infarct	0 (0)		16 (7.5)		0.121
PICA infarct	13 (43.3)		110 (51.4)		0.408
Multiple-territory infarct	13 (43.3)		35 (16.4)		**< 0.001**
4th ventricular compression	27 (90)		63 (29.4)		**< 0.001**
Hydrocephalus	20 (66.7)		6 (2.8)		**< 0.001**
Cistern compression	22 (73.3)		8 (3.7)		**< 0.001**
Posterior fossa atrophy	2 (6.7)		95 (44.4)		**< 0.001**
Discharge to home	1 (3.3)		103 (48.1)		**< 0.001**
Discharge to skilled nursing	18 (60)		88 (41.1)		**0.051**
30-day mortality	13 (43.3)		36 (16.8)		**0.001**
90-day mortality	14 (46.7)		39 (18.2)		**< 0.001**
Withdrawal of care	12 (40)		36 (16.8)		**0.003**

Bold values are P less than of equal to 0.05, the level that was considered statistically-significant in the text

higher incidence of craniectomy, older age, higher incidence of diabetes, and lower incidence of isolated PICA-territory infarctions (Table 5). Additional statistical analyses are shown in Tables 4 and 5.

Discussion

In the large cerebellar stroke group, 27 patients required ventriculostomy (11% of group), 30 required suboccipital craniectomy (12.1% of group), and 22 received endovascular mechanical thrombectomy (8.9% of group). These primary outcomes represent 3.5%, 3.9%, and 2.8% of patients with posterior fossa ischemic infarction, respectively.

Level of consciousness

Among the varying signs and symptoms used to predict clinical outcome in cerebellar stroke patients, the least contested is level of consciousness at admission [7, 15–18]. Jauss et al. (1999) found that decreased level of consciousness was the most robust predictor of poor outcome out of all factors examined [7]. Patients who presented with acute decrease in consciousness in the setting of cerebellar infarction had decreased functional outcome in a study by Kelly et al. (2001) [15]. Level of consciousness on admission in our patient group was assessed by NIHSS and GCS. Patients receiving craniectomy and patients receiving mechanical

Table 3 Descriptive statistics for patients receiving endovascular thrombectomy. *AICA*, anterior inferior cerebellar artery; *CHF*, congestive heart failure; *CI*, confidence interval; *cistern*, basilar cisterns; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GCS*, Glasgow coma score; *GOS*, Glasgow outcome score; *MRS*, modified Rankin score; *NIHSS*, National Institutes of Health Stroke Scale; *PICA*, posterior inferior cerebellar artery; *SCA*, superior cerebellar artery; *Std. Dev*, standard deviation

Variables	Thrombectomy		No thrombectomy		*p* value
	Mean	Std. Dev	Mean	Std. Dev	
Age	60	17.3	65.7	15.4	0.108
Admission GCS	9.2	4.5	13.9	2.5	**< 0.001**
Admission NIHSS	17.7	13.0	5.5	8.0	**< 0.001**
Brainlab infarct volume	28.1	40.7	23.7	23.7	0.433
ABC/2 infarct volume	27.1	42.7	23.0	25.0	0.495
GOS 30 days	3.8	1.4	2.6	1.5	**< 0.001**
NIHSS at discharge	13.2	10.9	3.6	5.6	**< 0.001**
MRS at discharge	4.5	1.6	2.8	1.9	**< 0.001**
MRS 30 days	4.5	1.7	2.9	2.0	**< 0.001**
Variables	Thrombectomy		No thrombectomy		*p* value
	Number (%)		Number (%)		
Female	7 (31.8)		83 (37.4)		0.606
Smoking	9 (40.9)		120 (54.1)		0.239
Atrial fibrillation	5 (22.7)		53 (23.9)		0.904
Hypertension	16 (72.7)		162 (73)		0.980
Diabetes	8 (36.4)		76 (34.2)		0.841
COPD	5 (22.7)		33 (14.9)		0.332
CKD	0 (0)		27 (12.2)		0.083
CHF	2 (9.1)		32 (14.4)		0.492
SCA infarct	8 (36.4)		49 (22.1)		0.131
AICA infarct	3 (13.6)		13 (5.9)		0.160
PICA infarct	4 (18.2)		119 (53.6)		**0.002**
Multiple-territory infarct	7 (31.8)		41 (18.5)		0.133
4th ventricular compression	8 (36.4)		82 (36.9)		0.958
Hydrocephalus	3 (13.6)		23 (10.4)		0.635
Cistern compression	4 (18.2)		26 (11.7)		0.378
Posterior fossa atrophy	13 (59.1)		84 (37.8)		0.052
Discharge to home	4 (18.2)		100 (45.1)		**0.015**
Discharge to skilled nursing	9 (40.9)		97 (43.7)		0.802
30-day mortality	10 (45.5)		43 (19.4)		**0.002**
90-day mortality	10 (45.5)		43 (19.4)		**0.005**
Withdrawal of care	10 (45.5)		38 (17.1)		**0.001**

Bold values are P less than of equal to 0.05, the level that was considered statistically-significant in the text

thrombectomy had lower admission GCS and higher admission NIHSS. GCS had and expected inverse relationship with 30-day mortality rate, and admission NIHSS had a positive correlation with this outcome.

Ayling et al. (2018) and Tsitsopoulos et al. (2011) found that advanced age was not associated with worse outcomes; however, other groups show advanced age as predictor of poor outcome [8, 9, 17, 18]. In our patient group, older patients received significantly less ventriculostomy and mechanical endovascular thrombectomy. One potential bias may be the idea that elderly patients are offered less surgical intervention due to an assumption of worse prognosis. Though older patients were offered less ventriculostomy and mechanical thrombectomy, no significant association between age and craniectomy was seen on multivariate analysis, which would support the idea that elderly patients with stroke were offered surgery when relevant. Age was not predictive of mortality at 30 days in our patient sample, but older patients had a very slight increase in disability. Without a randomized trial arm, the complex interaction between age, expected clinical outcome, and likelihood of certain medical and surgical treatments being offered to each patient remains unknown.

Table 4 Multivariate analysis of variables predictive for each procedural primary outcome in posterior fossa stroke patients. *CHF*, congestive heart failure; *CI*, confidence interval; *cistern*, basilar cisterns; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GCS*, Glasgow coma score; *NIHSS*, National Institutes of Health Stroke Scale; *PICA*, posterior inferior cerebellar artery

	Ventriculostomy			**Craniectomy**			**Endovascular intervention**		
Variable	Odds ratio	95% CI	*p*	Odds ratio	95% CI	*p*	Odds ratio	95% CI	*p*
Age	0.92	0.85–1	**0.040**	0.95	0.9–1	0.056	0.94	0.89–0.98	**0.009**
Admission GCS	1.19	0.65–2.15	0.577	1.08	0.75–1.55	0.671	0.73	0.58–0.90	**0.004**
Admission NIHSS	0.78	0.62–0.98	**0.033**	0.99	0.88–1.1	0.810	1.07	0.99–1.16	0.077
Infarct volume	1.01	0.96–1.07	0.682	1.00	0.97–1.03	0.868	1.01	0.98–1.04	0.706
Female	0.36	0.03–3.72	0.390	0.49	0.12–2.13	0.344	0.73	0.17–3.12	0.674
Smoking	2.21	0.23–21.12	0.492	0.39	0.09–1.62	0.194	0.16	0.03–0.8	**0.026**
Atrial fibrillation	0.36	0.02–5.79	0.475	1.26	0.25–6.42	0.782	0.68	0.14–3.43	0.641
Hypertension	8.82	0.51–151.19	0.133	1.19	0.26–5.4	0.824	1.48	0.28–7.96	0.647
Diabetes	0.11	0–3.4	0.206	0.43	0.07–2.73	0.374	0.39	0.09–1.75	0.218
COPD	0.48	0.02–10.50	0.640	2.46	0.28–21.71	0.419	8.19	1.16–58.09	**0.035**
CHF	9.07	0.17–470	0.274	3.02	0.26–35.12	0.377	0.75	0.06–8.67	0.815
PICA territory	2.53	0.08–81.74	0.600	3.32	0.45–24.66	0.241	0.33	0.06–1.77	0.196
Multiple vessel territory	2.55	0.07–90.83	0.607	1.34	0.15–12.29	0.795	1.10	0.18–6.58	0.919
4th ventricle compression	7.49	0.49–115	0.148	3.65	0.61–21.87	0.156	1.96	0.32–11.96	0.465
Cistern compression	38.44	1.66–887	**0.023**	5.57	0.63–48.88	0.121	11.09	0.27–460	0.206
Hydrocephalus	87.55	1.6–4783	**0.028**	8.73	1.29–59	**0.027**	0.10	0–4.32	0.232
Posterior fossa atrophy	0.72	0.03–15.02	0.830	0.32	0.04–2.37	0.266	15.33	2.31–101.62	**0.005**

Bold values are P less than of equal to 0.05, the level that was considered statistically-significant in the text

Table 5 Multivariate analysis of variables predictive for select secondary outcomes in posterior fossa stroke patients. *CHF*, congestive heart failure; *CI*, confidence interval; *cistern*, basilar cisterns; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *GCS*, Glasgow coma score; *NIHSS*, National Institutes of Health Stroke Scale. *PICA*, posterior inferior cerebellar artery

	Mortality at 30 days			mRS at 30 days		
Variable	Odds ratio	95% CI	*p*	Coefficient	95% CI	*p*
Ventriculostomy	3.95	0.25–62.34	0.329	− 0.07	− 0.48 to 0.35	0.756
Craniectomy	3.35	0.24–47.67	0.372	0.51	0.13–0.88	**0.008**
Thrombectomy	0.39	0.05–3.36	0.391	− 0.08	− 0.035 to 0.20	0.583
Age	1.04	1.00–1.08	0.067	0.01	0.00–0.01	**0.046**
Admission GCS	0.70	0.55–0.88	**0.002**	− 0.03	− 0.07 to 0.00	0.052
Admission NIHSS	1.11	1.04–1.19	**0.002**	0.02	0.01–0.03	**0.000**
Infarct volume	1.03	1.00–1.06	0.080	0.00	0.00–0.01	**0.039**
Female	0.91	0.28–2.94	0.871	− 0.04	− 0.20 to 0.12	0.635
Smoking	3.13	0.84–11.61	0.088	0.02	− 0.14 to 0.19	0.788
Atrial fibrillation	1.14	0.34–3.80	0.831	0.04	− 0.14 to 0.22	0.634
Hypertension	1.57	0.34–7.28	0.566	0.16	− 0.05 to 036	0.128
Diabetes	4.60	1.33–15.97	**0.016**	0.18	0.01–0.35	**0.040**
COPD	1.26	0.34–4.71	0.731	0.04	− 0.18 to 0.26	0.708
CKD	1.13	0.22–5.77	0.885	0.07	− 0.20 to 0.33	0.617
CHF	0.46	0.09–2.39	0.355	0.00	− 0.24 to 0.24	0.977
PICA territory	0.24	0.06–0.95	**0.042**	− 0.22	− 0.41 to 0.02	**0.028**
Multiple vessel territory	0.49	0.10–2.33	0.373	− 0.14	− 0.38 to 0.09	0.234
4th ventricle compression	0.72	0.16–3.14	0.657	0.06	− 0.15 to 0.26	0.581
Cistern compression	3.28	0.15–69.96	0.446	− 0.08	− 0.54 to 0.39	0.749
Hydrocephalus	0.14	0.01–1.73	0125	− 0.25	− 0.64 to 0.13	0.196
Posterior fossa atrophy	0.97	025–3.71	0.966	0.05	− 0.13 to 0.23	0.584

Bold values are P less than of equal to 0.05, the level that was considered statistically-significant in the text

Radiographic variables

Vascular territory affected in stroke is a variable of interest in several studies and is not uncommon [16, 19]. Kase et al. studied 66 patients with posterior fossa stroke and found a higher rate of mortality and disability in patients with PICA stroke when compared to SCA stroke [10]. The opposite was found in larger study by Toghi showing a higher rate of comatose state and correlative death and disability with SCA infarctions compared to PICA and AICA [16]. Kelly et al. noted worse functional outcome with SCA territory infarctions [15]. Infarction territories in our study were classified into the three major vessels supplying the posterior circulation, with a separate group if multiple territories were involved. Multi-territory infarctions typically have a higher volume of affected tissue. Patients with multiple-territory infarctions received more ventriculostomy and craniectomy but multi-vessel territory infarction was not predictive of discharge disposition or 30-day mortality rate. Glass et al. studied more than 400 patients with posterior circulation infarctions and noted that multiple-vascular territory infarctions had worse functional outcome. This has been mirrored by other studies [6, 20]. Patients with isolated PICA infarctions in our study showed a lower relative mortality rate when compared to other territories. This may be related to the idea that PICA infarctions tend to affect the brainstem less than SCA or AICA strokes. A clinical and pathological study by Amarenco and Hauw noted a high frequency (73%) of associated rostral basilar territory ischemic injury in SCA infarcts [21]. A study by the same group noted no stroke-related death in isolated PICA infarctions, with a very low incidence of concurrent brainstem infarction [22]. In a review of 124 patients with cerebellar infarction, Cano et al. found that more PICA infarcts had associated hydrocephalus, and multi-territory infarctions had worse functional outcomes than isolated PICA [23]. These and our data may suggest that isolated PICA infarctions may have a less morbid course, and that neurological decline from PICA infarctions may be related to the treatable entity of hydrocephalus, as opposed to concurrent brainstem ischemic injury.

In situations where multiple vascular territories are involved in stroke, compressive symptoms may develop. Multiple studies have reported a ~ 3–4-day time interval between stroke onset and clinical decline suggesting posterior fossa compression in CIS [2, 7, 10]. A larger retrospective study of 322 patients with CIS by Pfefferkorn et al. (2009) suggested an overall 40% mortality with no correlation between the interval between symptom onset-surgery and outcome [4]. In our own patient group, the average timing of suboccipital craniectomy was 61 h. The most typical procedure for our patient group to receive was suboccipital craniectomy, with the majority of patients receiving ventriculostomy placement following boney decompression.

Other indices used to estimate mass effect in the posterior fossa include hydrocephalus, compression of the 4th ventricle, and cisternal compression. Tonsillar herniation is typically a late finding and portends a terminal prognosis, so was not formally analyzed in our study. A retrospective study from Juttler et al. [5] labeled pre-operative basal cistern effacement as a predictor of poor outcome in CIS. Patients with PICA and SCA infarctions were more likely to have mass-effect and ventricular compression on MR imaging in another retrospective review [12]. In the same study, 4th ventricular shift, brainstem compression, hydrocephalus, and basilar cistern effacement were shown to have correlation with clinical decline and need for surgical intervention [12]. Multivariate analysis of our group showed hydrocephalus and cistern compression as a significant predictor of ventriculostomy procedure. Hydrocephalus was also significantly related to performance of craniectomy, showing the agreement between our data and the existing literature for this variable and other consistently stated radiographic variables that occur in patients receiving surgery.

Preoperative stroke volume as an outcome predictor

Although cisternal compression and hydrocephalus are surrogate markers for posterior fossa compartment syndrome, the actual volume of a stroke is also relevant for surgical considerations. The volume of tissue affected by posterior fossa stroke was calculated via BrainLab software (Munich, Germany) and the "ABC/2" method in our patient population. The "ABC/2" formula allows for quick approximation of the volume of intracerebral lesions with little training required and has high inter-rater reliability for ischemic strokes [14, 24, 25]. In our own study, the ABC/2 method had very high correlation with Brainlab software volume calculations, which was used for formal analysis in our patients. The smallest calculated stroke volume that received surgery was 15.5 mL^3. Volumes calculated in our surgical procedure group were statistically higher than those not receiving procedures. It may be pertinent to calculate volume regularly on CIS patients during admission to guide suspicion for development of posterior fossa compartment syndrome that requires surgery. No relationship was seen between stroke volume and 30-day mortality or disability, however. Puffer et al. did not find volume of infarct as a factor predicting 30-day mortality in their analysis [8]. A separate study of patients receiving suboccipital craniectomy for cerebellar infarction did not find a relationship between pre/post-operative volumetric measurements and clinical outcomes [26]. This study performed craniotomy in approximately 1/3 of patients (as opposed to craniectomy) and resection of necrotic cerebellum in a similar proportion of the sample [26]. Post-operative volumetric analysis was performed and demonstrated reduction of mean infarct size to ½ that before necrosectomy [26]. Since surgery performed at our institution did not include brain resection or craniotomy in any cases, it would be difficult to determine how these events impact functional outcome. The mean pre-operative volume in Fernandes et al. (64 mL^3) was relatively similar to our patient group receiving surgical intervention (Tables 1 and 2), and neither study showed a strong relationship between pre-operative stroke volume and clinical outcomes (Table 5). Time to surgical decompression from stroke onset was similar between studies [26]. Both this and our work utilized BrainLab software to calculate stroke volume.

Apart from volume of ischemic lesion, our study also categorized patients as having or not-having cerebellar atrophy. This was determined by the study team on evaluation of midline sagittal imaging. Patients perceived to have cerebellar atrophy may be seen as having less significant stroke mass effect requiring surgical decompression. It may be reasonable to suggest that the presence of posterior fossa atrophy reflects an underlying lack of reserve of a brain to deal with ischemic insult or a decreased functionality at baseline. Studies have shown that intelligence quotient correlates inversely with brain atrophy, and that all patients have age-related brain atrophy (males > females) [27]. There is also a significant correlation between cerebellar atrophy and disability in conditions such a multiple sclerosis, spinocerebellar ataxia, and in patients with childhood posterior fossa neoplasm resection [28, 29]. In our patients with "large" CIS, 36% had cerebellar atrophy. Of the patients with atrophy in this group, the average mRS on 30 days after stroke was 3.10, compared to 3.01 in those without atrophy. In the subset of large CIS requiring surgery, patients with and without cerebellar atrophy had an average 30-day mRS of 3.25 and 4.75, respectively. Despite these perspectives, no relationship was found between atrophy and 30-day mortality or MRS in our study. These clinical outcomes may be of limited value, as only four patients in the ventriculostomy and craniectomy group were found to have cerebellar atrophy. The relationship between presence of cerebellar atrophy and clinical outcome following ischemic stroke may be complex; it is uncertain if atrophy predisposes to more or less toleration of ischemic mass lesions.

Implications and limitations

Our above data supports known literature in that level of consciousness shows a strong correlation with stroke severity, procedural interventions, and clinical outcomes in CIS. Close monitoring of this variable is required for the first 3–5 days following stroke, as neurological decline requiring surgery typically occurs at 48–72 h. Multiple radiographic parameters were found to be significantly related to performance of surgical procedures for CIS. Hydrocephalus, cistern compression, and 4th ventricular compression should all be noted by the evaluating surgical team, and stroke volume should be calculated. Brainlab software is a useful tool for quick volume calculation. We propose considering all stroke volumes > 15 mL^3 as at-risk for clinical decline from compression affect and a potential candidate for craniectomy/ventriculostomy, as no stroke smaller than this in our data was deemed to require surgical intervention. Based on our data, increasing stroke volumes, especially with multi-territory involvement, should increasingly be considered for surgical intervention at or below GCS of 13. Patients requiring surgical procedures for CIS are likely much more ill than those managed non-surgically and tend to have worse morbidity and mortality. Mortality in larger cerebellar ischemic strokes is typically related to direct effects of the stroke.

A major limitation of our study is the smaller sample size of patients receiving surgery as a proportion of our total sample size. Determining which size of stroke is alarming is not a uniform feature across studies—our study chose a threshold of 1 cm diameter on axial imaging, which is not standardized. Calculating the true volume of brain tissue affected by stroke is difficult. We attempted to address this by including two separate methods of calculation. The inter-rater reliability of use of Brainlab software to assess lesion volume is not well documented in the literature. The ABC/2 score has been shown to have high inter-rater reliability, but various studies document the tendency of this method to incorrectly estimate lesion volume—primarily due to the formulaic assumption that simple ellipsoid geometry is involved [13, 14]. User error inherent to these methods may have introduced inaccuracies into the determined relationship between volume and need for surgical intervention. Due to differences in the pathophysiology of ischemic and hemorrhagic cerebellar infarctions, the Kirollos protocol for measurement of 4th ventricular effacement was not applied to our study [30]. The radiographic analysis in our study could have been further improved if a standardized imaging protocol existed for all patients with CIS at our institution, as any imaging available was obtained at the discretion of the supervising care physician. The retrospective nature of our study is another clear limitation.

Author contribution All authors contributed to the study conception and design. Material preparation and data collection were performed by Nolan Winslow, Sven Ivankovic, Jonathan Garst, Elsa Olson, and Ryan Martin. The initial draft of the manuscript was written by Nolan Winslow and Ryan Martin. All authors commented on previous versions of the manuscript for revision purposes. All authors reviewed and approved the final version of the manuscript.

Data Availability Data are not publicly available but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval The study was performed in line with the principles of the Declaration of Helsinki, and approval was granted by the Peoria Institutional Review Board.

Competing interests The authors declare no competing interests.

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