



## Minimally Invasive Surgery for Spontaneous Cerebellar Hemorrhage: A Multicenter Study

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■ **BACKGROUND:** Spontaneous intracranial hemorrhage (ICH) of the cerebellum can be life threatening because of mass effect on the brainstem and fourth ventricle. Suboccipital craniectomy is currently the treatment of choice for cerebellar ICH evacuation. Minimally invasive surgery (MIS) is currently being investigated for the treatment of supratentorial ICH. However, its utility for cerebellar ICH is unknown. The aim of this multicenter, retrospective cohort study is to evaluate the outcomes of MIS for cerebellar ICH.

■ **METHODS:** We retrospectively reviewed the records of all patients with cerebellar ICH who underwent MIS using either the Apollo or Artemis Neuro Evacuation Device (Penumbra Inc., Alameda, California, USA) at 3 institutions from May 2015 to July 2018. Data from each contributing center were deidentified and pooled for analysis.

■ **RESULTS:** The study cohort comprised 6 patients with a median age of 62.5 years. The median pre- and post-operative Glasgow Coma Scale scores were 10.5 and 15, respectively. The median degree of hematoma evacuation was 97.5% (range, 79%–100%). There were no procedural complications, but 1 patient required subsequent craniectomy (retreatment rate 17%). The median discharge modified Rankin scale score was 4, including 3 patients who improved to functional independence at follow-up durations of 3 months. Two patients died from medical complications (mortality rate 33%).

■ **CONCLUSIONS:** MIS could represent a reasonable alternative to conventional surgery for the treatment of appropriately selected patients with cerebellar ICH. However, further studies are needed to clarify the perioperative and long-term risk to benefit profiles of this technique.

### INTRODUCTION

Spontaneous intracranial hemorrhage (ICH) accounts for 10%–20% of all strokes and causes significant disability and death.<sup>1,2</sup> The cerebellum is a relatively uncommon location for nontraumatic ICH, comprising only 5%–12.5% of cases.<sup>3</sup> Cerebellar ICH generally carries a dismal prognosis, with mortality rates of 18%–75%.<sup>3</sup> The current management of cerebellar ICH ranges from conservative management for small, minimally symptomatic hematomas in neurologically stable patients to emergent suboccipital craniectomy with or without external ventricular drain placement for large (diameter >3 cm) hematomas causing compression of the brainstem or fourth ventricle.<sup>4,5</sup> Minimally invasive surgery (MIS) has been extensively investigated as an alternative to conventional craniotomy for the treatment of supratentorial ICH,<sup>6–9</sup> and the Artemis (formerly Apollo) Neuro Evacuation Device (Penumbra Inc., Alameda, California, USA) is one such system that has been specifically designed for the minimally invasive treatment of ICH.<sup>10,11</sup> However, unlike supratentorial ICH, the literature describing MIS for

### Key words

- Apollo
- Artemis
- Cerebellum
- Endoscopy
- Intracranial hemorrhages
- Minimally invasive
- Stroke

### Abbreviations and Acronyms

- CT:** Computed tomography  
**GCS:** Glasgow Coma Scale  
**ICH:** Intracranial hemorrhage  
**MIS:** Minimally invasive surgery

**mRS:** Modified Rankin scale

**OR:** Odds ratio

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cerebellar ICH is sparse.<sup>12,13</sup> Therefore, the aim of this multicenter, retrospective cohort study is to evaluate the outcomes of MIS for the treatment of cerebellar ICH using the Apollo and Artemis devices.

## METHODS

### Patient Selection

We retrospectively reviewed the medical records of all patients presenting with cerebellar ICH who underwent MIS using the Apollo or Artemis device at 3 participating centers between March 2015 and July 2018. Institutional review board approval was obtained from each participating center, and the need for patient consent was waived because of the retrospective design of the study. The eligibility criteria for the use of MIS for cerebellar ICH evacuation included hematoma volume  $\leq 30$  cm<sup>3</sup>, symptomatic of brainstem compression, progressive neurologic deterioration, and obstructive hydrocephalus because of fourth ventricular compression.

### Neuroimaging Evaluation

Preoperative thin-slice (slice width  $\leq 1$  mm) brain computed tomography (CT) scan was performed in each patient. Hematoma volume was calculated based on preoperative CT scan using the modified ellipsoid formula as follows:  $(A \times B \times C)/2$ , where A, B, and C are the maximum diameters of the hematoma in each of the 3 dimensions. Postoperative brain CT scan was performed in each patient, and it was compared with the preoperative CT scan to determine the degree of hematoma evacuation.

### MIS Technique for Cerebellar ICH

After induction of general endotracheal anesthesia, the patient's calvarium was affixed in a 3-point fixation Mayfield Skull Clamp System (Integra LifeSciences, Plainsboro, New Jersey, USA). The patient was placed in the prone position with head rotation toward the side of the hematoma in Mayfield pins, and StealthStation (Medtronic, Minneapolis, Minnesota, USA) or BrainLab (BrainLab, Munich, Germany) was registered for frameless stereotactic neuronavigation. Neuronavigation registration was performed in a standard manner using anatomic surface landmarks and additional surface refinement. A trajectory along the long axis of the hematoma was planned. A suboccipital burr hole was trephined, and using neuronavigation, a peel-away sheath was advanced to approximately two thirds of the long axis of the hematoma. The Apollo or Artemis device was then advanced through the sheath. The device was then used to aspirate the hematoma under direct visualization with an endoscope for most cases. Repetitive cycles of irrigation and clot fragmentation were performed to ensure satisfactory evacuation of the hematoma. Copious irrigation was used to control intraoperative hemorrhage. In the event of intraoperative bleeding refractory to irrigation, a monopolar electrocautery probe was advanced through the endoscope and used to cauterize any persistent sources of hemorrhage. Once hematoma removal was deemed to be satisfactory by the operating neurosurgeon, the Apollo or Artemis device and sheath were removed, and the burr hole defect and incision were closed in a standard fashion.

### Baseline and Follow-Up Data

Baseline data comprised patient demographics, clinical presentation, ICH scores, and hematoma characteristics. Patient demographics included age, sex, baseline modified Rankin scale (mRS) score, and preexisting medical comorbidities. Clinical presentation included symptoms and Glasgow Coma Scale (GCS) score at presentation. Hematoma characteristics included hematoma volume and presence of intraventricular hemorrhage with or without hydrocephalus.

Follow-up data included degree of hematoma evacuation, postoperative neurologic status (classified as improved, unchanged, or worsened), discharge status, follow-up duration, and mRS score at last follow-up.

### Statistical Analysis

Microsoft Excel 2016 (Microsoft Corp., Redmond, Washington, USA) was used to collect and analyze data. Baseline and follow-up variables were analyzed using descriptive statistics. Categorical variables were presented as frequency and percentages, and continuous variables were presented as median and range.

## RESULTS

The study cohort comprised 6 patients, including 4 from the University of Louisville and 1 each from the University of Maryland and Geisinger Medical Center. **Table 1** details the baseline characteristics and postoperative outcomes of the study cohort.

### Baseline Characteristics

The median age was 62.5 years (range, 44–69 years), and 80% were men. The median baseline mRS score was 0 (range, 0–3). The clinical presentations included severe headache in 1 patient (17%), dysarthria in 2 patients (33%), hemiplegia in 1 patient (17%), and respiratory failure and coma in 3 patients (50%). Median GCS score on admission was 10.5 (range, 4–14). The median hematoma volume was 19.5 cm<sup>3</sup> (range, 15–30 cm<sup>3</sup>). None of the hematomas extended into the brainstem or were associated with intraventricular hemorrhage. The median ICH score was 2 (range, 1–4).

### Postoperative and Follow-Up Outcomes

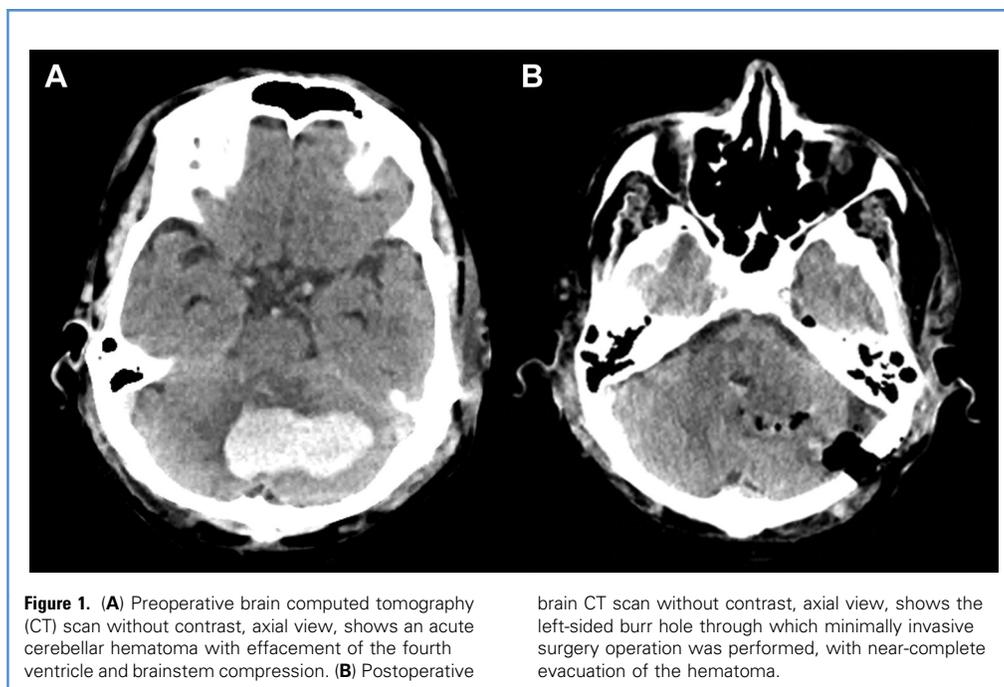
The median degree of hematoma evacuation was 97.5% (range, 79%–100%). There were no operative complications. One hematoma could not be adequately evacuated using the MIS approach, and the patient subsequently underwent a suboccipital craniectomy for evacuation of the residual hematoma (retreatment rate 17%). The postoperative neurologic status was improved, unchanged, or worsened in 67%, 33%, and 0%, respectively. Four patients with a preoperative GCS score of 7T, 13, 13, and 14 improved to a postoperative GCS score of 15. Two patients with a preoperative GCS score of 4T and 8T remained unchanged postoperatively.

One patient improved postoperatively, but significant complications associated with preexisting liver cirrhosis eventually resulted in death. One patient failed to improve postoperatively, and his family elected for withdrawal of care. Overall, the mortality rate was 33%. The discharge destination of the 4 survivors was acute inpatient rehabilitation in 3 patients (50%) and a long-term

**Table 1.** Baseline Characteristics and Postoperative Outcomes of the Study Cohort

Patient Number	Age (Years)/ Sex	Clinical Presentation	Preoperative GCS Score	Admission mRS Score	Postoperative GCS Score	Preoperative ICH Volume (cm <sup>3</sup> )	Postoperative ICH Volume (cm <sup>3</sup> )	Degree of ICH Evacuation (%)	Discharge mRS Score	Follow-Up Duration (Months)	Follow-Up Outcome
1	44/M	Severe headache and respiratory failure	8T	0	8T	17.5	3.6	79	6	1	Required subsequent suboccipital craniectomy, withdrawal of care
2	62/M	Slurred speech	14	3	15	29.1	3.8	87	6	1	Death from cirrhosis
3	54/F	Respiratory failure and Right hemiplegia	7T	0	15	21	0.5	98	3	3	Acute inpatient rehabilitation with significant improvement
4	69/M	Slurred speech and respiratory failure	4T	0	4T	30	1	97	5	2	Long-term acute care facility
5	69/M	Syncope and altered mental status	13	3	15	15	0	100	3	3	Acute inpatient rehabilitation with significant improvement
6	63/F	Slurred speech and dysmetria	13	0	15	15	0	100	3	3	Acute inpatient rehabilitation with significant improvement

GCS, Glasgow Coma Scale; mRS, modified Rankin Scale; ICH, intracerebral hemorrhage; M, male; T, intubated; F, female.



**Figure 1.** (A) Preoperative brain computed tomography (CT) scan without contrast, axial view, shows an acute cerebellar hematoma with effacement of the fourth ventricle and brainstem compression. (B) Postoperative

brain CT scan without contrast, axial view, shows the left-sided burr hole through which minimally invasive surgery operation was performed, with near-complete evacuation of the hematoma.

acute care facility in 1 patient (17%). The median follow-up duration was 2 months (range, 1–3 months). The median follow-up mRS score was 3 (range, 0–6), including a mRS score of 0–2 in 50%.

### Case Example

A 54-year-old woman with a baseline mRS score of 0 presented with right-sided hemiplegia, respiratory failure, and coma (GCS score 7). Brain CT scan showed a 21-cm<sup>3</sup> cerebellar ICH (Figure 1). The patient underwent MIS using the Artemis device 6 hours after presentation. A 98% hematoma evacuation was achieved. Postoperatively, her GCS score improved to 15 and her right-sided weakness improved during acute hospitalization. She was discharged to an acute inpatient rehabilitation facility. At 3-month follow-up, the patient's mRS score was 3. Her weakness had resolved completely, but she continued to have residual dysmetria and gait disturbances.

### DISCUSSION

The neurologic morbidity and mortality associated with cerebellar ICH is because of the limited anatomic confines of the posterior fossa, which causes critical structures (e.g., brainstem, fourth ventricle) to be particularly susceptible to compression by space-occupying lesions. The management of cerebellar ICH has not considerably changed over the past 2 decades.<sup>5</sup> Medical management of cerebellar hematomas is generally recommended in patients presenting without neurologic compromise (e.g., GCS score 14–15) with small hematomas exerting minimal mass effect.<sup>14</sup> In contrast, prompt surgical intervention is necessary for the treatment of large cerebellar hematomas (diameter >3 cm) and ones that are enlarging and

symptomatic. Patients who present with a cerebellar ICH in poor neurologic condition and those with progressive neurologic deterioration could benefit from surgery. The timing of ICH surgery may be a relevant factor, given that perihematomal edema can increase by up to 75% within the first 24 hours.<sup>15</sup>

MIS has been adopted as a viable treatment for supratentorial ICH, with numerous ongoing trials evaluating its efficacy in relation to conservative management. A recent meta-analysis of MIS versus craniotomy for spontaneous supratentorial ICH showed better outcomes for MIS, with a lower mortality rate (odds ratio [OR], 0.76), decreased recurrent hemorrhage rate (OR, 0.42), and improved neurologic recovery (OR, 2.27).<sup>16</sup> MIS also spares patients from large incisions and craniotomies, which may reduce the risk of postoperative infections, need for intensive care unit stay, duration of hospitalization, and overall treatment costs.<sup>17</sup> The potential disadvantages of MIS for ICH include less relief of overall mass effect compared with craniotomy or craniectomy, which is particularly relevant to cerebellar hematomas, and more difficulty in controlling active bleeding.<sup>18</sup> The Artemis (formerly Apollo) Neuro Evacuation Device is a low-profile irrigation-aspiration system that allows for ICH evacuation with minimal disruption of the overlying normal brain parenchyma.<sup>19,20</sup> The Artemis device was designed for use through an endoscope; however, as evidenced by one of the cases in our study, it is not limited to endoscopic ICH evacuation.

Many studies have shown that MIS, with or without neuro-endoscopy, is an acceptable alternative to craniotomy for the evacuation of supratentorial ICH, but the evidence supporting MIS for cerebellar ICH is largely absent.<sup>6,10,16,21</sup> In this multicenter, retrospective cohort study, we examined the outcomes of MIS for 6 patients with cerebellar ICH using the Apollo or Artemis Neuro Evacuation Devices. There were no operative complications;

however, retreatment with suboccipital craniectomy was necessary in 1 patient (17%). The median degree of evacuation was excellent at 97.5%, and 67% of patients had postoperative neurologic improvement. The rates of mortality and functional independence at last follow-up (median duration 2 months) were 33% and 50%, respectively. Deininger et al.<sup>13</sup> reported 2 cases of cerebellar ICH in patients taking Aspirin, which were successfully treated with freehand catheter placement at the bedside, with evacuation using aspiration and the thrombolytic agent urokinase. Recently, Kellner et al.<sup>12</sup> reported the outcomes of 10 patients who underwent MIS for cerebellar ICH through a mini-craniectomy. The mean hematoma volume decreased from 25.4 cm<sup>3</sup> preoperatively to 2.8 cm<sup>3</sup> postoperatively, the mortality rate was 10%, and the mean follow-up mRS score was 2. Although the size of our cohort was modest, we think our findings contribute to the currently limited literature pertaining to MIS for cerebellar ICH and demonstrate the feasibility of this approach. The role of MIS in the contemporary management of cerebellar ICH is not clearly defined, but we suggest that this technique may be considered in patients requiring surgical evacuation who are suboptimal candidates for suboccipital craniectomy, such as those taking anticoagulant or antiplatelet medications or those with extensive medical comorbidities.

The limitations of this study should be noted. First, the small size of the study cohort precludes any meaningful statistical analyses, particularly regarding identifying predictors of outcome.

Additionally, the retrospective design of the study subjects our findings to selection and treatment biases. A similar group of patients who underwent conventional surgery (i.e., suboccipital craniectomy) for cerebellar ICH evacuation was not available to evaluate the comparative effectiveness of MIS. Therefore, additional studies comprising larger patient cohorts are needed to validate our findings.

## CONCLUSIONS

MIS using the Artemis Neuro Evacuation device appears to represent a reasonable alternative to conventional suboccipital craniectomy for the treatment of appropriately selected cases of cerebellar ICH. Further studies are necessary to better define the perioperative and long-term risk of benefit profiles of this technique for patients with cerebellar ICH who require intervention, and to determine the comparative effectiveness of MIS versus conventional surgery for cerebellar ICH.

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