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# Indications for Surgical Intervention in the Treatment of Ischemic Stroke

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**Abstract:** Stroke is a leading cause of morbidity and mortality worldwide. The increasing prevalence of acute ischemic stroke treatment has stimulated many areas of active research and contributions to literature, particularly advancements in surgical management. The aim of this chapter is to provide a comprehensive review of the indications for surgical intervention in the treatment of ischemic stroke. Specifically, the evidence surrounding the indications for mechanical thrombectomy, ventriculostomy and decompressive craniectomy is discussed. Decompressive craniectomy is further divided into individual sections on hemicraniectomy and suboccipital craniectomy. Furthermore, mechanical thrombectomy is analyzed with consideration for the plethora of recent data on perfusion imaging.

**Keywords:** decompressive craniectomy; hemicraniectomy; mechanical thrombectomy; suboccipital craniectomy; ventriculostomy

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## INTRODUCTION

Stroke is the second most common cause of morbidity and mortality worldwide (1). Globally, more than 15 million people suffer from stroke every year, with a lifetime risk for adults of approximately 25% (2). Furthermore, in a growing and aging population, the prevalence of stroke has increased significantly, necessitating a greater understanding of the pathology and its management. Broadly, stroke is classified into ischemic or hemorrhagic types. Ischemic stroke can be further categorized into thrombotic, embolic, systemic hypoperfusion and other subtypes, which combine for greater than 80% of all strokes (3). The principal goal of therapy in the acute phase of ischemic stroke is reperfusion of salvageable brain tissue, chiefly the penumbra. With advancements in medical and surgical treatment, reperfusion can be accomplished via thrombolysis, namely in the form of intravenous thrombolytic therapy or mechanical thrombectomy in eligible patients. Historically, eligibility for intravenous thrombolysis required a treatment window within 4.5 hours of stroke onset. While recent clinical trials have studied an extension of this window for medical intervention, surgical management has been increasingly studied in literature and relied upon in clinical practice (4–6). In the event that a stroke is complete—the absence of significant penumbra to be saved from reperfusion—the principal goal of therapy is to manage cerebral edema and prevent brain herniation and death. If medical management is unsuccessful, interventions such as ventriculostomy and decompressive craniectomy are performed by skilled neurosurgeons to ameliorate complications of acute ischemic infarction. With an ample amount of novel research in the efficacy of these treatment modalities, an update on the indications of surgical intervention for the treatment of ischemic stroke is necessary.

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## MECHANICAL THROMBECTOMY

Patient selection is a key component of determining outcomes. Determining which patients will have the best outcome after a mechanical thrombectomy has been the source of numerous research initiatives in recent years. The major advances that guide current patient selection for mechanical thrombectomy is summarized in Table 1, stratified by whether perfusion imaging was examined. The authors feel this is an important distinction as the use of perfusion imaging safely extends the window for surgical treatment.

### Without perfusion imaging

Five multicenter, randomized controlled trials in 2015 demonstrated the efficacy of mechanical thrombectomy compared to intravenous thrombolysis alone in proximal anterior circulation large artery occlusions within an early treatment window (8–13).

The first and largest of the studies, the Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands (MR CLEAN) enrolled 500 patients (mean age 65 years) into mechanical

TABLE 1

## Recommendations for Mechanical Thrombectomy Indications

Class	LOE	Recommendation
<u>0 to 6 Hours from Onset</u>		
I	A	1. Patients should receive mechanical thrombectomy with a stent retriever if they meet all the following criteria: (i) prestroke mRS score of 0 to 1; (ii) causative occlusion of the internal carotid artery or MCA segment 1 (M1); (iii) age $\geq 18$ years; (iv) NIHSS score of $\geq 6$ ; (v) ASPECTS of $\geq 6$ ; and (vi) treatment can be initiated (groin puncture) within 6 hours of symptom onset.
IIb	B-R	2. Although the benefits are uncertain, the use of mechanical thrombectomy with stent retrievers may be reasonable for carefully selected patients with AIS in whom treatment can be initiated (groin puncture) within 6 hours of symptom onset and who: <ol style="list-style-type: none"> <li>have causative occlusion of the MCA segment 2 (M2) or MCA segment 3 (M3) portion of the MCAs</li> </ol>
IIb	B-R	<ol style="list-style-type: none"> <li>have prestroke mRS score <math>&gt;1</math>, ASPECTS <math>&lt;6</math>, or NIHSS score <math>&lt;6</math>, and causative occlusion of the internal carotid artery (ICA) or proximal MCA (M1)</li> </ol>
IIb	C-LD	<ol style="list-style-type: none"> <li>have causative occlusion of the anterior cerebral arteries, vertebral arteries, basilar artery, or posterior cerebral arteries</li> </ol>
<u>6 to 24 Hours from Onset</u>		
I	A	3. In selected patients with AIS within 6 to 16 hours of last known normal who have LVO in the anterior circulation and meet other DAWN or DEFUSE 3 eligibility criteria, mechanical thrombectomy is recommended
IIa	B-R	4. In selected patients with AIS within 16 to 24 hours of last known normal who have LVO in the anterior circulation and meet other DAWN eligibility criteria, mechanical thrombectomy is reasonable

Note: Recommendations adopted from Guidelines for the Early Management of Patients with Acute Ischemic Stroke: 2019 Update (7)

- Class of recommendation (Class): I (strong benefit), IIa (moderate benefit), IIb (weak benefit), III (moderate no benefit or strong harm)
- Level of evidence (LOE): A (high quality), B-R (moderate quality randomized), B-NR (moderate quality nonrandomized), C-LD (observation or registry with limited data), C-EO (expert opinion).

thrombectomy versus usual care cohorts (8). Eligibility criteria included an occlusion of the distal intracranial carotid artery, middle cerebral artery (M1 or M2) or anterior cerebral artery (A1 or A2) confirmed on angiography within 6 hours of symptom onset. 89.0% of all patients were treated with intravenous alteplase prior to randomization, and retrievable stents were used in 81.5% of mechanical thrombectomy patients. The primary outcome, modified Rankin score (mRS) at 90 days, revealed a 13.5% absolute difference in rate of functional independence (mRS 0–2) in favor of the mechanical thrombectomy group (32.6% vs. 19.1%, 95% CI 5.9–21.2), with no significant difference in complications or mortality.

The number needed to treat (NNT) for one additional patient to reach functional independence was 7.4. Moreover, 2-year follow-up studies demonstrated similar findings, with lower mRS scores in mechanical thrombectomy compared to conventional treatment (OR 1.68, 95% CI 1.15–2.45) (9).

In the Randomized Trial of Revascularization with Solitaire FR Device versus Best Medical Therapy in the Treatment of Acute Stroke Due to an Anterior Circulation Large Vessel Occlusion Presenting within Eight Hours of Symptom Onset (REVASCAT) trial, 206 subjects were randomly assigned to medical therapy alone versus medical therapy plus mechanical thrombectomy (10). Eligibility criteria for this trial included an occlusion of the proximal artery in the anterior circulation within 8 hours of symptom onset. Perhaps more stringent than MR CLEAN, the REVASCAT trial further required evidence of a small infarct core, defined as an Alberta Stroke Program Early Computed Tomography Score (ASPECTS) of 6–10 and moderate-to-good collateral circulation via multiphase CTA. The results of this trial at 90 days showed higher rates of functional independence (mRS 0–2) in the mechanical thrombectomy group (43.7% vs. 28.2%, OR 2.1, 95% CI 1.1–4.0), with similar rates of mortality compared to the medical therapy alone group. The NNT for one additional patient to reach functional independence was 6.3.

Following suit, the Endovascular Treatment for Small Core and Anterior Circulation Proximal Occlusion with Emphasis on Minimizing CT to Recanalization Times (ESCAPE) trial enrolled 316 patients into standard of care versus standard of care plus mechanical thrombectomy cohorts (11). Like REVASCAT, eligibility criteria included patients with a proximal anterior circulation occlusion and the absence of a large infarct via ASPECTS criteria on neuroimaging (CT 0–6, MRI 0–5), although within 12 hours of symptom onset. Approximately 75% of all patients were treated with intravenous alteplase. Although the trial was stopped early because of efficacy, the rate of functional independence (mRS 0–2) at 90 days was significantly higher for the mechanical thrombectomy group compared to standard of care (53.0% vs. 29.3%, rate ratio 1.8, 95% CI 1.4–2.4). Moreover, mortality was significantly lower for the mechanical thrombectomy group (10.4% vs. 19.0%, rate ratio 0.5, 95% CI 0.3–1.0), with similar rates of symptomatic intracerebral hemorrhage. The NNT for one additional patient to reach functional independence was 4.2.

### With perfusion imaging

In the Solitaire with the Intention for Thrombectomy as Primary Endovascular Treatment (SWIFT PRIME) trial, 196 adults were randomized into usual care versus mechanical thrombectomy groups (12). Eligibility criteria for this trial included patients with confirmed occlusions in the proximal anterior intracranial circulation in the absence of large ischemic-core lesions (core-infarct volume <50 mL on perfusion imaging) who could be treated with thrombectomy within 6 hours of symptom onset. All patients in the trial received intravenous alteplase prior to randomization. At 90 days, the rate of functional independence (mRS 0–2) was significantly higher in the mechanical thrombectomy group compared to the control group (60% vs. 35%, risk ratio 1.70, 95% CI 1.23–2.33), with no significant between-group differences in mortality or

symptomatic intracranial hemorrhage. The NNT for one additional patient to reach functional independence was 4.0.

In the last of the five 2015 studies, the Extending the Time for Thrombolysis in Emergency Deficits (EXTEND-IA) trial randomly assigned 70 patients who were receiving IV alteplase into mechanical thrombectomy (within 6 hours) versus usual care cohorts (13). The eligibility criteria for this study included an occlusion of the internal carotid (IC) or middle cerebral artery (MCA), evidence of salvageable brain tissue and an ischemic core infarct of <70 mL on CT perfusion. Although the results were stopped early due to efficacy, the trial demonstrated a greater percentage of ischemic territory reperfusion at 24 hours in the mechanical thrombectomy group compared to the alteplase-only group (median, 100%, 37%;  $p < 0.001$ ) and improved functional outcome at 90 days (mRS 0–2, 71% vs. 40%,  $p = 0.01$ ). The NNT for one additional patient to reach functional independence was 3.2.

As the efficacy of mechanical thrombectomy became cemented in literature, investigators questioned whether an extension of the treatment window would yield similar results. In 2018, two major clinical trials quantified the benefit of mechanical thrombectomy within a larger treatment window, taking advantage of available perfusion imaging (14, 15).

The first trial, DWI or CTP Assessment with Clinical Mismatch in the Triage of Wake-Up and Late Presenting Strokes Undergoing Neurointervention with Trevo (DAWN), 206 patients were enrolled in thrombectomy versus control groups (14). The eligibility criteria included patients with an occlusion of the intracranial internal carotid artery or proximal middle cerebral artery last known to be well 6 to 24 hours earlier and a mismatch between clinical severity of neurologic deficit (NIH stroke scale) and infarct volume (automated software on diffusion-weighted MRI or CT perfusion permitted). At 90 days, the rate of function independence (mRS 0–2) favored the mechanical thrombectomy group over the control group (49% vs. 13%, adjusted difference 33%, 95% CI 24–44), with no differences in symptomatic intracranial hemorrhage (6% vs. 3%,  $p=0.50$ ) or 90-day mortality (19% vs. 18%,  $p = 1.00$ ).

The second trial, Endovascular Therapy Following Imaging Evaluation for Ischemic Stroke (DEFUSE 3), enrolled 182 patients into endovascular-therapy versus medical-therapy groups (15). In comparison to DAWN, this trial had eligibility requirements including patients with a proximal occlusion who were last known well between 6 and 16 hours. Moreover, the neuroimaging criteria included initial infarct size <70 mL and a ratio of ischemic tissue volume to infarct volume of >1.8 (automated software on MRI perfusion). Similar to DAWN, the 90-day rate of function independence (mRS 0–2) was higher in the mechanical thrombectomy group compared to the medical therapy only group (45% vs. 17%, risk ratio 2.67, 95% CI 1.60–4.48). Further, the 90-day mortality rate was significantly lower in the mechanical thrombectomy group (14% vs. 26%,  $p = 0.05$ ), with no difference in rates of symptomatic intracranial hemorrhage (7% vs. 4%,  $p = 0.18$ ).

The results of these two trials directly led to an update in the American Heart Association (AHA) 2018 stroke guidelines, expanding the treatment window of thrombectomy from 6 hours to 16 hours (class IA) and 24 hours (class IIA) based on trial-specific eligibility criteria (16).

## VENTRICULOSTOMY AND DECOMPRESSIVE CRANIECTOMY

In the event that reperfusion of salvageable brain tissue is not possible, such as in cases of completed stroke, the care team may rely on neurosurgery for the management of critical infarct sequelae. Namely, ventriculostomy and decompressive craniectomy are performed by neurosurgeons to alleviate obstructive hydrocephalus and elevated intracranial pressure, respectively.

### Ventriculostomy

A critical complication of ischemic stroke, namely cerebellar stroke, is obstructive hydrocephalus, a condition where the free flow of cerebrospinal fluid (CSF) through the ventricular system is inhibited, leading to dilation of one or more ventricles. To prevent further brain tissue damage, definitive treatment includes removal of CSF and resolution of the source of obstruction.

Ventriculostomy is a common neurosurgical procedure in which a catheter is placed within the cerebral ventricle to allow for drainage of excess CSF. A temporary catheter is connected to an external ventricular drain (EVD), whereas a permanent catheter is considered a shunt. The most common entry point on the skull is 2.5 cm from midline and 11 cm posterior to the nasion, known as Kocher's point. The most common posterior entry point on the skull is 6 cm above and 4 cm lateral to theinion, known as Frazier's point (17).

In the 2014 AHA/ASA recommendations for management of cerebral and cerebellar infarction with swelling, routine intracranial pressure (ICP) monitoring was not indicated in hemispheric ischemic stroke (Class III; level of evidence C) (18). This notable recommendation stemmed from a prospective observational study of 19 patients who underwent ICP monitoring prior to hemicraniectomy for malignant MCA infarction (19). The results of study found a lack of consistent correlation between ICP values and pupillary abnormalities, midline shift or ischemic tissue volume, concluding that continuous ICP monitoring cannot substitute for close clinical and radiological follow up in the management of malignant MCA infarction.

In the same AHA/ASA statement, ventriculostomy was recommended in obstructive hydrocephalus after a cerebellar infarct, followed or accompanied by decompressive craniectomy (Class I; level of evidence C) (18). This recommendation was given following a retrospective study of 44 patients treated for cerebellar infarction, divided into conservative treatment, EVD alone, EVD plus suboccipital decompressive craniectomy (SDC), and SDC plus removal of necrotic tissue subgroups (20). EVD was performed on patients who experienced rapidly worsening consciousness levels, ICP increases and acute hydrocephalus on neuroimaging without transtentorial herniation. The results demonstrated that for patients with worsening levels of consciousness, EVD led to a higher proportion of patients with good recovery (Glasgow Outcome Scale = 5).

### Hemicraniectomy

Decompressive hemicraniectomy (DHC) describes the procedure of removing a portion of the skull in order to allow swelling brain tissue to expand outward to

relieve compression against the skull in a closed system. While the surgical removal of skull portions, termed trepanation, has been dated in skeletons up to 6,000 years ago (21), a growing body of literature has demonstrated its utility in ischemic stroke (Table 2). Specifically, hemicraniectomy with durotomy has been shown to relieve elevated ICP in the management of malignant MCA infarction.

From a procedural standpoint, decompressive craniectomy often requires a large, low frontotemporoparietal bone flap in order to permit adequate ICP reduction. As described by Simard et al. (22), this is accomplished with an initial “question-mark” scalp flap incision extending from the widow’s peak posteriorly to then curving inferiorly above the pinna and ending caudally to the zygoma. A frontotemporoparietal bone flap of at least 14 cm in diameter is removed (medial

TABLE 2

### Recommendations for Decompressive Craniectomy Indications

Class	LOE	Recommendation
		<u>Supratentorial Infarction</u>
IIa	A	1. Although the optimal trigger for decompressive craniectomy is unknown, it is reasonable to use a decrease in level of consciousness attributed to brain swelling as selection criteria
IIa	A	2. In patients $\leq 60$ years of age who deteriorate neurologically within 48 hours from brain swelling associated with unilateral MCA infarctions despite medical therapy, decompressive craniectomy with dural expansion is reasonable
IIb	B-R	3. In patients $>60$ years of age who deteriorate neurologically within 48 hours from brain swelling associated with unilateral MCA infarctions despite medical therapy, decompressive craniectomy with dural expansion may be considered
		<u>Infratentorial Infarction</u>
I	C-LD	4. Ventriculostomy is recommended in the treatment of obstructive hydrocephalus after cerebellar infarction. Concomitant or subsequent decompressive craniectomy may or may not be necessary on the basis of factors such as the size of the infarction, neurological condition, degree of brainstem compression, and effectiveness of medical management
I	B-NR	5. Decompressive suboccipital craniectomy with dural expansion should be performed in patients with cerebellar infarction causing neurological deterioration from brainstem compression despite maximal medical therapy. When deemed safe and indicated, obstructive hydrocephalus should be treated concurrently with ventriculostomy
IIb	C-LD	6. When considering decompressive suboccipital craniectomy for cerebellar infarction, it may be reasonable to inform family members that the outcome after cerebellar infarct can be good after the surgery

Note: Recommendations adopted from Guidelines for the Early Management of Patients with Acute Ischemic Stroke: 2019 Update (35)

- Class of recommendation (Class): I (strong benefit), IIa (moderate benefit), IIb (weak benefit), III (moderate no benefit or strong harm)
- Level of evidence (LOE): A (high quality), B-R (moderate quality randomized), B-NR (moderate quality nonrandomized), C-LD (observation or registry with limited data), C-EO (expert opinion).

limit ~2 cm from midline, posterior limit ~5 cm from external auditory canal) and the temporal squama is resected to the floor of the middle cranial fossa. From here, a stepwise expansive duraplasty is performed and subgaleal drain is placed to bulb suction. A two-layer scalp closure is performed and medical management to relieve ICP elevations is continued.

As a general rule, ischemic strokes are classified as malignant due to the presence of space-occupying cerebral edema that may lead to brain compression and herniation. The principal goal of DHC in malignant infarction is to decrease intracranial hypertension, brain compression, and herniation while increasing cerebral perfusion (23, 24).

The efficacy of DHC in malignant MCA infarction has been reinforced in several recent randomized controlled trials (25–28). The Decompressive Craniectomy in Malignant MCA Infarction (DECIMAL) trial enrolled 38 patients into early decompressive craniectomy plus standard medical therapy versus standard medical therapy alone groups (26). The inclusion criteria for this trial comprised of patients between 18 and 55 years of age within 24 hours of malignant MCA infarction, defined by three parameters: NIHSS score  $\geq 16$ , CT demonstrated ischemic signs involving  $>50\%$  of MCA territory, and DWI infarct volume  $>145 \text{ cm}^3$ . Patients with significant pre-existing disability (mRS  $\geq 2$ ), contralateral infarction and secondary hemorrhage were excluded. The results were prematurely stopped on the basis of high disparity in mortality between the two groups across 3 trials, in favor of decompressive craniectomy. At 6-months, the proportion of patients with mRS  $\leq 3$  was 25% for the surgery group, compared to 5.6% for the medical therapy group ( $p = 0.18$ ). Furthermore, at 1-year follow up, the proportion of patients with mRS  $\leq 3$  was 50% vs. 22.2% in favor of the surgery group ( $p = 0.10$ ). Moreover, this study demonstrated a 52.8% absolute risk reduction of death after decompressive craniectomy compared to standard medical therapy only ( $p < 0.0001$ ).

In the same year as DECIMAL, the Decompressive Surgery for the Treatment of Malignant Infarction of the Middle Cerebral Artery (DESTINY) trial results were published (27). In a similar manner, the randomized controlled trial enrolled 32 patients into DHC versus medical therapy only cohorts. In contrast, the eligibility criteria included patients 18–60 years of age within a 12–36-hour treatment window of symptom onset, clinical signs of MCA infarction (with NIHSS  $>18$  vs. 20 for lesions in the non-dominant vs. dominant hemisphere) and CT demonstrated unilateral MCA infarction including  $\geq 2/3$  of the territory and at least part of the basal ganglia. Similar to DECIMAL, the results of this study were pooled and identified a high disparity of mortality in favor of DHC, leading to premature termination. Of the results that were collected, 88% of patients in the hemicraniectomy group survived after 30 days, compared to 47% of patients in the medical therapy only group ( $p = 0.02$ ). At 6-months, the proportion of patients with mRS  $\leq 3$  was 47% for the surgery group and 27% for the medical therapy only group ( $p = 0.23$ ).

During the time period of DECIMAL and DESTINY, a third study, Hemicraniectomy After Middle Cerebral Artery Infarction with Life-Threatening Edema Trial (HAMLET), investigated the efficacy of DHC through a randomized, open trial (28). In HAMLET, 64 patients were assigned to DHC or best medical treatment groups. Unlike the two aforementioned studies, HAMLET expanded the eligibility criteria to patients 18–60 years of age with stroke onset within

96 hours of trial treatment. The study also required NIHSS score  $\geq 16$  vs. 21 for right- vs. left-sided lesions and ischemic changes on CT that affected 2/3 of the MCA territory with space-occupying edema. In this study, surgical decompression did not demonstrate an effect on rate of good outcome (mRS  $\leq 3$ , ARR 0,  $p = 1.0$ ) but did reduce case mortality rates (ARR 38%,  $p = 0.002$ ) at 1 year. HAMLET was the third study utilized in the joint analysis that demonstrated efficacy of DHC, yielding a premature stop in the trial.

As alluded to, a pooled analysis of the DECIMAL, DESTINY and HAMLET trials demonstrated significant efficacy of decompressive hemicraniectomy compared to medical therapy alone among the patients studied (29). Specifically, of the 93 patients included in the analysis, a greater proportion of patients in the surgery group compared to the control group had an mRS  $\leq 4$  (75% vs. 24%, ARR 51%, 95% CI 34–69) and rate of survival (78% vs. 29%, ARR 50%, 95% CI 33–67). Moreover, a 2016 meta-analysis of seven randomized controlled clinical trials (including DECIMAL, DESTINY and HAMLET) aggregated data among 338 patients and found that DHC, compared to medical therapy alone, had significantly reduced rates of mortality (30% vs. 69%,  $p < 0.001$ ) and greater rates of patients with slight to moderate disability (mRS 2–3, 37% vs. 14%,  $p < 0.001$ ) (30). On the other hand, the DHC groups also had higher rates of severe disability (mRS 4, 32% vs. 10%,  $p < 0.001$ ) and very severe disability (mRS 5, 11% vs. 7%,  $p < 0.001$ ), indicating that the large reduction in mortality yields higher disease burden. Of note, in subgroup analyses, the impact of DHC on mortality was similar across age of patient ( $\leq 60$  vs.  $> 60$  years old,  $p = 0.38$ ) and timing of surgery (up to 48 hours vs. 96 hours,  $p = 0.59$ ).

## Suboccipital craniectomy

In comparison to the role of DHC for malignant MCA infarction, the role of suboccipital decompressive craniectomy (SDC) for malignant cerebellar infarction is less documented in literature. As described in Beez et al. (31), the best available evidence derives from one retrospective case-control study, several case series, and a recent meta-analysis (32–35).

The retrospective matched case control study, published by Kim and colleagues, compared clinical outcomes between 28 patients who underwent preventive SDC for cerebellar infarction with 56 patients who did not undergo the procedure with cerebellar infarction (32). Selection criteria included initial GCS  $\geq 9$  without clinical deterioration within 72 hours from onset and a cerebellar infarction volume ratio between 0.25 and 0.33 on neuroimaging (volume ratio = cerebellar infarction volume / total cerebellar volume). Among the patients in the SDC cohort, 50% additionally received an EVD and 57% received a debridement of infarcted tissue. In the results, the SDC group, compared to the control group, had a greater proportion of patients with favorable clinical outcomes (mRS  $\leq 2$ ) at discharge (64% vs. 48%,  $p = 0.048$ ) and 1-year follow up (67% vs. 51%,  $p = 0.030$ ). Moreover, the SDC group had a lower mortality rate than the control group at 1-year follow up (5% vs. 15%, log rank  $p < 0.05$ ).

In the largest case series studying the long-term outcome of SDC in malignant cerebellar stroke, a total of 57 patients were identified as having undergone bilateral SDC at a single institution in Germany (34). Additionally, 82% of all patients

received an EVD, and 56% of all patients underwent evacuation of necrotic tissue. A standardized surgical protocol was implemented for all patients, requiring clinical deterioration and evidence of acute space-occupying cerebellar infarction with brainstem compression, impending herniation or occlusive hydrocephalus on neuroimaging. Within the first 6 months of surgery, 28% of patients had died. Moreover, at follow-up (mean interval 4.7 years), 40% of patients lived functionally independent (mRS  $\leq 2$ ) and 8% lived with major disability (mRS 4–5). Interestingly, in a univariate analysis, only neuroimaging evidence of brain stem infarction was associated with poor outcome (mRS  $\geq 4$ ) at follow-up, whereas patient age, unilateral vs. bilateral cerebellar infarction, and timing of surgery were not significantly associated with poor outcome. Furthermore, 96% of surviving patients at follow-up retrospectively felt that surgery was the best decision for them.

In 2017, a systematic review and meta-analysis of 283 patients further elucidated the relationship between SDC and clinical outcomes in cerebellar infarction (35). Literature that was included in the pooled analysis consisted of prospective or retrospective studies where SDC with or without EVD insertion was performed for cerebellar stroke confirmed on neuroimaging. The combined results at follow-up (median 9.4 years, range 3 months–11.9 years) identified a 20% mortality rate (95% CI 12–31%) and 28% rate of moderate to severe disability (mRS 3–5, 95% CI 20–37%). In sensitivity analysis, variables that had lower rates of moderate to severe disability included preoperative GCS score ( $\geq 9$ , 22% vs.  $< 9$ , 37%), and timing of surgery after stroke onset ( $\leq 48$  hours, 16% vs.  $> 48$  hours, 30%), although overlapping confidence intervals limit interpretability.

Overall, SDC continues to be a utilized approach in a neurosurgeon's toolkit in the management of malignant cerebellar infarction. The paucity of literature in the form of randomized controlled trials limits our current understanding on the impact of SDC on perioperative outcomes. Future studies are needed to create definitive criteria for the indications of SDC for malignant cerebellar infarction.

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## CONCLUSION

In summary, a plethora of research in the surgical domain of ischemic stroke requires a periodic update on the latest indications for treatment. With the advancements of perfusion neuroimaging in the last decade, the inclusion criteria for mechanical thrombectomy have broadened. Ventriculostomy is indicated for ischemic stroke management in the presence of acute hydrocephalus on neuroimaging, primarily noted in the context of cerebellar infarction. On the horizon of decompressive hemicraniectomy for malignant MCA infarction, evidence has demonstrated efficacy irrespective of age and timing from symptom onset. In the case of suboccipital decompressive craniectomy for cerebellar stroke, while efficacy has been noted, further studies are necessary to elucidate the impact of preoperative inclusion criteria on outcomes.

**Conflict of Interest:** The authors declare no potential conflict of interest with respect to research, authorship and/or publication of this chapter.

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