Surgery for malignant acute Ischaemic stroke: a narrative review of the knowns and unknowns

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Abstract

Malignant acute ischemic stroke (AIS) is characterised by acute neurological deterioration caused by progressive space occupying brain edema, often occurring in the first hours to days after symptom onset. Without any treatment, the result is often fatal. Despite advances in treatment for AIS, up to 80% of patients with a large hemispheric stroke or cerebellar stroke are at risk of poor outcome. Decompressive surgery can be life-saving in a subgroup of patients with malignant AIS, but uncertainties exist on patient selection, predictors of malignant infarction, peri-operative management and timing of intervention. Although survivors are left disabled, most agree with the original decision to undergo surgery and would make the same decision again. In this narrative review, we focus on the clinical and radiological predictors of malignant infarction in AIS, outline the technical aspects of decompressive surgery as well as duraplasty and cranioplasty. We discuss the current evidence and recommendations for surgery in AIS, highlighting gaps in knowledge, and suggest directions for future studies.

Key words: decompressive hemicraniectomy; ventriculostomy; suboccipital craniectomy; acute stroke; morbidity; mortality; indication for surgery; surgical decompression

Introduction

Acute ischemic stroke (AIS) affects ~12 million people each year worldwide.(1) About 20% of patients do not survive the first year, and the majority of survivors have significant disability.(1) The morbidity and mortality is higher in patients with a large stroke, which is estimated to occur in ~10% of patients. (2, 3) There have been advances in management of AIS: intravenous thrombolysis (IVT) within 4.5 hours of onset improves outcome, with earlier treatment associated with greater benefit.(4) In 2015, five clinical trials showed that mechanical thrombectomy (MT) significantly reduced disability in anterior circulation AIS compared to best medical treatment.(5) Recently, similar benefits of MT in AIS have been shown in basilar artery thrombosis up to 24 hours from estimated symptom onset.(6, 7) However, there are limitations: only a quarter of patients are eligible for intravenous thrombolysis, and less than half respond to treatment despite reperfusion.(4, 8, 9). Only 10% of patients with AIS are eligible for MT, and it is not routinely available in countries with limited resources.(10) Moreover, MT is not always successful, and a large infarct from occlusion of the proximal middle cerebral artery (MCA) with or without involvement of the anterior cerebral or posterior cerebral arteries can develop edema very quickly (malignant infarction), leading to increased intracranial pressure (ICP), brain herniation and death.(11) Similarly, a cerebellar infarct could become life-threatening by causing brainstem compression and obstructive hydrocephalus. The precise incidence is not known, but the accompanying edema can lead to poor outcome in ~50% of patients.(12) Although interventions such as intubation and ventilation, blood pressure lowering, hyperventilation, osmotic agents and barbiturates are used to manage elevated ICP, none have proven to be effective in phase 3 randomized clinical trials.(2, 13)

Surgery in malignant AIS has been studied for many decades.(14) Studies have shown that decompressive surgery in malignant MCA AIS or cerebellar AIS can reduce ICP, increase cerebral blood flow and improve brain compliance.(15) Decompressive surgery involves opening the skull, removal of a bone flap and durotomy to allow the edematous brain to

expand outwards.(14) In cerebellar stroke, an external ventricular drain (EVD) may be used to drain cerebrospinal fluid (CSF) in acute hydrocephalus. (16) Surgery for AIS is not without complications, and some patients may need a repeat operation. This naturally leads to the question whether decompressive surgery for AIS improves clinical outcomes.

In this narrative review, we discuss predictors of malignant MCA AIS and cerebellar AIS, and summarize the current evidence including recommendations for decompressive surgery. We also provide an overview of technical aspects of surgery, highlighting gaps in evidence, and suggest directions for future clinical trials.

Clinical predictors

Patients with large MCA territory infarction often present with hemiplegia or hemiparesis, hemianopia, eye or head deviation and aphasia or neglect. As intracranial pressure increases from space-occupying edema, patients may have reduced consciousness, pupillary changes, papilledema, cranial nerve palsies, nausea and vomiting.(2) One study found that reduced consciousness within hours after stroke is a poor prognostic sign. (17) It is important to highlight that not all patients develop malignant edema, hence it is important to identify patients at risk. Studies have shown that a severe stroke on the initial NIHSS (15 or more) and impairment of consciousness especially (score > 1 on item 1a of the NIHSS) is associated with neurological deterioration and significant brain swelling.(18) Younger patients are at risk because there is little intracranial space for a swollen brain to expand.(19) In addition, younger patients are unable to maintain perfusion from intracranial collaterals and are more likely to decompensate.(19) One post-mortem study found that predictors of death from malignant MCA infarction included female sex, increased heart weight, no history of prior stroke, carotid artery occlusion and an abnormal ipsilateral circle of Willis.(20) Factors such as fever on admission, post-stroke hypertension, history of high

blood pressure and congestive cardiac failure are also reported to increase the risk of malignant infarction.(19, 21, 22)

Neuroimaging predictors

Various radiological markers and measures have been assessed but there is no single pathognomonic feature that predicts malignant MCA infarction. On the other hand, relying on a single measure at a fixed timepoint could underestimate or overlook the evolution of malignant edema.(21) Computed tomography (CT), magnetic resonance imaging (MRI), ultrasound descriptors (vascular, anatomical, volumetric), and predictive scores can be helpful in the assessment and prediction of malignant MCA AIS (Table 1).

CT is the mainstay of diagnosis of AIS because it is quick, cheap and widely available. Studies suggest that a thrombus in the proximal MCA ("hyperdense MCA sign") or internal carotid artery on plain CT predicts the risk of severe edema, but others have found no association.(2, 23) Data also suggest that increased thrombus length and poor collateral circulation are associated with malignant MCA infarction, but this needs to be validated. (24) Independent predictors associated with risk of death from malignant MCA AIS include involvement of greater than 50% of the middle cerebral artery territory on baseline CT, infarct volume or size of greater than 220 ml within 24 to 48 hours, and midline shift of >3.7 mm.(19, 21)

CT Perfusion may also be useful in identifying patients at risk of malignant edema in AIS. An infarct-core volume involving more than two-thirds of the MCA territory within hours of stroke has been shown to be highly sensitive and specific (92% and 94%, respectively) for predicting malignant transformation.(25) One study (26) reported that when the blood supply to additional areas of the brain are also affected, the risk of poor outcome is higher.(27)

MRI has the advantage that it is more sensitive than CT to assess for signs of early brain ischemia. One observational study reported that diffusion-weighted imaging (DWI) infarct volume of > 82 ml within 14 hours of ictus was highly predictive of malignant MCA AIS. Another report showed that a volume of >145 ml was associated with risk of brain herniation and death. (28, 29) Similar to CT, early perfusion mismatch on MRI can also be helpful to predict malignant MCA infarction.(30) Thomalla et al reported that an apparent diffusion coefficient value of <80% of infarct volume >82 ml in the affected cerebral hemisphere and increased mean transit time (the average time it takes for blood to pass through an infarct) predict malignant infarction (21, 31-33). However, MRI is time consuming, expensive and not a routine imaging modality for acute stroke in many countries. Moreover, patients with claustrophobia may not be able to tolerate MRI, and those with implanted cardiac devices or pacemakers may not be eligible.

Other imaging techniques including Xenon CT, single-photon emission CT (SPECT) have been used to assess metabolism, measure blood-brain barrier permeability, predict infarct volume and malignant edema. One study found that SPECT was more sensitive than non-contrast CT (82% versus 36%) in predicting brain herniation.(34) In another small study, flumazenil positron emission tomography reliably predicted malignant edema within 24 hours of ictus in patients who had an infarct involving >50% of the middle cerebral artery territory.(35)

Assessment of the optic nerve sheath diameter using ultrasound is an emerging useful tool and comparable to invasive monitoring of intracranial pressure in AIS. (36, 37) In a small prospective study, the mean optic nerve sheath diameter in patients who developed malignant edema was higher on admission compared to patients without significant edema.(38) Furthermore, there was strong correlation between the optic nerve sheath diameter and volume of infarct at 24 hours. An optic nerve sheath diameter of 5.6 mm or

greater was shown to predict malignant edema with a sensitivity of 100%, specificity of 90%, positive predictive value of 83% and negative predictive value of 100%(38).

Transcranial Doppler (TCD) ultrasonography is another non-invasive method to detect cerebral blood flow, and dynamic variations could reflect changes in cerebral perfusion pressure.(39) One review assessed dynamic cerebral autoregulation using TCD in 45 patients with acute MCA infarction, including some treated with intravenous thrombolysis.(26) The results showed that poor autoregulation in the ipsilateral cerebral hemisphere within 48 hours of ictus significantly correlated with increase in infarct size and poor outcome.(26) It is suggested that TCD may be helpful to monitor cerebral blood flow when lowering intracranial pressure with treatment such as osmotic diuretics for malignant edema(40), but the use of this modality in guiding decompressive craniectomy surgery is limited.(39)

Prediction scores for malignant edema

Several scoring tools have been developed to predict the risk of malignant edema after AIS using clinical, radiological and laboratory characteristics (**Table 1**). The Alberta Stroke Program Early CT score (ASPECTS) can be used to assess the severity of ischemia, and a score of $\leq$7 is associated with risk of malignant infarction.(41) The EDEMA score uses three clinical variables (serum glucose, history of stroke and reperfusion therapy) and two imaging characteristics (midline shift and cistern effacement); a score more than 7 has been shown to predict death from malignant infarction with a positive predictive value of 93%.(42)

Recently, a score calculated as the sum of the measurement of the maximum anterior-posterior and medio-lateral diameter of infarction multiplied by visually graded assessment of hypodensity on admission non-contrast CT (NEMMI score) was found to be useful to predict malignant MCA infarction.(43) In one study, the ability of the NEMMI score to predict malignant transformation was higher than patient age, stroke severity and infarct

volume.(43) This could be important in an emergency, as the score is not dependent on any other clinical or laboratory characteristics. More research is needed to validate these results with interobserver agreement.

In patients undergoing mechanical thrombectomy, the Malignant Brain Edema score (MBE) and ACORNS (Baseline **A**SPECT score, **C**ollateral circulation, Fasting bl**O**od glucose, blood pressure, recombinant tissue plasminogen activator before thrombectomy, **R**eperfusion status, baseline **N**IHSS score, occlusion **S**ite) score have been developed to predict the risk of malignant infarction. Both are based on stroke severity at baseline, ASPECTS score, collateral status and whether the occluded vessel has recanalized.(28, 44) The ACORNS score also takes into account risk factors including hypertension, blood glucose on admission and whether the ipsilateral middle cerebral artery or internal carotid artery was occluded.(44)

Another score has been developed based on MRI characteristics in AIS - the DASH score is calculated as the sum of four variables: DWI ASPECTS score, involvement of the anterior cerebral artery, M1 susceptibility-weighted vessel sign and hyperglycemia.(45) A score of 3 and above is associated with >90% risk of malignant edema.(45)

It is important to highlight that none of the aforementioned scores have been used to identify which patients require DHC, and the role is to complement decisions when stratifying patients at risk. This could be particularly important in hospitals where access to neurosurgery or a neurocritical care unit is not readily available.

Biomarkers

Serum biomarkers are emerging as predictors of malignant MCA infarction when combined with clinical and imaging data, with potential as endpoints in clinical trials.(46) Serum

glucose, white blood cell and red blood cell count, hemoglobin, international normalized ratio, pro-calcitonin levels and C-reactive protein have been shown to be useful, but none have been found to be individually specific or sensitive.(47, 48) It is known that the ratio of neutrophils to lymphocytes indicates systemic inflammation, and one recent study reported that the risk of malignant edema in AIS increased as the ratio became higher.(49) Another analysis found that a neutrophil to lymphocyte ratio of >3.5 combined with stroke severity best predicted the risk of malignant edema in AIS irrespective of whether patients had reperfusion therapy or not. (49)

Another biomarker is the structural glial protein S100B, which has been shown to correlate with stroke severity, infarct size and functional outcome.(50) One study reported that a significant increase of S100B between 12-24 hours was associated with brain herniation after AIS.(51). A recent systematic review including 28 studies with 7,239 patients found that elevated levels of the proteolytic enzyme matrix metalloproteinase-9 and serum fibronectin after AIS were associated with severe edema and poor prognosis;(52) (50) One study reported that high levels of serum cellular-fibronectin predicted malignant transformation with a specificity of 90% and sensitivity of 100%.(53)

Studies have evaluated microdialysis, correlating levels of neurotransmitters and products of metabolism in the cerebrospinal fluid with the pathogenesis of malignant edema.(35, 54) One prospective study showed that the excitatory neurotransmitters glutamate and aspartate were significantly elevated as well as products of metabolism (lactate, pyruvate, glycerol) in patients who progressed to malignant infarction compared to those who did not.(35) The investigators also found lower levels of concentrations of non-transmitter amino acids in the extracellular region which correlated with the size of the infarct. This phenomenon was observed even before there were changes in cerebral blood flow, suggesting there was early expansion of the extracellular space from vasogenic edema.(55)

Decompressive Hemicraniectomy: technical aspects

Decompressive hemicraniectomy (DHC) involves removal of a large fronto-temporal-parietal bone flap to allow decompression of the swollen brain and avoid impingement on underlying cortex and its vasculature by the bony edges (**Figure 1**). The patient is placed in a supine position, with the head elevated and turned to the contralateral side, with or without fixation in a head clamp. The abdomen (or thigh) may also be exposed if an autologous cranioplasty is planned and the bone flap needs to be stored under the skin. The scalp is incised between the midline and the mid-pupillary line, 10 cm superior to the supraorbital notch and extended posteriorly, usually in a question mark shape, curving posteriorly and ending caudally at the insertion of the zygoma.(56) Variations include ending the incision posterior behind the pinna, which spares the superficial temporal artery. If the more common question mark incision is used, a myocutaneous flap, or separate skin and muscle flaps, can be reflected; the former allows better access to the floor of the middle cranial fossa.

Burr holes can be turned with a Hudson-Brace, or using a perforator. A bone flap of greater than 11 cm in its maximum diameter is then created by use of a craniotomy or a jiggly saw. (56) The bone-flap is then removed, and the squamous temporal bone can be removed down to the floor of the middle cranial fossa to decompress the temporal lobe. (56) The dura is then incised. Some surgeons prefer to leave the dura open in a stellate fashion while others perform duraplasty.(57) If the infarct involves the temporal lobe and there are signs of herniation, some surgeons advocate limited lobectomy with resection of the uncus.(15) Once the cerebral hemisphere is decompressed, the galea is closed with absorbable sutures and the skin closed with sutures or clips, which can then be removed 7-10 days later. Some surgeons may choose to leave a dural substitute or synthetic sheet as a barrier between the galea and the cortex. Some may also leave a drain for post-operative subgaleal haematoma. Typically, patients require post-operative management in a high-dependency or intensive

care setting. After surgery, patients are resumed on antiplatelet therapy. The iterations of surgical technique have not been tested in randomized clinical trials.

Complications associated with DHC include infection, seizures and uncontrolled brain herniation. Injury to the middle meningeal artery and superior sagittal sinus can result in hemorrhage.(57) Brain herniation may cause cortical injury as the expanding cortex impinges on the bony edges; this is exacerbated if area of the craniectomy is too small.(56) Occasionally patients may need repeat surgery if the bony or dural decompression is not sufficient.(56) Other common complications include hygroma, which is reported to occur between 20-80% of patients, and ~30-40% develop communicating hydrocephalus from disruption of the meningeal lymphatics.(15)

The sunken flap syndrome, or “syndrome of the trephined,” is another late complication after DHC and reported to occur in ~10% of patients.(58, 59) This defect is visible as an obvious area of scalp depression at the site of craniectomy and easily identified on a plain CT. The precise mechanism of the sunken flap syndrome is unknown but it is thought to occur because of direct pressure from the atmospheric pressure on the brain with no scalp for protection.(58, 59) If untreated, a sunken flap can cause headaches or acute neurological deterioration and in extreme cases lead to brain herniation, coma and death.(58)

Summary of evidence for Decompressive Hemicraniectomy for malignant middle cerebral artery infarction

Altogether there are eight prospective, randomized trials of DHC for malignant MCA infarction (**Table 2**). All patients were randomised 1:1 to surgery or medical management. However, there were differences in patient selection, assessment and surgical intervention. (**Table 2**)

The Decompressive Surgery for the treatment of Malignant Infarction of the Middle Cerebral Artery II study (DESTINY II) and Hemicraniectomy after Middle Cerebral artery infarction with life-threatening edema trial (HAMLET) focused on patients who were older than 60.(60-62) The Hemicraniectomy and durotomy upon deterioration from infarction-related swelling trial (HeADDFIRST), allowed recruitment up to 75 years, and Zhao et al included patients up to the age of 80.(63, 64)

Six trials included patients who were previously independent (modified Rankin score $\leq$1), with severe stroke (NIHSS $\geq$ 15) and reduced consciousness.(65) Four trials included patients with infarction involving two-thirds or more of the MCA territory (62, 64-66)and the other four trials included an infarct of more than 50% of the MCA territory.(63, 65, 67, 68) In HeADDFIRST, the protocol required participants to have midline shift.(63) Two trials included patients based on infarct volume >145 ml measured on MRI.(68-70) It is important to highlight that the definition of symptom onset in patients was not known was not reported in any of the trials.

Two trials were not specific about the length of the surgical incision for DHC, while five trials mandated a size of at least 12 cm.(62, 64-68, 70) HeADDFIRST was specific in that the boundaries of the bone flap had to extend anteriorly from the floor of the anterior cranial fossa at the mid-pupillary line, posterior to the external auditory canal, superiorly to 1 cm lateral to the superior sagittal sinus and inferiorly to the floor of the middle cranial fossa.(63)

The trials were subject to three meta-analyses, and the key conclusions are as follows:

- DHC within 48 hours of ictus was associated with an increase in survival from 30% to 80%, and this remained significant up to 1 year.
- One review(71) had suggested benefit with DHC only up to the age of 60 but the meta-analyses found that the survival benefit extended up to the age of 80.

- There was a higher proportion of survivors after DHC with mild to moderate disability (mRS ≤3) and moderately severe to severe disability (mRS 3-5). (11, 69, 72).

A recent analysis of individual patient data including 488 patients from seven trials showed that the survival benefit with DHC was independent of age, aphasia, stroke severity and whether there was an infarct in the anterior cerebral or posterior cerebral artery territory in addition to the middle cerebral artery territory.(65). The odds ratio of mRS ≤ 3 at one year in patients up to the age of 60 was 2.95.(65) This translates to a number needed to treat (NNT) of less than 3, with the exception of two trials: HeMMI and HeADDFIRST, with NNT of 6 and 23 respectively.(63, 65, 67) One reason for this variation is that HeADDFIRST had the lowest number of deaths (40%) in the medical treatment arm while the mortality with DHC was the same as in the other trials.(63) As highlighted, HeADDFIRST mandated that participants had to have midline shift on imaging at baseline, suggesting that the strokes were probably more severe which could have affected the results. Moreover, the protocol for medical management in HeADDFIRST was standardized, suggesting that optimization was helpful before DHC. (63)

Despite the evidence, there were limitations in the trials which merit discussion. There was performance bias as patients and investigators knew which treatment they were assigned to, and blinding during outcome assessment was not applied or was unclear in most trials.(60) There was attrition bias in three other trials as well.(60, 65) The method of allocation concealment was also unclear, and in DESTINY II, there was attrition bias as there was no report on why patients were lost in both arms (surgical: 47 patients instead of 49; medical: 62 patients instead of of 63).(61, 68) There was no adjustment for stroke severity or time to randomization because this was missing in some studies. Another important point is that some trials defined a favorable outcome as mRS of ≤ 3, while others used ≤ 4.(73) The

definition of mRS may be justified in that the stroke itself was severe so it is unlikely that survivors would recover enough to be able to walk without any assistance.

Although the technique of DHC was comparable, none of the trials reported if there was any technical deviation from the protocol. Another limitation is that there could have been differences in medical treatment that may not have been reported. It is also important to highlight that participants included in some trials may not reflect real-world clinical practice. For example, in the DECIMAL trial, patients were excluded if they were unable to have a MRI or were treated with intravenous thrombolysis.(68) HAMLET excluded patients who were treated with thrombolysis within 12 hours of randomization.(62)

The finding of survival benefit of DHC irrespective of age should also be interpreted with caution. In DESTINY II, patients older than 60 years were mostly severely disabled (19% versus 4%) and had less moderate disability compared to patients aged $\leq$ 60 years (6% versus 43%).(61) This could be because increasing age is a predictor of poor outcome after major surgery and critical care.(74) In addition, studies have also shown that older patients are less able to adjust to mood and cognitive problems after stroke.(74) Older patients may not progress with rehabilitation because of frailty and comorbidity.(12) One report also suggests that older patients are less likely to consent to major surgery at the risk of death or severe disability.(74)

It is important to highlight that the differences between the surgical and the medical arms of the trials were mainly driven by the primary outcome of mortality. It is unclear from the data whether there was limitations of treatment based on participant/family wishes, cultural factors or if decisions were made by the treating clinicians.(60)

There was little information on quality-of-life and mood after stroke, either because this was not assessed or there was significant variation in the assessments that were used in the

trials.(60) A systematic review of 16 trials (382 patients) assessing quality of life in survivors after DHC revealed that most patients and caregivers (77%) were satisfied and did not regret having the procedure.(75) This was in spite of moderate to severe disability (47% had mRS Score 4) and moderate to severe depression at one year follow up.(75) Another analysis showed that, in retrospect, most patients would consent again to have DHC, even though 44% had an mRS score of $\geq$4.(76) As for long-term outcomes, another study reported that quality-of-life of survivors after DHC was acceptable and improved at 3 years.(60)

Knowns of malignant cerebellar AIS

Cerebellar AIS can present with focal symptoms, with or without signs of acute hydrocephalus, or brainstem compression. The clinical presentation can be variable, from isolated dizziness, vertigo or vomiting to obtundation with signs of coning (i.e., transforaminal herniation) (77). In addition, involvement of the pons can cause ophthalmoplegia, lower motor neuron facial palsy, locked-in-syndrome, dysfunctional breathing or cardiac arrhythmias from catecholamine release and damage to the central autonomic network.(78) Patients with posterior inferior cerebellar artery infarction could also have Wallenberg syndrome, hearing loss and hiccups.(78)

CT imaging is often insensitive in the acute diagnosis of cerebellar AIS. DWI MRI is the preferred imaging modality. (79) One imaging finding that has been consistent in predicting neurological deterioration is involvement of more than two-thirds of the posterior inferior cerebellar artery.(18) However, this is observed only in a small group of patients.(18)

One study showed that CT perfusion imaging could help with early identification of patients at risk of life-threatening cerebellar infarction.(80) A perfusion deficit of 22 ml had the highest diagnostic threshold for sensitivity (100%) and specificity (90%).(80) However, assessment

of perfusion deficits for cerebellar stroke requires manual segmentation because quantitative thresholds are not established.(80)

Surgery for cerebellar AIS: technical aspects

For decompressive sub-occipital craniectomy (DSC), the patient is positioned prone, with the head secured in a clamp and the neck flexed, while avoiding compression of the jugular veins (**Figure 2**). A vertical incision is made from the occipital protuberance to the level of C2. The muscle layers are separated in a mid-avascular plane to expose the sub-occipital skull, atlanto-occipital membrane and posterior arch of atlas.(16, 57) A wide craniectomy is then performed. The dura is opened in a Y-shaped manner above the cerebellar hemispheres and the medulla. Some surgeons do not routinely remove infarcted tissue.(32) However, in a large stroke, the infarcted brain can herniate when the dura is being opened, so osmotic agents such as mannitol and/or hypertonic saline are often given prophylactically.

The fascia is then closed with absorbable sutures and the muscles closed in layers. Finally, the skin is closed with clips or sutures, which can be removed after 7-10 days. A ventriculostomy can be performed at the same time, or can be performed alone, although this poses a theoretical risk of causing upward herniation. The commonest point of entry for placement is Kocher's point which is ~2.5 cm from the right of midline and 11 cm posterior to the nasion.(15) With the patient prone, a posterior point of entry can be used (Frazer's point), which is 6 cm above and lateral to the inion.(15) With the burr hole turned, a catheter is then placed 5-7cm perpendicular to the cortex, increasingly with the use of ultrasound or co-registered CT or MRI. The catheter is then attached to an adjustable burrette, which is levelled to the tragus (the approximate level of the Foramen of Munroe). The burrette drainage height is then increased to adjust drainage pressure, which is often set slightly higher at 15 cmH20. This aims to reduce upward brainstem herniation, caused by a negative pressure differential between the infratentorial and supratentorial compartments. The aim is

to remove the drain within 7 days after gradual ‘challenge’, where the drainage pressure is gradually increased to test for patient’s need for external CSF drainage. Gradual increase in the draining pressure in the absence of neurological deterioration, along with radiographic stability, is sufficient to allow safe removal of the EVD.

Complications associated with DSC include hemorrhage from damage to the transverse sinus or the vertebral artery, which courses around the arch of the C1 vertebra. The reported rate of infection with EVD placement is ~9%, and prolonged EVD (>7days) is an independent risk factor for infection.(14, 56) Patients may develop persistent hydrocephalus and require permanent CSF shunting. A rare complication of DSC is cerebellar ptosis or brainstem slump, where after the edema has resolved, the cerebellum can descend through the defect causing CSF disturbance, effacement of the brainstem on the clivus and spinal cord syrinx.(81) The incidence after cerebellar AIS is unknown, but patients may present with headaches, lower cranial nerve palsies or myelopathy.(14) Treatment is primarily CSF diversion either from the supratentorial ventricles or a spinal cord syrinx, or occasionally cranioplasty.(56)

Evidence for surgery in malignant cerebellar AIS

The evidence for decompressive surgery for cerebellar stroke is based on small, retrospective, non-randomized studies, and reports on functional outcome are heterogeneous.(16)

There is no randomized trial that has shown that sub-occipital DSC or EVD improves outcome after cerebellar AIS. A meta-analysis including 283 patients after cerebellar AIS (82) reported that the pooled event rate for moderate to severe disability was 28.0% and the mortality was 19%. Variables associated with lower rates of death or severe disability after surgery included age (<60 years), timing of surgery ($\leq$ 48 hours) and Glasgow Coma Scale

(> 9).(82) There is little data on factors which affect prognosis after cerebellar AIS as well as long-term functional outcomes.(16) It is suggested that younger patients are less likely to be disabled and dependent after decompressive surgery, but this needs to be prospectively tested.(82)

One case series including 84 patients with cerebellar infarction found that there was no difference in functional outcome between DSC versus medical management for awake/drowsy or somnolent/stuporous patients.(83) It is important to highlight that there was an imbalance between the groups at baseline: 50% of the patients treated by surgery were drowsy and had significant mass effect compared to no patients in the medical arm.(83) Kim et al., reported a case-matched study comparing DSC with or without an external ventricular drain vs. medical management.(84) Poor outcome (mRS >2) was observed in 49% of patients treated medically compared to 33% with surgery, indicating a survival benefit with surgery.(84)

In conclusion, there is little randomized data to show that surgery for cerebellar AIS by EVD or DSC, improves functional outcome. Equally, there is insufficient evidence to suggest surgery results in more death or disability.

Unknowns of decompressive surgery in AIS

Dominant versus non-dominant hemispheric stroke

In clinical practice, uncertainty remains regarding the benefit of DHC for AIS of dominant (usually left) cerebral hemisphere, due to perceived impact on functional outcome and quality of life.(32) A systematic review showed that there was no difference in outcomes in patients between dominant hemispheric AIS compared to non-dominant hemisphere infarction.(71) Of note, measures including the modified Rankin Scale score, Glasgow Outcome Scale score and the extended version (GOS-E) are focused on motor recovery,

and not on the impact of a speech deficit. Nevertheless, a small study analyzing recovery of aphasia after DHC in dominant hemispheric stroke found that it was variable but 90% of patients were able to communicate at one year.(85) It is suggested that age and time from ictus to surgery are associated with improvement, but aphasia recovery is dependent on the intensity, length and timing of rehabilitation.(85, 86) As for quality-of-life, studies have reported no difference between survivors of DHC with and without aphasia. (60, 87) In addition, there seems to be no association between the presence or absence of aphasia on neuropsychological deficits or depression after stroke.(88)

Timing of surgery

One of the most important questions in surgical management is the optimal timing of DHC. One review of non-randomized studies showed that there was no difference in functional outcomes based on time to treatment.(89) Although the trials of DHC mandated time windows for participant inclusion, none specifically addressed the question of when to perform DHC.(65, 69) The protocol of the Early Decompressive Craniectomy in Malignant Middle Cerebral Artery Infarction (DECIMAL) trial mandated that surgery had to be performed within 6 hours of randomization.(68) DESTINY I allowed participants to be randomised if DHC could be performed between 12 and 36 hours of symptom onset, but the procedure itself had to begin no later than 6 hours of randomization.(66) By comparison, three trials, HeMMI, HeaDDFIRST and HAMLET allowed randomisation after 48 hours.(62, 63, 67) Although HAMLET was negative in the primary endpoint,(62) analysis combining a subgroup of patients with three other trials showed that DHC within 48 hours was associated with an absolute risk reduction of 49% (95% CI 33.9-65.9) in preventing death, corresponding to a number needed to treat of 2.(90) As for the effects of surgery beyond 48 hours, only 32 patients in the trials were randomized at that later time point, so it is difficult to draw conclusions on outcomes.(60)

One national registry reported the effect of timing of DHC in 1,301 patients treated as part of routine clinical care.(89) Delayed surgery increased the odds of poor outcome and discharge to institutional care.(89) Subgroup analysis showed that there was no relationship between timing of DHC and outcome in patients who did not have brain herniation. This suggests that timing alone is not important and surgery could be life-saving as long as neurological deterioration has not occurred.(45)

There have been no trials comparing the effects of early versus late DHC. Small studies suggest that DHC within hours of ictus is associated with reduced mortality and fewer complications such as hydrocephalus.(91, 92) It would seem logical to perform surgery as soon as possible to reduce injury to the salvageable brain and avoid significant elevation in ICP.(89, 91, 93) Even if it is feasible to undertake such a major operation within hours of ictus, little is known on the clinical characteristics and radiological predictors during this period.(94)

The conclusion from the current evidence for timing of DHC is that eligible patients should be treated within 48 hours of ictus. Until there are trials comparing early versus late surgery, there is no evidence to exclude patients who present in late time windows.(94)

Monitoring intracranial pressure

ICP monitoring is routinely used to monitor patients with traumatic brain injury (TBI), and a pressure >22 cm is used routinely to guide treatment. In AIS, monitoring ICP could be used as a trigger for DHC but the use may be limited because patients with malignant MCA infarction may have normal ICP.(95) One retrospective study found patients who died from MCA infarction had clinical signs of brain herniation before an increase in ICP.(96)

In the post-operative period, ICP monitoring could be helpful to assess complications such as hydrocephalus or hemorrhage, and the ICP readings may be used to monitor treatments

such as osmotic therapy, drainage of cerebrospinal fluid or resection of infarcted tissue. Other indications for ICP monitoring in malignant AIS could include assessment of response to neuroprotective measures such as therapeutic hypothermia, anti-seizure medications or sedation, but the optimal thresholds, accuracy and reliability need to be tested.

Cost effectiveness

The high rates of disability among survivors of DHC and DSC for malignant infarction raise questions whether it is cost effective. Investigators from the HAMLET trial for DHC reported that operated patients had more quality-of-life-adjusted years (QALY) than medically treated patients, with a mean difference of 1 QALY but at a higher cost (€127,000) in the first 3 years.(97) Estimates over a lifetime showed that the QALY gained was €60,000.(97) A recent UK-based cost effectiveness analysis study using data from the DECIMAL trial showed that DHC had an incremental cost (£116,595) compared to medical treatment.(98) DECIMAL excluded patients above the age of 60 years, and so DHC in older patients, which reduces mortality but increases the proportion of dependent survivors, may have higher costs.(68) In exclusively tax-funded health systems, such as in the United Kingdom, commissioning of medical care is dependent on cost effectiveness thresholds, which may not be met by surgery for AIS. However, at least for DHC, the reduction in mortality and the low incidence of malignant MCA infarction provide justification. (98) If more patients are able to access MT, the number of patients referred for DHC surgery could decrease and balance the overall cost of care.(98)

Duraplasty

Duraplasty in DHC allows expansion of the swollen brain, while providing a physical and microbiological barrier between the cortex and the galea. However its impact on leakage of CSF and post-operative wound infection are unknown. (57) Duraplasty may also avoid

complications of cranioplasty, which can cause injury to the cortex.(57) Materials that are available for duraplasty include autograft from patients, allograft, xenograft and synthetics from silicone or poly-tetra-fluoro-ethylene.(15) Each of these vary in availability, immunogenicity, risk of infection, toxicity, ease of use and cost.(14, 57) There is international variation in recommendations for duraplasty and material of choice, and there are no data on head-to-head comparisons, complications or functional outcome.(99, 100)

Cranioplasty

Cranioplasty aims to correct the cranial defect after DHC by replacement of the bone flap (autologous) or insertion of a manufactured implant. Cranioplasty is associated with morbidity and mortality. Studies have reported that complications can be as high as 50% and up to a quarter of patients need revision surgery; ~ 1% of procedures result in death.(101-103) A recent report from the United Kingdom and Ireland Cranial Reconstruction Registry showed that titanium was the most common implant (64%), followed by autologous bone flap (14%), and other materials are used infrequently (~5%).(104) Autologous bone flaps are stored in a variety of ways (e.g. peritoneum or thigh), frozen or kept in cryoprecipitate solution in a tissue bank prior to implantation.(15) Autologous bone is biocompatible and inexpensive, (15) but it is associated with higher risk of resorption and implant failure requiring surgical removal.(105) The choice of implant is an area of equipoise and should be tested in future randomized trials. Indeed, studies have demonstrated the benefits of antibiotic-impregnated neurosurgical implants, and represent important avenues for investigation.

The optimal timing of cranioplasty after DHC for ischaemic stroke is unclear. Studies have varied in the definition of timing, and there have been no randomized trials.(106) Some studies have attempted to compare the effects of early (<3 months) versus late cranioplasty.

(106, 107) The results suggest that earlier cranioplasty is associated with an increased risk of complications such as hydrocephalus, but the effects on functional outcome are unknown.(73, 107, 108)

Guidelines

Based on the current evidence, national and international guidelines recommend that patients with malignant MCA AIS should be offered surgery. (**Table 3**). Guidelines broadly agree that it is reasonable to use reduced consciousness as an indicator of clinical deterioration (although the optimal trigger is unclear) and to perform DHC in patients $\leq$ 60 years within 48 hours despite medical treatment. In patients older than 60 years, guidelines suggest DHC can be considered within 48 hours if there is deterioration from a malignant MCA infarct despite maximum medical therapy, although there is no clear benefit in functional recovery to independence. In patients with an infarct affecting $\geq$50% of the MCA territory or a volume of >145 cm3 on DWI MRI, guidelines are similar in stating that patients would be eligible for DHC. Early involvement of the patient or their caregivers to discuss the intended benefits and risks of DHC is recommended.(18, 99, 100) This could include the use of decision-making aids to illustrate the balance of survival and disability (**Figure 3**).

As for surgery in cerebellar stroke, guidelines for DSC and EVD for cerebellar AIS are variable. (**Table 4**) International guidelines agree that triggers for surgery for malignant cerebellar AIS include patients with signs of brainstem compression, symptomatic hydrocephalus and reduced level of consciousness. Authors from the American Heart Association /American Stroke Association (18) suggest that DSC is associated with an acceptable functional outcome. (**Table 4**)

Conclusions

In conclusion, significant progress has been made in the surgical treatment of ischaemic stroke which is an important component of routine clinical care.

Uncertainty exists in various aspects and more research is needed:

- to understand the pathogenesis of malignant edema after ischemic stroke, the role of biomarkers which could lead to better understanding of predictors and factors which lead to clinical deterioration.
- to determine the optimal timing of DHC and the impact of pre-operative inclusion criteria on outcomes
- to assess the age limit after which potential benefit might be outweighed by risks, taking into account prior comorbidity
- to test the effects of decompressive surgery on long-term dependency, depression and quality-of-life
- to refine surgical technique including value of duraplasty, understand the role of ICP monitoring, and benefits and risks of medical treatments such as osmotic agents during and after surgery
- to assess the ethical aspects of functional outcome in survivors after surgery and potential for rehabilitation. This could include social factors, cultural differences between race/ethnicity and health economics.
- to understand factors associated with morbidity and mortality after cranioplasty, safety and efficacy of the implant and comparisons between them. There are ongoing studies on the sunken flap syndrome (NCT03186157) and resorption of autologous bone flap (NCT02320955).

It is possible that the survival benefit shown in the trials and recent meta-analyses increase the number of DHCs for malignant AIS, but on the other hand, the benefit with MT in internal

carotid artery terminus or proximal middle cerebral artery occlusions could reduce the number of patients requiring surgery.(109) Research into the aforementioned aspects is needed to identify subgroups of patients who will require surgery. Such results would inform patient triage and pre-operative counselling of patients or their caregivers. To-date, there is no proven treatment for malignant cerebral edema after ischemic stroke apart from DHC, and so research complemented by developments in medical treatment/neurocritical care are warranted.(109)

As for surgery in cerebellar ischemic stroke, studies are needed on whether DSC, ventriculostomy, or the combination, are effective. More work is also needed on the optimal timing of intervention, length of decompression and whether removal of infarcted brain affects functional outcome. Clinical trials in cerebellar stroke could be challenging given the potential for survival benefit and so where randomization into a study may be considered unethical, for example in a patient with a large cerebellar infarction and brainstem compression, treatment may be guided using data from collaborative registries.

Finally, more work is needed to identify ways to enhance shared decision making between the patient, their caregiver and the treating clinician to understand the expectations of surgery for a life-threatening condition such as malignant ischemic stroke.

Disclosures

None

References

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Tables

Table 1. Predictive imaging scores for malignant cerebral infarction

ASPECTS	EDEMA	Malignant Edema Score	ACORNS	NEMMI score	Kasner Risk Index	DASH
Max score 10 deduct 1for every region involved in CT: • caudate • putamen • internal capsule • insular cortex • frontal operculum • anterior temporal lobe • posterior temporal lobe • superior to M1 • immediately superior to M2 • immediately superior to M3	Summative score (max 11) Basal Cistern Effacement (3) Midline Shift: • 3 mm (1) • 3-6mm (2) • 6-9mm (3) • >9mm (4) Glucose >150 mg/dL (2) Previous Stroke (1) No intervention (1)	Summative score (max 7) ASPECTS Score <8 (1) NIHSS: • 9-17 (1) • NIHSS >17 (2) Collateral Score <2 (2) Not revascularized (1)	Summative score (max ASPECTS Score: • 6-7 (1) • <6 (3) Poor collaterals (2) Glucose: • 7.1-11.1 (1) • > 11.1 (2) History of hypertension (1) Thrombolysed (1) Reperfusion status (mTICI): • 0-2a (2) NIHSS: • 13-20 (1) • >20 (2) Occlusion site: • ICA (2)	Formula: (maximum anterio-posterior and mediolateral dimensions (cm)) multiplied by the visual hypoattenuation factor Visual hypoattenuation factor • None (1) • Subtle (2) • Obvious (3)	Sum score (max 5) History of hypertension (1) History of congestive heart failure (1) WCC > 10, 000/μL (1) CT involvement: • >50% MCA territory and (1) • involvement of additional territories (1)	Sum score: DWI ASPECTS ≤ 3 (1) ACA territory involvement (1) M1 SVS as (1) Glucose ≥ 145 mg/dL (1)
A score of ≤7 is associated with a positive predictive value of 77% and negative predictive value of 65%	A score over 7 was associated with 93% positive predictive value	Score>4: 80% Malignant edema	Score of 7 had 71% sensitivity and 80% specificity	Score >10.5 identified Malignant cerebral infarction: sensitivity 93%; specificity: 70.7%	>4 or more associated with >85% risk of fatal edema	Score>3 associated with >90% risk of malignant edema

ACA: anterior cerebral artery; CT: Computed tomography; DWI: Diffusion-weighted imaging; mTICI: modified Thrombolysis in cerebral infarction; M1: proximal segment of the middle cerebral artery; NIHSS: National Institutes of Health Stroke Scale; WCC: white cell count

Table 2. Summary of randomised controlled trials and meta-analyses of decompressive surgery versus medical management in malignant middle cerebral artery territory infarction

Trial acronym/ author, country, year, n	Age for inclusion/ actual mean age (yrs)	Timing of randomisation (protocol actual time)(hrs)	Time*, to surgery	NIHSS or GCS	MCA territory involved	Basal ganglia involved	Infarct volume ∏ (cm3)	Presence of oedema (yes/no)	Pre-stroke mRS	Primary outcome	Result
DECIMAL, France, 2007, n=38	18-55/43	<30/20	≤ 6	>15; NIHSS 1a≥ 1	>50%	NA	>145	**	0-1	mRS 0-3 at 6 months	No difference in mRS; significant reduction in mortality with surgery vs medical treatment (25% vs 78%) at 6 months
DEMITUR, Turkey, n=151	40-80	**	<6	>18 if right sided; >20 if left sided; NIHSS 1a≥ 1	≥ 2/3	Yes	>150	**	-	mRS 0-3 at 6 months and 12 months	-
DESTINY, Germany, 2007, n=32	18-60/43	<36/24	≤ 6	>18 if right sided; >20 if left sided	≥ 2/3	Yes		**	0-1	mRS (0-3 vs 4-6) at 6 months	No difference in mRS; survival with surgery vs medical treatment at 30 days (88% vs 47%; OR 6.37; 95% CI 1.35-29.17)
HAMLET 2009, n=64	18-60/50	<96/41	≤ 3	>15 if right sided; >20 if left sided	≥ 2/3	**	**	Yes	0-1	mRS (0-3 vs 4-6) at 12 months	No difference in mRS; significant reduction in mortality with surgery (22% vs 59%; ARR 38%; 95%CI 15-60)
Slezins et al, 2012; Latvia, n=24	>18/57	<48/21	**	>15	≥50%	**	>145	Yes	0-1	mRS (0-4 vs 5-6) at 12 months	More survival with surgery compared to medical treatment (46% vs 8%)
Zhao et al, China, 2012; n=47	18-80/63	<48/23	**	GCS eye and motor score ≤ 9	≥ 2/3	**	**	Yes	0-1	mRS at 6 months (0-4 vs 5-6)	Significant difference in mRS 5-6:33% vs 82%; ARR 49.3% (24.4-72.3) and mortality at 6 months compared to medical treatment

											(12.5% vs 60.9%)
DESTINY II 2014; n=112	>60/70	<48/28	≤ 6	>14 if right sided; >19 if left sided; NIHSS 1a≥ 1	≥ 2/3	Yes	**	**	0-1	mRS 0-4 at 6 months	Significant difference in mRS 0-4: 38% vs 18%; OR 2.91(1.06-7.49) and mortality (33% vs 70%)
HeADDFIRST, 2014; North America, n=24	18-75/52	<96/53	**	>17; NIHSS 1a<2	≥50%	Yes	**	**	0-2	Death at 21 days	No significant difference
HeMMI, Philippines, 2015; n=24	18-65/50	<72/36	**	GCS 6-14 if right sided; 5-9 if left sided or GCS 15 on arrival and then deterioration with NIHSS 1a≥ 1	>50%	**	**	**	0-2	mRS (0-3 vs 4-6) at 6 months	No significant difference in mRS or death
Meta-analysis											
Back et al 2015; n=317	-	-	-	-	-	-	-	-	-	-	OR for death from DHC compared vs medical treatment was 0.17(0.10-0.29); mortality benefit up to 80 years. mRS of 2 was significantly higher in the surgery group, OR 4.51 (1.06-19.24); number of patients with severe disability mRS 3-5 was also higher with surgery
Alexander et al 2016; n=338	-	-	-	-	-	-	-	-	-	-	Chance of survival with DHC had a RR 2.05 (1.54-2.72); severe disability was higher with DHC (4% more patients with mRS 5; 22% more with mRS 4)
Das et al 2019; n=692	-	-	-	-	-	-	-	-	-	-	DHC resulted in reduced mortality but high morbidity especially in the elderly; increase in quality adjusted life years for survivors but at high costs; patients and caregivers were satisfied with quality of life
Ayling et al 2018; n=283											Sub-occipital craniectomy for cerebellar stroke was associated with better outcomes compared to

											DHC for hemispheric infarcts. The pooled event rate for moderate to severe disability was 28% and mortality was 20%. In sensitivity analysis, variables associated with lower rates of death or severe disability after surgery included age (<60 years), timing of surgery (≤ 48 hours) and Glasgow Coma Scale (≥ 9).(82)
Relnink et al 2020; n=488	-	-	-	-	-	-	-	-	-	-	DHC was associated with decreased odds of death OR 0.16 (0.10-2.54) and increased odds of favourable outcome OR 2.95 (1.55-5.60)

*time from randomisation to surgery; **not applicable/not assessed; ∏ infarct volume was computed using diffusion weighted imaging; ARR: absolute risk reduction; DHC: decompressive hemicraniectomy; DWI: diffusion weighted imaging; MCA: middle cerebral artery; mRS: modified Rankin scale; OR: odds ratio; - not listed as main result publication was withdrawn

Table 3. Summary of selected national and international guidelines for decompressive surgery in malignant middle cerebral artery territory infarction

	United Kingdom*	European Stroke Organisation	AHA/ASA	Canadian Stroke Best Practices	Chinese Stroke Association	NPCDCS, India	Australia and New Zealand	Japan Stroke Society	Malaysian Society of Neurosciences: Stroke Council
Guidance	Discuss the risks and benefits with the patient, family or carers considering pre-stroke functional status and wishes	Surgery should only be done after a shared decision making process including the patient or their representative	Include patient-centred preference in shared decision making. Patients and family should be consulted quickly	Discuss with patient, family members and legal decision-maker regarding potential DHC	-	-	-	-	-
Clinical criteria	Clinical signs of MCA infarction with NIHSS ≥15 and impaired consciousness, ≥1 on item 1a NIHSS	-	Optimal trigger not known It is reasonable to use a decrease in level of consciousness attributed to brain swelling	Proceed urgently to surgery prior to significant decline in GCS or pupillary change. Change in status may include level of drowsiness/consciousness, change in CNS score by ≥1, or NIHSS score by ≥4	Patients who deteriorate despite medical therapy. It is reasonable to use a decrease in level of consciousness attributed to brain swelling as selection criteria. Also: new or worsening change disturbance of consciousness, in pupillary size, fixation or	MCA territory infarction Decrease in GCS (total 6-13; or eye and motor score only <9; or motor score <6)	-	NIHSS > 15 and Item 1a score ⩾1	-

					reduction in motor response				
Age	>16 years	Reasonable to offer DHC to those ≤60y to reduce risk of poor outcome, it may be considered in >60 years to reduce risk of death	Reasonable to offer surgery to ≤60y who deteriorate despite medical therapy reasonable, and it should be considered for patients >60y	>18y or <18y with progressive extensive malignant MCA infarction	It is reasonable to offer surgery to ≤60y who deteriorate despite medical therapy reasonable, and it should be considered for patients >60y	-	Should be considered in Selected patients aged 60 years and under and highly selected stroke patients over 60 years	18-60 years meeting the criteria for indication of DHC except age	<60 y and >60 y in selected cases
Timing of surgery	< 48 h of ictus	<48 h of brain swelling associated with unilateral infarction. >48 hours can be considered if death by herniation appears likely	Deterioration < 48 h from brain swelling associated with unilateral MCA infarctions	< 48 hours from ictus may provide benefit	< deteriorate neurologically within 48 hours despite medical therapy	<operated as early as possible, preferably within 48 hours	hemicraniectomy should ideally be performed within 48 hours of stroke onset	<48 hours after ictus	<48 hours
Radiological Criteria	≥50% of the MCA territory +/- additional ipsilateral infarction in ACA/PCA territory or infarct volume > 145 cm^3 on diffusion-weighted MRI	-	-	Infarct size > 50% MCA territory, or infarct volume > 150 ml		> 50% of the MCA territory on CT, with evidence of midline shift >4 mm +/- infarction of the territory of ipsilateral ACA or PCA; on diffusion-weighted MRI showing infarct volume >145mL	-	infarct in the territory of the MCA involves at least 50% on CT; or >145 cm^3 in diffusion-weighted image	very large infarcts of the cerebral hemisphere.
Recommended technique	DHC	DHC + dural expansion is reasonable. diameter of the craniectomy	DHC + dural expansion	HDHC	DHC with dural expansion	DHC	DHC	DHC with duroplasty	DHC

		should be at least 12 cm							
Transfer	Patients should be monitored by appropriately trained professionals skilled in neurological assessment	Early transfer of patients at risk for malignant brain swelling to an institution with appropriate neurosurgical expertise should be considered. ICU should be considered	Transfer of at risk patients to an institution with appropriate neurosurgical expertise should be considered	the patient should transferred to a centre where stroke care and neurosurgical services are available Monitoring should include assessments of level of consciousness (e.g., Canadian Neurological Scale Score), worsening symptom severity, and blood pressure at least hourly Repeat CT scans are recommended for patients when deterioration in neurological status occurs		Patients with indication for neurosurgery should be referred to a centre with neurosurgical facility	patients with brain oedema and raised intracranial pressure, osmotherapy and hyperventilation can be trialled while a neurosurgical consultation is undertaken		

Table 4. Summary of selected national and international guidelines for surgery in cerebellar ischaemic stroke

	United Kingdom *	European Stroke Organisation	AHA/ASA	Canadian Stroke Best Practice	Chinese Stroke Association	NPCDCS, India	Australia and New Zealand	Japan Stroke Society	Malaysian Society of Neurosciences : Stroke Council
Discussion	-	-	Early discussion. It may be reasonable to advise families that outcome can be good after surgery	-	-	-	-	-	-
Transfer	-	-	Early transfer of those at risk should be considered	-	-	-	-	-	-
Decompressive Suboccipital Craniectomy	-	Consider DSC +/- CSF drainage in selected patients with space-occupying cerebellar infarction, such as in those with a reduced consciousness caused by brainstem compression. The precise selection of	DSC should be offered in patients with cerebellar infarction causing brain stem compression	DSC can be considered in selected patients with significant cerebellar stroke with evidence of mass effect and / or hydrocephalus	DSC with dural expansion should be performed in patients with cerebellar infarction causing neurological deterioration from brainstem compression despite maximal medical therapy. When deemed safe	Patients with large cerebellar infarct causing compression of brainstem and altered consciousness should be surgically managed with DSC	For selected patients with large cerebellar infarction threatening brainstem and 4th ventricular compression, DSC should be offered	In patients presenting severe consciousness disorder such as coma due to compression of the brain stem, posterior fossa DSC is reasonable	Ventriculo-stomy and DSC are effective in relieving hydrocephalus and brain stem compression caused by large cerebellar infarctions

		patients and the optimal timing of treatment remain uncertain. There is insufficient evidence to support its routine use.			and indicated, obstructive hydrocephalus should be treated concurrently				
External ventricular drainage	-		EVD should be offered to patients with obstructive hydrocephalus after infarction		EVD is recommended in the treatment of obstructive hydrocephalus after a cerebellar infarct. Concomitant or subsequent DSC may or may not be necessary on the basis of factors such as infarct size, neurological condition, degree of brainstem compression and effectiveness of medical management	Symptomatic hydrocephalus should be treated surgically EVD		In patients with cerebellar infarction who have moderate consciousness disorder due to hydrocephalus, ventricular drainage may be considered	

Figures

Figure 1. Decompressive Hemicraniectomy (DHC) for malignant middle cerebral artery acute ischaemic stroke.

A typical DHC has a question mark incision. The incision also be extended behind the ear to spare the superficial temporal artery (dashed line). To extend the size of the flap, a linear incision perpendicular to the incision can be made. Care must be taken to avoid laceration of the superior sagittal and transverse sinus.

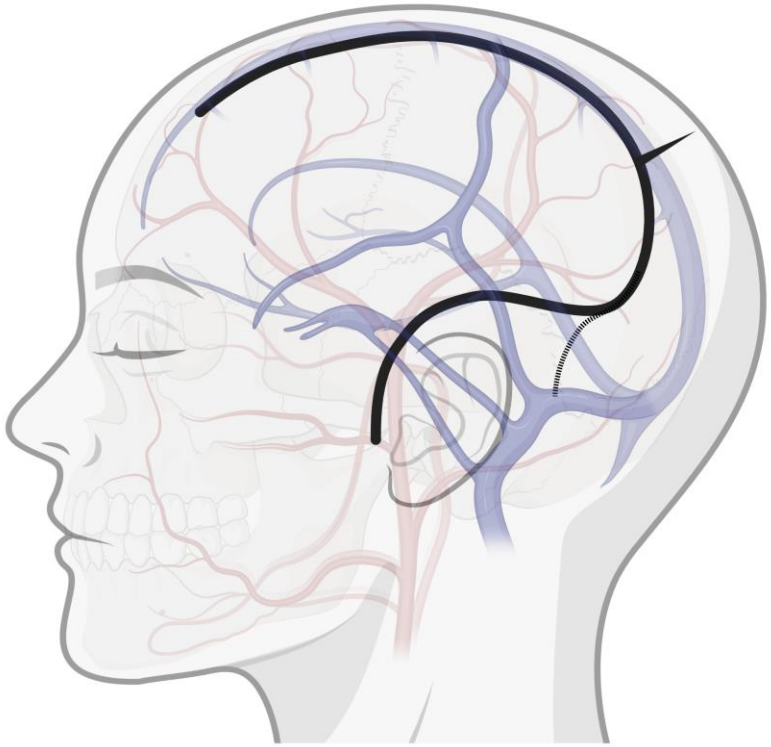

Figure 2. Surgery for Malignant Cerebellar Acute Ischaemic Stroke.
Surgery involves suboccipital craniotomy involving a vertical incision over the occiput, exposure of the arch of C1 and a quadrangular craniectomy to expose the cerebellar tonsils. An external ventricular drain can also be placed by making a burr hole at Kocher's Point, 11 cm from the nasion, and 2.5cm from the midline/mid pupillary line (dashed line). The EVD is placed 5-7 cm perpendicular to the cortex to drain the ipsilateral lateral ventricle.

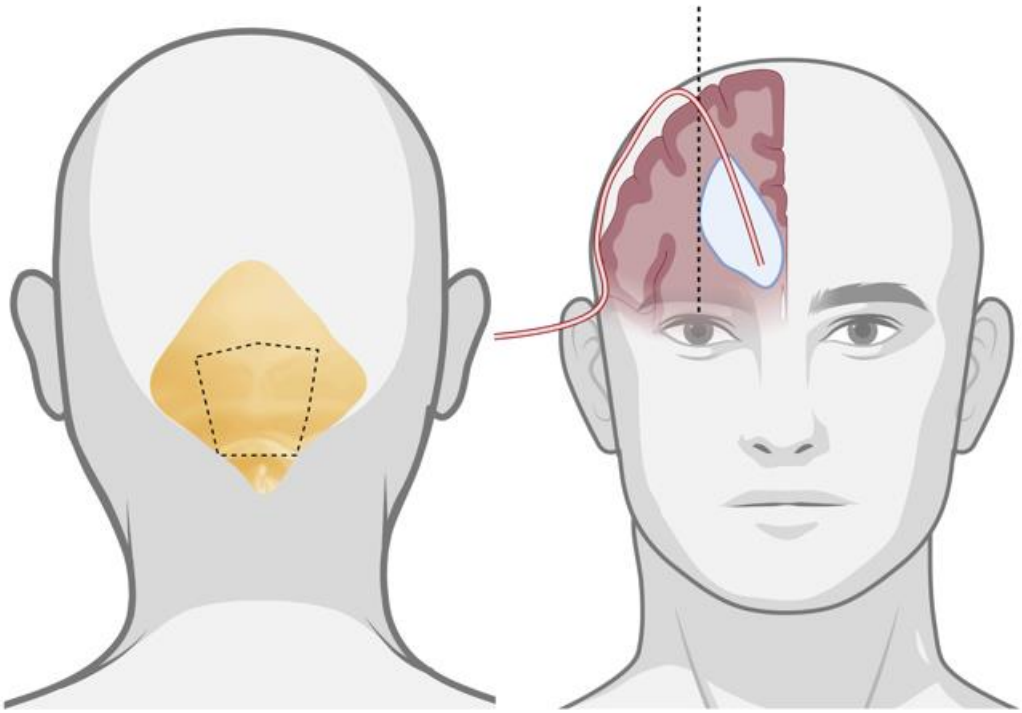

Figure 3. Decision-making aid for surgery in malignant middle cerebral artery acute ischaemic stroke.* This could be provided to patients and families during discussion regarding balance of benefits versus risks

***** adapted from the patient decision aid developed by the National Institute for Health and Care Excellence, United Kingdom

Key points

- Acute ischemic stroke from occlusion of a proximal intracranial artery can progress quickly to malignant edema, which can be fatal in 80% of patients despite medical management.
- Decompression surgery is life-saving within 48 hours of stroke onset, but the benefits beyond this time and in the elderly are unknown.
- Decompressive surgery is associated with high morbidity, particularly in the elderly. The decision to operate must be made after considering the individual's preference and expectations of quality-of-life in the context of the clinical condition.
- Further studies are needed to refine surgical technique including value of duraplasty, understand the role monitoring intracranial pressure during and after decompressive surgery.
- More studies are needed on the pathophysiology of malignant cerebral edema, prediction models including imaging and biomarkers to identify which subgroup of patients will benefit from decompressive surgery.
- More research is needed on factors associated with morbidity and mortality after cranioplasty, safety and efficacy of implants and comparisons between them.
- Further studies are needed to assess the long-term effects of physical disability and quality-of-life of survivors after surgery, particularly those with severe neurological deficits.