The Effect of Size of Decompressive Craniectomy on Outcome in Deep Spontaneous Intracerebral Hemorrhage

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Abstract

Introduction Spontaneous intracerebral hemorrhage (SICH) is one of the most devastating forms of stroke with a mortality of 30 to 40%. We aimed to evaluate the effect of craniotomy size and volume of decompression on surgical outcome, complications, mortality, and morbidity in patients with supratentorial capsuloganglionic bleeds who underwent a decompressive craniectomy (DC) at our institute.

Materials and Methods It is a retrospective study done between January 2015 and December 2019. All patients with capsuloganglionic bleeds who had DC and hematoma evacuation were included in the study.

Results A total of 55 patients underwent DC for SICH at our hospital during the study period. Mean anteroposterior (AP) diameter of the bone flap was 12.42 cm. The volume of decompression did not influence mortality and morbidity in our study but a larger AP diameter was associated with a higher incidence of hydrocephalus. A smaller craniectomy with an AP diameter of < 12 cm caused a lesser reduction in midline shift (MLS). Persistent postoperative MLS had a significant impact on mortality and its reduction was dependent on the size of craniectomy ($p = -0.037$)

Conclusion DC with a recommended AP diameter of 12 to 13 cm achieves optimal results in terms of reduction in MLS. Larger DC volume carries a higher risk of hydrocephalus and requires close follow-up.

Keywords
► decompressive craniectomy
► spontaneous intracerebral hemorrhage
► stroke
► mRs
► surgical outcome

Introduction

Spontaneous intracerebral hemorrhage (SICH) is one of the most devastating forms of stroke with a mortality of 30 to 40%.[1] Following the STICH trials[2] interest in surgery for SICH had declined, and even to date there is no class 1 evidence on the ideal management of SICH with refractory raised intracranial pressure (ICP). However, of late there is mounting evidence in literature that minimally invasive surgery is associated with significantly improved outcomes when compared with conservative treatment and conventional surgical evacuation strategy. There has been a revived interest in decompressive craniectomy (DC) also over the past few years with several large studies and meta-analysis highlighting the superiority of DC in intracerebral hemorrhage (ICH) for reducing mortality. In fact the recent American

Heart Association guidelines on SICH recommend that DC with or without hematoma evacuation might reduce mortality for patients with supratentorial ICH who are in a coma, have large hematomas with significant midline shift (MLS), or have elevated ICP refractory to medical management (class 2b; level of evidence C).[2] The rationale for DC is based upon the Monro-Kellie doctrine and the procedure was first described by Kocher and Cushing in the early 1900s.[3] DC aims to enlarge the intracranial space and expand intracranial volume with the restoration of perimesencephalic cisterns, decrease the MLS, and thereby improve cerebral compliance[4] and reduce ICP.[5] The optimal size of the craniectomy, which results in maximal decompression without increasing the risk of complications, is still an enigma. The size and volume of DC have been studied in detail for ischemic stroke[6] and traumatic brain injury (TBI).[7] However, no attempt has been made to study the effect of craniectomy size in SICH. No level 1 evidence exists regarding the ideal size of DC[8] with various studies suggesting that anteroposterior (AP) diameter of at least 8 cm[9] is adequate and others suggesting that at least 15 cm is mandatory.[10] Unlike in patients with trauma and ischemic stroke, where the primary insult results in significant cerebral edema, in SICH hematoma evacuation causes significant brain tissue collapse, which is noted intraoperatively. However, perihematomal edema, rebleed, or residual bleed may lead to delayed deterioration and DC tends to have a therapeutic role in preventing such secondary deteriorations.

Our study was based on the hypothesis that in patients with large SICH, as there tends to be a collapse of brain tissue post hematoma evacuation, a large DC might not be required, like in cases of trauma or ischemic stroke. Moreover, large DC may be harmful as intraoperative brain collapse might lead to complications like shearing of bridging veins. We aimed to evaluate the effect of craniotomy size and volume of decompression achieved on surgical outcome, complications, mortality, and morbidity in patients with supratentorial capsuloganglionic bleeds who underwent DC at our institute.

Methods and Methodology

We retrospectively reviewed records of all patients who underwent primary standard DC with hematoma evacuation for unilateral spontaneous capsuloganglionic hemorrhage at our center between January 2015 and December 2019. As per our institutional protocol, patients who had two of the following features were taken up for DC: hematoma volume greater than 60 mL, MLS > 10 mm, Glasgow Coma Score (GCS) < 8, and pupillary asymmetry. Patients with lobar hemorrhage were excluded in this study.

Patient Information and Initial Management
Patient demographic data, that is, age, sex, comorbidities, GCS at admission, were collected retrospectively from our prospectively maintained institutional ICH register. All the patients underwent nonenhanced computed tomography (CT) of the brain on admission and the images were analyzed after retrieving from our picture archiving and recovery

system. On admission, all the patients were intubated given the poor GCS. Blood pressure reduction was performed in all cases with a target of < 140 mmHg as per INTERACT II.[11] Brain-specific antiedema measures were initiated in all patients. Hematoma volume was calculated from the CT brain done before surgery using the formula ABC/2, where A and B are the perpendicular maximal diameters of the lesion and C is the total length in the vertical plane.

Surgery and Measurement of Craniectomy
Following the confirmation of the decision to operate—a reverse question mark—Dandy's flap was taken and the fronto-temporoparietal bone was exposed. Burr holes were placed at the key, midline, temporal floor, and behind the parietal eminence and craniotomy was performed using a high-speed cutter. The craniectomy flap was made to include subtemporal decompression, medially till 1 to 2 cm from the midline and posteriorly up to the posterior ear line. There was no standardization in the size of craniectomy. Complete evacuation of hematoma was attempted in all cases. Lax duroplasty was performed in all cases using a free pericranial patch. Six surgeons with various levels of experience performed the cases. The bone flap was placed in the abdomen in a subcutaneous pouch. Postoperative CT scans were performed routinely at 12 to 24 hours following surgery. CT scanning was obtained in 3-mm-slice thickness without gap or overlap. Scans were assessed for completion of hematoma removal, MLS, and size of DC.

The distance between the posterior and anterior margins of the bone defect was measured on each slice using the inner table of the skull bone. AP diameter and height of the craniectomy were measured in axial and coronal CT sections, respectively. The measurements were confirmed after three-dimensional (3D) reconstruction of the images using InVasalius version 3.1. The distance between the lower border of the craniectomy and the middle cranial fossa base was measured at the level of the uncus. The distance of the margin of the craniotomy from the midline in coronal sections was measured and the mean was used in the analysis (►Fig. 1). The MLS was assessed in the patients pre and postoperative scans at the level of foramen of Monro in axial cuts.

The volume gained by craniectomy—decompressive volume (DV)—was measured using the Eq. ½ABC, which has a strong correlation with computed 3D volumetric assessment,
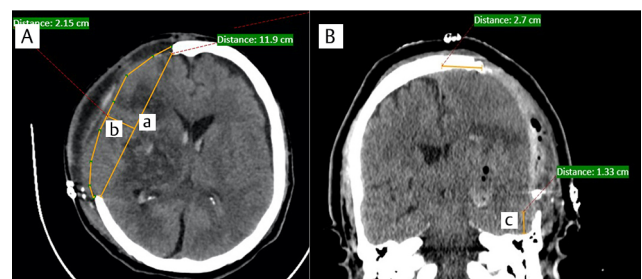

Fig. 1 Representative computed tomography scan of a brain: (**A**) (**a**) diameter of the craniectomy; (**b**) longest perpendicular line to the dura. Margin of the area gained by the craniectomy was hand-traced. Image **B**- (**c**) Distance from midline and base of craniectomy.

which remains the gold standard.[12] The CT slice showing the largest diameter in AP measurement was measured as A. A perpendicular line (B) was measured from A to the dural flap. The number of CT slices of the craniectomy, multiplied by the slice thickness, was the height (C) of DV (►**Fig. 1**). Area that was gained by DC was calculated as suggested by Nagatani et al.[12]

Outcome

The outcome was measured using the Modified Rankin Scale (mRS) at discharge and 90 days. A favorable outcome was defined as mRS 0 to 3, and a poor outcome was defined as mRS 4 to 6.

In all patients who survived, a CT brain was performed at 6 weeks post surgery to assess hydrocephalus, subdural hygroma, and to plan replacement of bone flap. Hydrocephalus was assessed using Evan's index [24]. A value of > 0.3 was considered significant. The following variables were analyzed for their influence on mRS, MLS, and hydrocephalus: AP length of the flap, height of the flap, and distance from the midline.

Statistical Analysis

Descriptive statistics were reported for continuous variables. Continuous variables were analyzed using independent Student's t-test and one-way analysis of variance for normally distributed data while Welch–Satterthwaite t-test was used for variables with unequal variances. Categorical variables were analyzed with the chi-squared test. Univariate Spearman's correlations were performed between all the independent variables and mRS at follow-up. Mann–Whitney U test was used to analyze nonparametric data. A 5% α error and 80% β error along with a corrected p-value of < 0.05 were considered as statistically significant. The analysis was performed using IBM SPSS version 24 for Windows.

Results

A total of 63 patients underwent DC during the study period, and 55 patients were included in the study group. The mean age was 50.73 ± 11.51 years with a male preponderance (47:8). Mean systolic blood pressure on admission was 186.47 ± 29.53 mmHg and diastolic was 104.69 ± 17.7 mmHg. Median GCS on presentation was 8 and preoperative GCS was 7 with the volume of hematoma of 49.39 ± 23.33 mL. Twenty-three patients had an intraventricular extension of hematoma and 10 had hydrocephalus in the presenting scan. Mean preoperative MLS was 1.05 ± 0.32, mean time to surgery was 18.47 hours, and hospital stay was 15 ± 8.12 days (►**Table 1**).

Mean AP diameter of the DC bone flap in our study was 12.42 cm (10.9–14.7 cm). The AP diameter had no statistically significant impact on morbidity or mortality of the patient ($p = 0.4$ and 0.8, respectively). The mean AP diameter of the patients who developed postoperative hydrocephalus was higher than the patients who did not (12.8 and 12.1 cm, respectively; $p = 0.036$). No similar correlation could be made with the development of postoperative hygroma ($p = 0.49$).

The mean height of the DC flap was 9.88 ± 0.8 cm. The patients who had a greater height of the flap had a better outcome. Mean height of DC in the patients who had a good outcome was: 10 vs. 9.2 cm ($p = 0.021$). Of the 55 patients, 28 had craniotomy flush with the temporal base and 27 patients did not. In these patients the residual temporal bone from the base ranged from 4 to 20 mm. The patients who had a craniotomy up to the temporal base had a 3-month mortality rate of 21% in comparison with 33% among the residual temporal bone group ($p = 0.227$). The mean distance from the midline to the craniotomy was 2.3 cm in patients who survived at 3 months compared with 2 cm in patients who did not. But no statistical significance was noted for the observation on overall mortality or outcome.

The volume gained by decompression was estimated by the formula ½ ABC. The mean volume was 126.67 ± 34.78 mm³. The mean volume of craniotomy was 123.87 ± 33.90 mm³ in patients who survived and 132.75 ± 37.30 mm³ in patients who died ($p = 0.317$). The volume of decompression did not influence mortality or outcome (►**Tables 2** and **3**) in our cohort.

Persisting postoperative MLS after hematoma evacuation and DC was assessed in the two groups and the patients with good outcome had an MLS of 0.34 ± 0.24 cm in comparison to 0.55 ± 0.27 cm in those with poor outcome ($p = 0.001$). Of the patients with persistent MLS of greater than 5 mm, 53% died in the first 3 months ($p = 0.001$). However, patients with an AP diameter of < 12 cm (14/55) had a significantly lesser reduction in MLS postoperatively (p-value:–0.037).

Overall mortality in the study group at 3 months was 14. Mean GCS and mRS on discharge were 10.34 and 4.85, respectively. Mean mRS at 90 days was 4.85. Ten patients had a good outcome and 45 had a poor outcome at 3 months.

Table 1 Demographic and radiological data, and outcome of our cohort

Parameter	n = 55
Age (y)	50.73 ± 11.51
Male (n)	47
Female (n)	8
Side (n): Right	33
Left	22
Volume of hematoma	49.39 ± 23.33 mL
Preoperative midline shift	1.05 ± 28.262 cm
Postoperative midline shift	0.39 ± 0.27 cm
Anteroposterior diameter	12.42 ± 0.90 cm
Height	9.88 ± 0.81 cm
½ABC (cm³)	126.67 ± 34.78
Patients with craniectomy to base (n)	28
Complications (n)	10
mRS at 3 months (median)	4
Mortality at 3 months (n)	14

Abbreviation: mRS, Modified Rankin Scale.

Table 2 Relationship between surgical parameters and mortality

Parameter	Alive (41)	Dead (14)	*p*-Value
AP (cm)	12.47 ± 0.85	12.27 ± 1.05	0.529
Diameter (cm)	1.99 ± 0.46	2.25 ± 0.52	0.116
Height (cm)	9.93 ± 0.82	9.71 ± 0.80	0.378
ABC/2 (mm3)	123.87 ± 33.90	132.75 ± 37.30	0.346
Distance from midline (cm)	2.14 ± 0.49	2.08 ± 0.69	0.76
Postoperative MLS (cm)	0.34 ± 0.24	0.55 ± 0.27	0.011

Abbreviations: AP, anteroposterior; MLS, midline shift.

Table 3 Relationship between surgical parameters and outcome

Parameter	mRS 0–3	mRS 4–6	*p*-Value
AP (cm)	12.47 ± 0.85	12.47 ± 0.86	0.981
Diameter (cm)	2.17 ± 0.45	1.93 ± 0.45	0.16
Height (cm)	9.35 ± 0.70	10.12 ± 0.77	0.009
ABC/2 (mm^3)	127.10 ± 30.21	122.83 ± 35.42	0.714
Distance from midline (cm)	2.09 ± 0.50	2.16 ± 0.49	0.701
Postoperative MLS (cm)	0.23 ± 0.22	0.37 ± 0.24	0.075

Abbreviations: AP, anteroposterior; MLS, midline shift; mRS, Modified Rankin Scale.

Follow-up scans were performed for all the patients at 6 weeks. Twenty-five patients had hydrocephalus (Evans index of > 0.3). Also, 68% patients with an AP diameter of > 13 cm were observed to have hydrocephalus compared with 35.6% patients with AP diameter of < 13 cm ($p = 0.025$; ►**Table 4**). Of them, eight patients who had improvement with lumbar cerebrospinal fluid (CSF) drainage were taken up for permanent CSF diversion procedure. A subdural hygroma along the ipsilateral convexities was observed in six of these patients. The volume of craniotomy and distance from the midline did not correlate with hydrocephalus or hygroma ($p > 0.05$).

Sixteen patients had tracheostomy due to prolonged ventilatory requirement. Of the total patients, five developed postoperative meningitis, one patient had wound complication with CSF leak, and four developed ventilator-assisted pneumonia. There was no correlation between the size of craniectomy and complications.

Discussion

Surgery for ICH has been a much-debated topic in the past few decades, with multiple studies comparing conservative and surgical methods. STICH 1 and 2 trials have concluded that early surgery might have a small but clinically relevant survival advantage for patients with spontaneous superficial ICH without intraventricular hemorrhage.[13] Some recent studies have opined that surgery improved survival in comparison with medical treatment with lasting benefits.[14] Many centers are henceforth reverting to surgery for SICH, but the ideal type of surgery for the best outcome has been the dilemma faced by neurosurgeons. Although minimally invasive procedures are at the forefront of surgery for SICH, DC has been found to improve mortality and morbidity outcome in several series.[14,15] A recent meta-analysis of seven high-quality studies to compare DC versus craniotomy for spontaneous intracerebral bleeds has concluded that DC effectively reduced mortality in patients with SICH.[14] The ideal size of the decompression required and the complications of DC in relation to the volume, dimensions, need for craniectomy up to the middle cranial fossa base, and the ideal distance from the midline have never been analyzed.

A study by Tanrikulu et al, with a cohort comprising of both TBI and SICH, concluded that a craniectomy of 12 to 18 cm was effective as complete hemispheric exposure (i.e., AP diameter > 18 cm) in relieving intracranial hypertension. Also, a less

Table 4 Anteroposterior diameter and mortality, and postoperative outcome

Parameter	AP diameter		*p*-Value
	>13 cm	**<13 cm**	
Mortality	10 (25.6%)	4 (25%)	0.96
Outcome (mRS < 3)	17.9%	18.8%	0.94
Mean reduction in MLS	0.52 cm	0.7 cm	0.53
Hydrocephalus	35.9%	68%	0.025

Abbreviations: AP, anteroposterior; MLS, midline shift; mRS, Modified Rankin Scale.

extensive approach does not increase the risk for secondary complications such as parenchymal shear stress, hemorrhage, and swelling.[16] In a similar study with 526 patients undergoing DC with 21% SICH patients, the size of the bone flap did not relate either to survival or outcome[7] disbanding the notion that larger the craniotomy better the outcome.

In our study, no direct correlation could be proved between AP diameter of the bone flap and outcome or mortality. The persistence of MLS, which is an indicator of raised ICP[17] in the postoperative scans after DC, and incomplete hematoma evacuation were observed to have a significant impact on mortality and outcome. We observed that a diameter of 12 to 13 cm is adequate to achieve the required reduction in MLS. Any further increase in size is associated with complications.

Extension of DC up to the temporal base is known to improve outcome in patients with TBI and large cerebral infarcts. Few authors believe this surgical step to be more important than the size of the craniectomy flap.[18] In our study, patients who had DC up to the temporal base had better survival (mortality 21 and 33%, respectively; p = 0.157), suggesting that extension up to the temporal base is a valuable addition in all cases even if the brain is lax post hematoma evacuation.

Volume Gained by Decompressive Craniectomy

The size of therapeutic DC is important in reducing refractory raised ICP.[19] Several methods have been described for the analysis of the volume of decompression, with computer-assisted volumetric analysis as the gold standard.[12] The mean volume gained through DC in our study was 126.64 ± 34.78 cm³, which was concurrent with other previously done studies that had used 3D volumetric analysis.[3] It has been a common belief in clinical practice that "go big or go home" is useful in DC, that is, larger the volume of decompression better the outcome.[16] This was not found to be true in our study as no significant inference could be achieved to prove the benefit of a larger volume of craniectomy.

Size of Craniotomy and Its Influence on Hydrocephalus

De Bonis et al postulated that if the DC margin is too close to the midline, it reduces the external force to the bridging vein and causes an increased venous outflow to the sinus. The increased extracellular fluid absorption results in the decreased volume of the brain parenchyma and induces ventricular enlargement. Craniectomy with a superior limit too close to the midline can predispose patients to develop hydrocephalus. Hence it is recommended to perform wide DCs with the superior limit of > 25 mm from the midline.[20] This correlation between hydrocephalus and distance from midline could not be proved in our study.

An interesting finding in our study was that patients with an AP diameter of > 13 cm had a significantly higher risk of developing hydrocephalus (p = 0.03). This was probably due to large DC playing a "flattening" role in the normally dicrotic CSF pulse wave in patients because of transmission of a pressure pulse out through the cranial defect. Arachnoid granulation function is dependent on the pressure difference between the subarachnoid space and draining venous supply. So, it is possible that disruption of pulsatile ICP dynamics secondary to opening the cranial defect results in decreased CSF outflow and absorption, thereby leading to hydrocephalus.[21]

Limitations

As it was a retrospective study, no randomization of the size of the craniotomy was performed preoperatively and it was left to the decision of the operating surgeon. As the cases were operated by six different surgeons with various levels of expertise, it could have played a role in the outcome.

Due to the small sample size, no specific recommendations could be made and further analysis with larger sample size is required.

Conclusion

The common belief that larger the craniectomy the better the outcome has not proven to be true in case of SICH. The recommended AP diameter of the DC is 12 to 13 cm to achieve best outcome with minimal complications. Larger AP diameter resulted in a higher incidence of hydrocephalus. Extension to the temporal base has better survival outcomes. Patients with persistent MLS of > 5 mm in the immediate postoperative scan after complete hematoma evacuation had a significantly poorer outcome and higher mortality.

Conflict of Interest
None declared.

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