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Predictors of Functional Outcome Following Decompressive Craniectomy for Malignant Middle Cerebral Artery Infarction and Intracerebral Hemorrhage: A Retrospective Single-Center Study

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Abstract

Decompressive craniectomy (DC) is a recognized surgical strategy for patients experiencing critically elevated intracranial pressure (ICP) that does not respond to conservative medical therapy. Evidence regarding factors predicting functional outcomes in patients undergoing DC for malignant middle cerebral artery (MCA) infarction versus intracranial hemorrhage (ICH) remains limited. In this study, we retrospectively examined 84 patients who received DC for either ICH or malignant MCA infarction at the Salmaniya Medical Complex Neurosurgery Unit in Bahrain between January 2017 and June 2021. To explore associations with functional recovery, clinical characteristics were analyzed alongside radiographic parameters. Postsurgical midline shift (MLS) demonstrated the strongest correlation with outcomes in both ICH (ρ = 0.434, P = 0.006) and MCA infarction (ρ = 0.46, P = 0.005) cohorts. Binary logistic regression including postsurgical basal cistern status and ΔMLS revealed statistically significant predictive value (odds ratio: 0.067, 95% CI: 0.007–0.67, P = 0.021). Overall, initial Glasgow Coma Scale, postsurgical MLS, basal cistern patency, and ΔMLS were identified as reliable indicators of functional prognosis in both patient groups.

Keywords: Decompressive craniectomy, Intracranial hemorrhage, Intracranial pressure, MCA infarction

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Introduction

Decompressive craniectomy serves as a life-saving surgical option when refractory intracranial hypertension can no longer be controlled by medical therapy alone [1–3]. This intervention serves as a critical measure to prevent both death and long-term neurological impairment. Prospective randomized trials indicate that DC reduces mortality by approximately 52.8% in patients suffering from malignant MCA infarction [4–6].

Despite limited high-quality evidence, DC is also commonly applied in cases of ICH with elevated ICP, with outcomes primarily supported by retrospective analyses [7–10]. Additional insight is expected from the upcoming RESCUEicp trial [11]. Nevertheless, comparative data on predictive factors for functional recovery in patients with MCA infarction versus ICH undergoing DC remain sparse. Current research suggests that age and postoperative MLS, assessed via CT imaging, may serve as valuable prognostic indicators for MCA infarction patients [12–14]. However, evidence for similar predictive

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factors in ICH is more heterogeneous, particularly in studies including post-DC traumatic brain injury (TBI) patients [15–17].

Aims and objectives

This investigation aimed to identify clinical and imaging variables capable of predicting functional outcomes after DC in patients with raised ICP. Special attention was given to differences between malignant MCA infarction and ICH caused by hypertensive bleeding, trauma, or coagulopathy, due to their distinct pathophysiological mechanisms. In MCA infarction, DC is intended to limit secondary brain injury associated with midline shift, such as ischemia of the brainstem or extension of contralateral infarction [18]. In contrast, damage caused by ICH is typically more diffuse and detectable prior to surgery.

Radiological markers discernible on standard CT scans, combined with craniectomy dimensions, were assessed for their prognostic relevance. Postoperative outcomes were evaluated considering factors such as ventilatory support requirement, tracheostomy, respiratory complications, and cause of death.

Materials and Methods

We conducted a retrospective study of patients who underwent DC for either malignant MCA infarction or ICH at Salmaniya Medical Complex, Ministry of Health, Manama, Bahrain, from January 2017 to June 2021. Data collected included demographics, clinical and radiological information, and craniectomy size. Functional outcomes were analyzed using the Glasgow Outcome Scale (GOS), radiographic findings, postoperative disposition, and need for mechanical ventilation or tracheostomy. Causes of mortality were also recorded.

Clinical data

Basic patient details were recorded, including age, gender, comorbid conditions, primary pathology, side of the lesion, and craniectomy diameter. Surgery followed German Association of Scientific Medical Societies recommendations and was offered only to individuals whose condition did not improve with maximal medical therapy. In malignant MCA infarction cases, decompression was performed early; in the ICH group, it usually followed evacuation of acute subdural hematoma (SDH), extradural hematoma (EDH), or intraparenchymal hematoma. For ICH patients, the indication for DC was based on the initial neurological examination, laboratory findings, and preoperative CT appearance.

Upon suspicion of raised ICP, a uniform tier-1 management bundle was started immediately in the emergency department. This comprised prevention of hypotension (systolic blood pressure < 90 mm Hg) and hypoxemia (PaO_2 < 60 mm Hg), brief controlled hyperventilation ($PaCO_2$ 28–32 mm Hg) via ventilator, head-up positioning at 20°–30°, fentanyl-based sedation, and osmotic therapy using mannitol (0.25–1 g/kg). Patients with traumatic brain injury showing acute SDH or EDH with considerable mass effect (unevacuated lesions) on CT were considered suitable for inclusion.

Final approval for hematoma evacuation and decompressive craniectomy was given by a consultant neurosurgeon after multidisciplinary review. In suspected malignant MCA infarction, the need for surgery was jointly decided by senior neurosurgeons and stroke neurologists on the basis of age, past medical history, blood tests, neurological deficit (including Glasgow Coma Scale score), imaging (CT/MRI), response to initial medical measures, and signs of worsening. Consistent with evidence from randomized trials and current guidelines, the goal was to complete decompressive craniectomy within 12–48 hours of symptom onset or deterioration.

Surgical procedure

The operation began with a large reverse question-mark skin incision extending across the frontotemporoparietal region and ending 1 cm in front of the tragus. Generous bone removal was performed with wide frontotemporal, parietal, and occipital exposure to guarantee adequate brain relaxation. Particular attention was paid to complete unroofing of the temporal fossa floor to relieve uncal and brainstem compression.

After dural opening, the temporalis muscle was mobilized and the galea-scalp flap was adjusted as needed. Individual technical details—including final craniectomy dimensions, type of duraplasty, and choice of suture—were left to the discretion of the operating surgeon. The removed bone flap was stored at −80°C for future cranioplasty.

Radiological parameters

Imaging variables analyzed included basal cistern visibility, midline shift (MLS), and lesion volume. Pre- and postoperative MLS was quantified on axial CT images at the septum pellucidum level. Craniectomy size was determined from postoperative sagittal reconstructions. A single investigator carried out all measurements according to a fixed protocol.

The reference midline was defined by a straight line connecting the frontal crest to the internal occipital protuberance on the appropriate axial slice. MLS was recorded as the maximum perpendicular deviation of the septum pellucidum from this line. Lesion volume (hemorrhage or infarct) was calculated with the ABC/2 formula, where A = longest diameter on any slice, B =

diameter perpendicular to A on the same slice, and C = slice thickness × number of slices showing the lesion.

Additional derived variables were change in MLS (ΔMLS) between pre- and postoperative scans and change in basal cistern status. Basal cisterns were graded on a 3-point scale: open = 1, compressed = 2, obliterated = 3.

Clinical parameters

Key clinical variables included initial GCS, pupillary size and reactivity, and Glasgow Outcome Scale (GOS) at discharge. Preoperative and postoperative pupillary measurements were recorded. Postoperative GCS was not assessed due to sedation and ventilation masking neurological changes. GOS scores ranged from 1 to 5, with 1 indicating favorable recovery, 2 moderate disability, 3 severe disability, 4 vegetative state, and 5 death.

Statistical analysis

Descriptive statistics summarized demographic and clinical characteristics. Associations between categorical variables were analyzed using chi-square tests. Numerical variable comparisons were performed with the Mann–Whitney U test. Correlations among continuous variables were assessed via Spearman correlation, with effect estimates expressed as Spearman rho (ρ). Binary logistic regression analyzed categorical outcomes, with odds ratios (OR) and 95% confidence intervals presented to indicate effect size. Statistical significance was defined as $P < 0.05$. Analyses were conducted using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, 2020).

Results and Discussion

Data from 126 patients were initially examined over a 54-month timeframe. Records were excluded if surgical methods differed in a way that hindered comparison (e.g., Bifrontal DC, suboccipital DC), if patients did not meet inclusion criteria (age under 18 years, absence of detectable mass on preoperative CT, incomplete records), if the mass effect was due to tumor, abscess, or arachnoid cyst, or if death occurred prior to ICU admission. Ultimately, 84 patients (67 men [79.76%] and 17 women [20.23%]) with complete datasets and accessible for follow-up were included.

Patient ages ranged from 20 to 90 years, with a mean of 45.4 years. Among these, 47 patients presented with ICH-related pathology: ICH alone (n = 28), SDH (n = 8), ICH with SDH (n = 5), ICH with EDH (n = 2), ICH with IVH (n = 1), ICH with SDH and IVH (n = 1), and SDH with EDH (n = 2). The remaining 36 patients (42.85%) suffered from malignant MCA infarctions. Within the ICH group, 24 patients (51.06%) had hypertensive hemorrhage, 22 (45.83%) had trauma-related hemorrhage, and 1 patient (2.08%) had coagulopathy-associated ICH. DC was performed on the right side in 50 patients (59.52%) and on the left side in 34 patients (40.47%).

No statistically significant differences were noted between the MCA infarction and ICH groups for sex, age, side of DC, GOS, defect size, preoperative MLS, or basal cistern status. However, initial GCS, postoperative MLS, ΔMLS, and postoperative basal cistern status demonstrated significant variation between the groups.

Spearman correlation analysis was used to examine the prognostic relevance of MLS before and after surgery. Postsurgical MLS had the highest correlation with functional outcome in the ICH group (ρ = 0.434; P = .006) and similarly in the MCA infarction group (ρ = 0.46; P = .005). Binary logistic regression considering postsurgical basal cistern status and ΔMLS indicated statistical significance (OR: 0.067, 95% CI: 0.007–0.67; P = .021). Preoperative MLS and basal cistern status were excluded due to weaker correlations.

Functional outcomes were assessed after rehabilitation, averaging 33 days post-DC (range: 3–225 days). Subgroup analysis was performed for each diagnosis type, separating patients by GOS ≤ 3 versus GOS > 3. **Table 1** summarizes the characteristics of patients according to outcome. Age, sex, affected side, craniectomy size, initial GCS, and pupillary response did not differ significantly between outcome groups.

Table 1. Characteristics based on the outcome (GOS).

Characteristic	ICH – Poor Outcome (GOS ≤ 3) (n = 21)	ICH – Favorable Outcome (GOS > 3) (n = 27)	p-value (ICH)	MCA Infarction – Poor Outcome (GOS ≤ 3) (n = 12)	MCA Infarction – Favorable Outcome (GOS > 3) (n = 24)	p-value (MCA-I)
Sex, n (%)			.09			.7
Male	20 (95.2%)	21 (77.8%)		7 (58.3%)	19 (79.2%)	
Female	1 (4.8%)	6 (22.2%)		5 (41.7%)	5 (20.8%)	
Age (years), median (range)	39 (20–80)	44.3 (20–80)	.6	47.5 (20–70)	51.25 (20–90)	.8
Side of lesion, n (%)			.5			.09
Right	12 (57.1%)	18 (66.7%)		6 (50%)	14 (58.3%)	

Left	9 (42.9%)	9 (33.3%)		6 (50%)	10 (41.7%)	
Preoperative GCS, median (range)	10.8 (3–15)	9.2 (3–15)	.2	14 (9–15)	13.2 (7–15)	.5
Craniectomy size (cm), median (range)	11.5 (9–13)	11.7 (9–15)	.9	11.75 (8–14)	11.7 (10–15)	.7
Preoperative MLS (cm), median (range)	1.1 (0.3–1.6)	1.1 (0.5–1.5)	.87	1.0 (0.5–1.8)	1.15 (0.4–1.7)	.7
Postoperative MLS (cm), median (range)	0.4 (0–1)	0.4 (0–1.2)	.85	0.55 (0–1.9)	0.6 (0–2)	.6
ΔMLS (cm), median (range)	−0.7 (−1.2 to 0)	−0.4 (−1.4 to −0.1)	.5	−0.3 (−1.4 to 0.3)	−0.45 (−1 to 0.8)	.7
Preoperative basal cisterns, n			.2			.001*
Patent	4	3		1	0	
Partially effaced	0	3		6	1	
Effaced	17	21		5	23	
Postoperative basal cisterns, n			.39			.2
Patent	17	11		7	7	
Partially effaced	3	5		2	3	
Effaced	1	2		3	14	

Values are expressed in mean (range) unless specified otherwise.
GCS = Glasgow coma scale, GOS = Glasgow outcome scale, ICH = intracranial hemorrhage, MCA = middle cerebral artery, MLS = midline shift, SDH = subdural hematoma.
*Statistically significant.

Logistic regression analysis revealed that ΔMLS was not predictive of outcome in patients with malignant MCA infarction (OR: 0.8, 95% CI: 0.2–3.7; P = .7) or in the ICH cohort (OR: 2.1, 95% CI: 0.5–8.6; P = .3). Likewise, postsurgical basal cistern status showed no significant association with outcomes for MCA infarction (OR: 1.5, 95% CI: 0.4–5.8; P = .5) or ICH patients (OR: 3.8, 95% CI: 0.8–17.9; P = .09).

In scenarios where intracranial pressure (ICP) remains unresponsive to medical management, decompressive craniectomy (DC) is frequently used as a salvage intervention [2, 3]. Extensive prospective studies have confirmed the benefit of DC in patients with malignant MCA infarction, whereas evidence supporting its use in intracranial hemorrhage (ICH), particularly due to hypertensive bleeding or traumatic brain injury (TBI), remains limited and inconclusive [12, 14]. The primary objective of this study was to evaluate the prognostic value of clinical and radiological factors in patients with malignant MCA infarction and ICH. Despite these conditions representing distinct pathophysiological origins of raised ICP leading to DC, the literature continues to present conflicting perspectives.

Our results highlighted that postoperative midline shift (MLS), basal cistern status, and ΔMLS serve as strong radiological predictors in both MCA infarction and ICH cohorts. Specifically, increased postoperative MLS, obliteration of basal cisterns, or larger ΔMLS values were associated with a reduced likelihood of favorable recovery. Preoperative imaging parameters, however, showed limited predictive utility. This may be attributable to the variable nature of ICH, which can present as diffuse or multifocal injury even in cases of focal hemorrhages such as SDH or EDH [7]. Conversely, MCA infarction initially manifests as a focal ischemic event that progresses to broader cerebral ischemia, influenced by post-surgical neurocritical care measures, including hydration and blood pressure optimization. Postoperative imaging captures these dynamic changes in both affected and contralateral hemispheres [18].

Among younger MCA infarction patients, pooled data from three randomized controlled trials demonstrated clear survival and functional benefits of DC; however, DESTINY II reported diminished benefit in patients over 60 years [5]. Consequently, DC is generally recommended for patients under 60 years of age. In our cohort, the mean age for MCA infarction patients was 50 years, and age did not significantly impact functional outcomes. The prognostic role of age in ICH patients undergoing DC remains debated [1–8]. For instance, De Bonis *et al*. [19] (2010) found no relationship between younger age and better outcomes, while Pompucci *et al*. [20] (2007) reported worse outcomes for those above 65 years but no significant difference between patients aged <40 years and those aged 40–65 years. These findings are consistent with our ICH cohort, which had a mean age of 42.2 years, showing no statistically significant association with favorable or unfavorable recovery.

Initial Glasgow Coma Scale (GCS) scores have been proposed as prognostic indicators in ICH, though prior studies report mixed results [8, 10]. In this study, lower GCS at the scene or admission correlated with worse outcomes (GOS > 3) in both ICH and MCA infarction patients. The timing of DC appears to influence the predictive capacity of GCS, particularly in patients where early surgical intervention alters the disease trajectory. GCS captures the patient's acute neurological status but may not reflect later deterioration post-DC, underscoring the need for additional postsurgical markers.

Our findings indicate that initial GCS, postoperative MLS, ΔMLS, and basal cistern status should be routinely considered when assessing prognosis for patients undergoing DC for malignant MCA infarction or ICH. These parameters provide essential guidance for clinical decision-making, interdisciplinary care planning, and communication with families regarding expected outcomes. Although functional disability may remain high, many patients retain meaningful levels of independence.

Limitations

Several limitations must be noted. This investigation was conducted at a single center, potentially limiting generalizability to other institutions. Additionally, the retrospective design and relatively small sample size constrain the strength of conclusions. Multicenter prospective studies are needed to provide more robust and generalizable evidence regarding prognostic factors in this population.

Conclusion

Initial GCS and postoperative radiological metrics, including MLS, ΔMLS, and basal cistern status, are reliable and quantifiable predictors of outcomes in patients with malignant MCA infarction and ICH undergoing DC. These factors can significantly inform early clinical management and assist healthcare teams and families in making treatment decisions. Future prospective and controlled trials are warranted to validate these observations and refine prognostic models.

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Conflict of interest: None

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Ethics statement: The study was reviewed and approved by the Bioethics committee of Governmental Hospital in Bahrain with serial number 5170122.

Written informed consent was obtained from the patient for the publication of this study. No potentially identifiable human images or data were available. A copy of the written consent form is available for review by the Editor-in-Chief of this journal upon request.

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