Outcomes of decompressive craniectomy in patients after traumatic brain injury

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ABSTRACT

Objective: Traumatic brain injury (TBI) can result in cerebral oedema and vascular changes resulting in an increase in intracranial pressure (ICP), which can lead to further secondary damage. Decompressive craniectomy (DC) is a surgical option in the management of ICP. We aimed to investigate outcomes of DC after TBI.

Design: We performed a retrospective audit of 57 adult patients (aged > 15 years) who underwent DC after TBI, at the Royal Melbourne Hospital from 1 January 2005 to 30 June 2011. Our functional outcome measure was the Extended Glasgow Outcome Scale (GOSE).

Results: Patients had a median age of 30 years (range, 17–73 years). The hospital mortality rate was 47% (27 patients). A higher postoperative median ICP was the most significant predictor of hospital mortality (OR, 1.1; 95% CI, 1–1.3). There was a mean decrease of 7.7 mmHg in ICP between the mean preoperative and postoperative ICP values (95% CI, – 10.5 to – 5.0 mmHg). There was a mean decrease of 3.5 mmHg in the mean cerebral perfusion pressure (CPP) from preoperative to postoperative CPP values (95% CI, – 6.2 to – 0.8 mmHg). At the 6-month follow-up, a poor outcome (GOSE score, 1–4) was seen in 39 patients (68%), while a good outcome (GOSE score, 5–8) was noted in 15 patients (26%). A high APACHE II score on admission was the most significant predictor of a worse GOSE score at 6 months (OR, 1.3; 95% CI, 1.1–1.5). Analysis of the APACHE II and IMPACT scores as models for predicting mortality at 6 months showed an area under the curve (AUC) of 0.792 and 0.805, respectively, and for predicting poor outcome at 6 months, showed an AUC of 0.862 and 0.883, respectively.

Conclusion: DC decreased ICP postoperatively. The IMPACT and APACHE II scores are good models for prediction of death and poor outcome at 6 months.

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Traumatic brain injury (TBI) is a significant contributor to morbidity and mortality. The primary injury frequently results in cerebral oedema and vascular changes resulting in an increase in intracranial pressure (ICP), which can lead to further secondary damage. Current therapies for management of TBI reduce effects that may lead to secondary injury, particularly high ICP. In patients for whom medical therapy has failed, a decompressive craniectomy (DC) can be performed. After the publication of the results of a randomised controlled trial (RCT) of early DC for TBI,[1] we describe the outcomes of DC at our centre.

Methods

Study design

Our retrospective study was conducted at the Royal Melbourne Hospital (RMH), a major tertiary referral centre for trauma in Victoria.

Patient selection

Patients for inclusion in the study were identified from the RMH trauma database from 1 January 2005 to 30 June 2011. All adult patients (patients older than 15 years) who had undergone DC after a traumatic brain injury were included in the study.

TBI was defined as abbreviated injury severity (AIS) score[2] of at least 4 for the head region. Patients who underwent DC primarily for depressed skull fractures were only included in the study if there was an underlying TBI, as assessed by computed tomography (CT) imaging.

Exclusion criteria were non-traumatic brain injury (eg, arterial dissection and hypoxic brain injury), surgery primarily undertaken for a depressed skull fracture without underlying TBI, non-decompressive surgeries for TBI, and loss of records or images.

Data collection

Patient records were studied retrospectively and information was accessed from the prospectively recorded RMH trauma database and intensive care unit database (Australian and New Zealand Intensive Care Society AORTIC dataset)[3] to gain information on patient demographics, admission, preoperative status, operative interventions and inhospital outcomes, as well as scores such as the Glasgow Coma Scale (GCS),[4] Acute Physiology and Chronic Health Evaluation (APACHE) II score,[5] Injury Severity Score (ISS)[6] and Abbreviated Injury Scale.[2]

A radiologist, blinded to patient outcome, assessed the preoperative CT scans to classify patients according to the Marshall classification of brain injury[7] (see Table 1) and identify other radiological findings. Information from the

Table 1. Marshall classification

Marshall class	Characteristic
I	No intracranial pathology seen with computed tomography
II	Cisterns present with midline shift of 0–5 mm and/or lesions/densities present; no high- or mixed-density lesions > 25 cm^3; may include bone fragments and foreign bodies
III	Cisterns compressed or absent with midline shift of 0–5 mm; no high- or mixed-density lesions > 25 cm^3
IV	Midline shift > 5 mm; no high or mixed density lesions > 25 cm^3
V	Any lesion surgically evacuated
VI	High- or mixed-density lesion > 25 cm^3; not surgically evacuated

RMH trauma database, RMH pathology service and Marshall classification of CT scans was used to determine the International Mission for Prognosis and Analysis of Clinical Trials in TBI (IMPACT) score.[8]

Six-month postinjury Extended Glasgow Outcome Scale (GOSE)[9] scores were obtained from the Victorian State Trauma Outcomes Registry,[10] a population-based register of all major trauma patients in Victoria. The GOSE scores were obtained by telephone interview.

Definitions

The initial GCS score[4] refers to the worst recorded GCS within the first 24 hours after resuscitation but before intubation or sedation. This information was often gathered from the scene of the trauma (using ambulance records) or in the emergency department (ED).

Pupil scores were derived from the trauma database using the first measure of pupil reactivity on admission. Intracranial pressure (ICP) and cerebral perfusion pressure (CPP) were noted from ICU records and included hourly recordings, rather than minimum or maximum values. Postoperative ICP and CPP for 24 hours were included in the study, as well as 12 hours preoperatively, if available.

Primary DC was defined as prophylactic DC to avoid an expected increase in ICP, rather than to control refractory ICP.[11] Secondary DC was performed in patients with continuous ICP monitoring, when ICP was refractory to medical treatment.[11]

Statistical analysis

Univariate analysis was used to identify variables for multivariate analysis. Hospital mortality and GOSE at 6 months were the outcomes used for univariate analysis. Variables analysed were the APACHE II score, IMPACT score (only compared with 6-month outcome), injury-to-decompression time, primary versus secondary decompression, midline shift ($\leqslant$ 5 mm v > 5 mm), haematoma mass evacuation (yes/no), patient age, and preoperative and postoperative median ICP values. Only patients who did not have bilateral unreactive pupils were included in univariate and multivariate analysis. Multivariate analysis involving backward, stepwise logistic regression was used to find the most parsimonious model, as well as the most significant predictors of outcome. However, area-under-the-curve (AUC) analysis of APACHE II and IMPACT score models in predicting outcome included all patients, including those with bilateral unreactive pupils, since this is an important prognostic sign that is incorporated into the IMPACT scoring system.

Ethics approval

Approval for the study at the RMH was granted by the RMH human research ethics committee as a quality assurance project, and the need for informed consent was waived.

Results

Study population

Fifty-seven patients (42 men) were included in the study, with a median age of 30 years (range, 17–73 years). Table 2 shows the patient characteristics. A total of 1799 patients were identified from the RMH trauma database as having had a TBI (AIS score, $\geqslant$ 4) during the study period.

The most common mechanism of injury involved motor vehicle accidents (n = 31 [54%]). Non-motorist motor vehi-

Table 2. Patient characteristics (n = 57)

Characteristic	Data
Median age, years (range)	30 (17–73)
Male, *n* (%)	42 (73.6%)
Mechanism of injury	
MVA (vehicle occupant)	16 (28.1%)
Struck by or collision with person or object	12 (21.1%)
Fall	10 (17.5%)
MVA (non-motorist)	8 (14%)
MVA (motorcycle)	7 (12.3%)
Other	4 (7%)
Median injury-to-hospital time, minutes (range)	88 (18–6966)
Median total hospital admission time, days (range)	18 (1–215)
Median ICU LOS, days (range)	10 (1–46)
Median total intubation time, hours (range)	190 (5–840)
Hospital mortality, *n* (%)	27 (47.4%)

MVA = motor vehicle accident. ICU = intensive care unit. LOS = length of stay.

Table 3. Preoperative imaging results

Finding	*n* (%)
Haematoma	
⩽ 25 mL	47 (82.5%)
> 25 mL	10 (17.5%)
Subarachnoid haemorrhage	49 (86%)
Intraventricular haemorrhage	11 (19.3%)
Midline shift (mm)	
0–5	35 (61.4%)
> 5–10	13 (22.8%)
> 10	9 (15.8%)
Basal cisterns	
Normal	14 (24.6%)
Compressed or absent	43 (75.4%)
Marshall class	
II	8 (14%)
III	14 (24.6%)
IV	7 (12.3%)
V	26 (45.6%)
VI	2 (3.5%)

cle accidents included collisions with seven pedestrians and one bicycle. Other injury causes ($n = 4$ [7%]) were a fall from a bicycle, a train collision, an equestrian accident and a machinery-related accident.

Preoperative data

The median initial GCS of patients was 4 (range, 3–13). Thirty-seven patients had a GCS of 3–5, 10 patients had a GCS of 6–8, and 10 had a GCS of 9–15. For primary DC patients, the median initial GCS was 3 (range, 3–9) and for secondary DC patients, the median initial GCS was 4 (range, 3–13). Pupils were bilaterally unreactive in 14 patients (25%), and bilaterally reactive in 40 patients (70%). Only one pupil was reactive in two patients and pupil reactivity was unknown in one patient. The median ISS for the study was 30 (range, 16–59), and the median APACHE II score was 20.5 (range, 2–34). Patients who underwent a primary DC had a median APACHE II score of 23 (range, 15–34), and those who had a secondary DC had a median APACHE II score of 18 (range, 2–29).

Preoperative imaging results are summarised in Table 3. On preoperative imaging, subarachnoid haemorrhage was noted in 49 patients. A midline shift of > 5 mm was noted in 22 patients, which included 17 patients who had a primary DC and five who had a secondary DC. A total of 43 patients had compressed or absent basal cisterns, which included 25 patients who had a primary DC and 18 patients who had a secondary DC.

Operative intervention

Twenty-eight patients had a primary DC, and 29 patients initially had a secondary DC.

A unilateral DC was performed in 24 patients and a bilateral DC in 33 patients, including three patients who initially underwent a unilateral DC but later underwent a DC on the contralateral side due to uncontrolled ICP. A bifrontal DC was performed in 22 patients, and 24 patients underwent a unilateral frontotemporoparietal (FTP) hemicraniectomy, and a further 11 patients underwent a bilateral FTP hemicraniectomy. The dura was not opened in five patients.

The mean duration from injury to decompression was 4.8 hours (interquartile range [IQR], 2–22.8 hours) in the primary DC group, and 63.4 hours (IQR, 6.8–227.3 hours) in the secondary DC group.

Evacuation of an intracranial haematoma took place for 26 patients, which included 21 patients who had a primary DC and five patients who had a secondary DC. For haematoma evacuations, the haematomas were only subdural in 17 patients, only extradural in three patients, only intracerebral in three patients, subdural and extradural in two patients, and one patient had intracerebral, subdural and extradural haematomas.

Two patients had haematomas evacuated before their DC, and 23 patients had haematoma evacuation during DC surgery. Of these patients, three underwent further surgery for haematoma evacuation, and two other patients underwent evacuation for haematomas that were not present on initial preoperative imaging.

Figure 1. Intracranial pressure (ICP) v hours since decompressive craniectomy

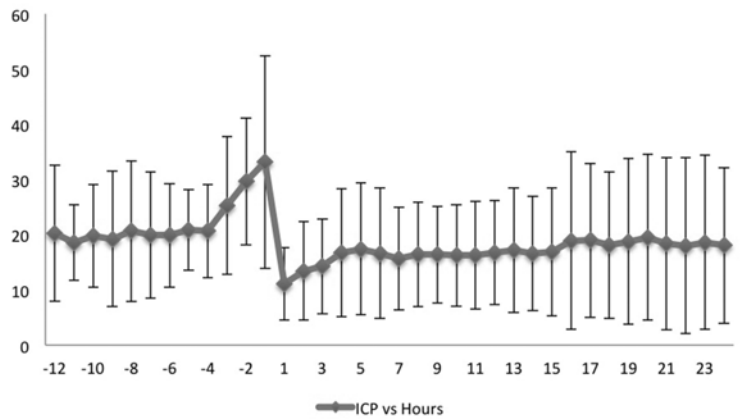
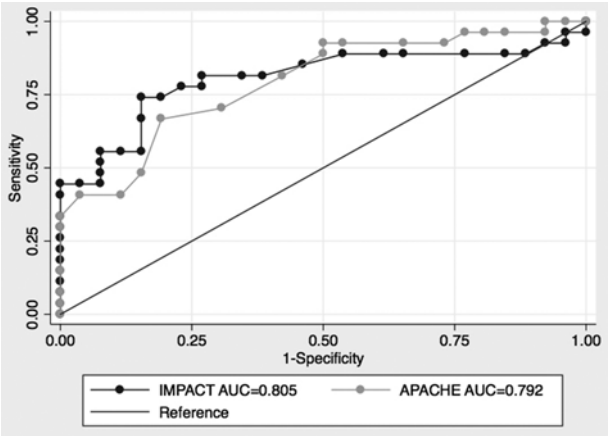
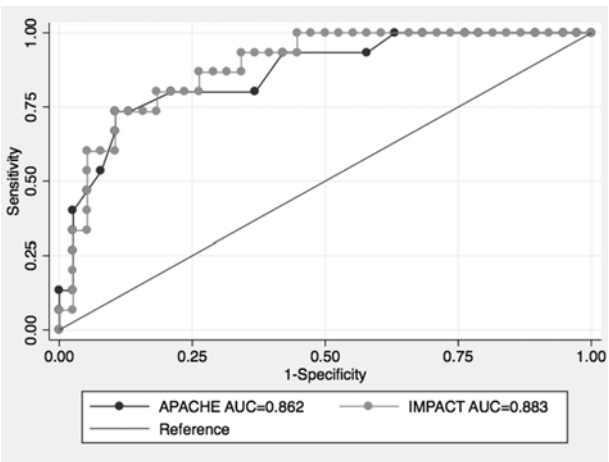


Figure 2. Area under the curve IMPACT and APACHE II scores: 6-month mortality



IMPACT = International Mission for Prognosis and Analysis of Clinical Trials in TBI. AUC = area under the curve. APACHE = Acute Physiology and Chronic Health Evaluation.

Figure 3. Area under the curve IMPACT and APACHE II scores: 6-month poor outcome



IMPACT = International Mission for Prognosis and Analysis of Clinical Trials in TBI. AUC = area under the curve. APACHE = Acute Physiology and Chronic Health Evaluation.

Postoperative outcome

Twenty-seven patients (47%) died during their hospital admission and one patient died 3 days after discharge. The median length of stay was 15.5 days for patients who died. A higher postoperative median ICP was the most significant predictor of hospital mortality (odds ratio [OR], 1.1; 95% CI, 1.0–1.3). Univariate analysis also showed a significant correlation with a greater preoperative median ICP (P = 0.03). Non-statistically significant correlations were noted between hospital mortality and older age (P = 0.071) and higher APACHE II score (P = 0.062). There were no significant correlations between hospital mortality and:

- whether patients had a mass evacuation (P = 0.184)
- the amount of midline shift (⩽ 5 mm v > 5 mm) (P = 0.148)
- the time from injury to decompression (P = 0.108)
- whether patients had a primary or secondary DC (P = 0.158).

Eighteen of the 27 hospital mortalities occurred among patients who had had a primary DC. Patients who died in hospital had a lower median ICU length of stay of 4 days (range, 1–23 days) compared with 15.5 days (range, 5–46 days) in patients who survived hospital admission; and they also had a shorter median duration of mechanical ventilation (MV) at 81 hours (range, 5–485 hours) compared with a median of 287 hours (range, 72–840 hours) in patients who survived the admission. Patients who had had a primary DC had a median ICU length of stay of 6.5 days (range, 1–35 days) compared with 15 days (range, 1–46 days) for patients who had had a secondary DC. Patients who had had a primary DC also had a shorter median duration of MV (90.5 hours; range, 5–766 hours) compared with 253 hours (range, 10–840 hours) for patients who had had a secondary DC.

Preoperative ICP values were available for 28 patients. There was a mean decrease of 7.7 mmHg in ICP between the mean preoperative and postoperative ICP values (95% CI, −10.5 to −5.0 mmHg). A graph of the mean ICPs of all patients for each hour since their DC is shown in Figure 1. Preoperative CPP values were available for 26 patients. There was a mean decrease of 3.5 mmHg in the mean CPP from preoperative to postoperative CPP values (95% CI, −6.2 to −0.8 mmHg). Thirteen of the 14 patients with bilateral unreactive pupils on admission died during the hospital admission.

Follow-up

Follow-up data were unavailable for three patients at the 6-month follow-up. There were no other recorded deaths in the 6-month follow-up period. A poor outcome (GOSE score, 1–4) was seen in 39 patients (68%), and a good outcome (GOSE score, 5–8) was noted in 15 patients (26%) at 6 months.

From the patients who survived hospital admission (n = 30), at the 6-month follow-up, 12 patients (40%) had a poor outcome, 15 patients (50%) had a good outcome, and three patients (10%) had no follow-up data.

A high APACHE II score was the most significant predictor of an unfavourable GOSE score at 6 months (OR, 1.3; 95% CI, 1.1–1.5). A worse GOSE score at 6 months was also significantly correlated with a high IMPACT score (P = 0.004)

as well as older age ($P = 0.007$). There was no significant correlation between the GOSE score at 6 months and time from injury to DC ($P = 0.61$), the amount of midline shift (≤ 5 mm v > 5 mm) ($P = 0.502$), primary versus secondary DC ($P = 0.186$), haematoma mass evacuation ($P = 0.502$), preoperative median ICP ($P = 0.319$) and postoperative median ICP ($P = 0.14$).

AUC analysis shows that the IMPACT score model is a reliable predictor of mortality and poor outcome at 6 months (AUC for mortality, 0.805; AUC for poor outcome at 6 months, 0.883). The APACHE II score model is also a good predictor of mortality and poor outcome at 6 months (AUC for mortality, 0.792; AUC for poor outcome at 6 months, 0.862) (see Figure 2 and Figure 3).

Discussion

Outcome

Our patients had a hospital mortality rate of 47% after DC. The DECRA study noted a 6-month mortality of 19% in patients after a DC.[1] The lower mortality rate is most likely due to the DECRA selection criteria, which did not include patients with a mass lesion or bilateral unreactive pupils. Similarly lower mortality rates were noted in other studies, which did not include patients who underwent primary prophylactic DC.[12-14] Howard and colleagues included primary DC patients and noted a hospital mortality rate of 55%.[15]

Primary DC was performed in 67% of patients who died in hospital. Overall, patients who had a primary DC were noted to have less favourable preoperative characteristics compared with patients who had a secondary DC, eg, a greater median APACHE II score (23 v 18), a greater proportion with one or more unreactive pupils (48% v 37%), and a greater proportion of patients with a midline shift of > 5 mm seen on a preoperative CT scan (61% v 17%).

We found a favourable outcome in 26.3% of our patients at 6 months. The results were comparable to the outcomes achieved in other studies.[1,12-14,16,17] Of the patients who survived hospital admission, 50% had a good outcome at 6 months. These results highlight the positive outcome that may be achieved by DC, but our study cannot draw conclusions about whether DC improves outcome compared with medical management.

A high APACHE II score was the most significant predictor of a worse GOSE score at 6 months (OR, 1.3; 95% CI, 1.1–1.5). Several studies have validated the use of APACHE II and IMPACT scores as models in predicting outcomes for TBI patients.[18-22]

AUC analysis showed that APACHE II and IMPACT scores were good models for predicting outcome of patients (death and unfavourable status) at 6 months. For death and unfavourable status at 6 months, the IMPACT score provided a stronger model for predicting outcome.

Our results show that DC leads to an overall reduction in ICP, with a mean decrease of 7.7 mmHg between mean preoperative and postoperative ICP values. The effects of DC in decreasing postoperative ICP are well documented.[1,12,13,16,23-25]

In our study, a high postoperative median ICP was a significant predictor of a worse GOSE score at 6 months (OR, 1.23; 95% CI, 1.03–1.48).

Our study found a mean decrease of 3.5 mmHg from preoperative to postoperative CPP values. Other studies have also shown a failure of CPP augmentation after decompression.[26,27]

The DECRA study, an RCT which focused on early decompression, noted a worse follow-up outcome for patients undergoing DC compared with standard therapy.[1] Cooper and colleagues theorised that this could be due to the axonal stretch and subsequent neuronal injury that results when the brain is able to expand outside the skull, as well as due to changes in cerebral blood flow and metabolism.[1]

Soustiel and colleagues reported that although DC led to an increase in CPP, the cerebral metabolic rate of oxygen uptake was significantly lower than in the non-DC group.[28] The study noted that higher rates of cerebral oxidative metabolism were associated with good functional outcomes, and suggested that while DC enhances survival, it does not solve the issue of cellular damage and subsequent functional outcome.[28] Hence, there are several mechanisms related to cerebral metabolism and blood flow which contribute toward outcome in TBI and require further investigation.

Study limitations

Our study was a retrospective uncontrolled observational study. Preoperative and postoperative ICP and CPP values were only available for 28 and 26 patients, respectively. Our sample size of 57 patients was relatively small, and this may have influenced the statistical significance of correlations that we identified.

Future directions

Since our study was not an RCT, we are unable to draw conclusions about the efficacy of DC over medical management of ICP. Further studies could provide insight into identifying clinical indicators and characteristics that would best identify subgroups of patients who would benefit most from DC. Furthermore, for patients who have a DC, the identification of clinical indicators to assist clinicians with deciding when to perform a DC should be examined.

Conclusion

DC did not result in an overall improvement in CPP but, as expected, it resulted in lower ICP postoperatively. The APACHE II and IMPACT scores are good models for predicting outcomes of death or unfavourable status at 6 months. We await results of further RCTs to obtain Class I evidence on the role of DC in TBI.

Competing interests

None declared.

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