Decompressive craniectomy for patients with severe non-traumatic brain injury: a retrospective cohort study

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ABSTRACT

Objective: To describe the current utilisation and outcomes for patients receiving decompressive craniectomy (DC) for acute non-trauma-related indications.

Design, setting and participants: Retrospective cohort study of neurosurgical patients who underwent DC to relieve acute intracranial hypertension after a non-trauma-related brain insult. The study was based on data from medical records of a tertiary referral neurosurgical intensive care unit over the period January 2001 to June 2008.

Main outcome measures: Patient demographics, treatments received, indication for and result of DC, length of stay, hospital outcomes and 6-month outcomes.

Results: 54 patients underwent 56 DC procedures during the study period. The number of DCs performed per year increased over this period. Although intracranial pressure was significantly reduced by the procedure, 10 patients later died of uncontrollable intracranial hypertension. The patients had long hospital stays and consumed significant health care resources. Among survivors, about two-thirds had a good outcome, although it was rare for patients to be free of any deficit or complaint at follow-up. Complications were frequent, but not associated with high mortality. Overall 6-month mortality was 39%.

Conclusions: DC has the potential to save lives, but also the potential to leave survivors in a severely debilitated state. The place of DC in managing patients with severe intracranial hypertension due to non-trauma related causes is yet to be definitively established.

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Surgical procedures for the treatment of intracranial pathology are thought to have been first performed by the Incas as early as 4000 BCE.[1] More recently, decompressive craniectomy (DC), the surgical procedure to remove part of the skull to allow an injured brain to swell, thereby relieving intracranial pressure (ICP), has been performed in patients with traumatic brain injury,[2] ischaemic stroke,[3-5] subarachnoid haemorrhage,[3,6] cerebellar stroke,[7] and intracranial infection.[8]

There is ample evidence to support the use of DC as a means of treating refractory intracranial hypertension,[9] but there is limited evidence from high-quality randomised controlled trials (RCTs) to show that DC is associated with improved long-term outcomes for patients with severe brain injury. One RCT has been completed, involving 27 children with traumatic brain injury in a single centre.[10] Two multicentre RCTs are underway to investigate the utility of DC in highly selected populations of adults with traumatic brain injury: the RESCUEicp (Randomised Evaluation of Surgery with Craniectomy for Uncontrollable Elevation of Intra-Cranial Pressure) trial in Europe, and the DECRA (Decompressive Craniectomy) trial in Australasia.[2] These trials should provide high-quality evidence on the utility of DC in patients with traumatic brain injury. In non-traumatic conditions, evidence supporting DC is strongest for patients with malignant middle cerebral artery infarction.[5] Apart from these studies, there is no high-quality evidence to support the use of DC in patients with severe brain injury and hard-to-control ICP.

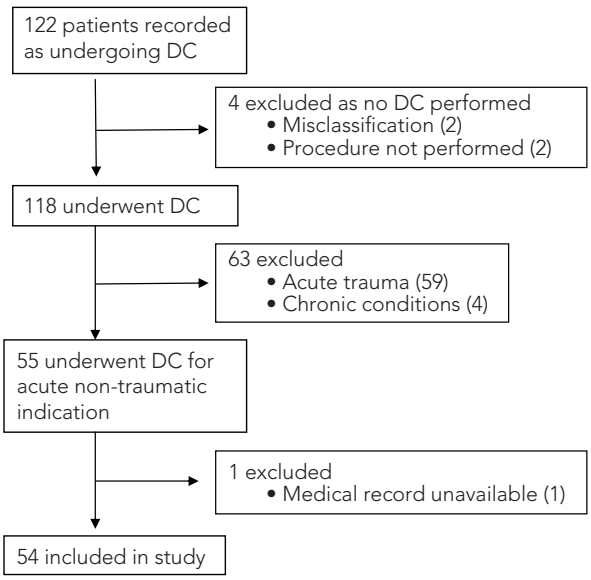
In spite of the paucity of high-quality evidence for the use of DC to treat severe intracranial hypertension in patients with acute non-trauma-related brain injury, the use of DC in these patients appears to be increasing. There are few reports of the use of DC in heterogeneous populations of neurosurgical populations, and no descriptions of current utilisation and outcomes for patients receiving this therapy in Australia. We performed a retrospective cohort study of the current utilisation and outcomes for patients receiving DC for acute non-traumatic indications.

Methods

The study was conducted at the tertiary referral neurosurgical centre at Royal North Shore Hospital, which caters for a referral population of about 1.2 million people in northern Sydney and northern New South Wales. The neurosurgical intensive care unit admits about 460 patients a year. We searched the ICU database for the period 1 January 2001 to 31 June 2008 using the keywords "decompressive", "decompression" and "craniectomy" to identify patients who underwent a DC. Patients' conditions were then classified as trauma- or non-trauma-related, with non-trauma-related cases selected for further scrutiny. We obtained ethics committee approval to access the hospital records.

Data were abstracted from each medical record onto a specifically designed data form. Baseline data, including

Figure 1. Patients identified in the ICU database search and reasons for exclusion from the study



DC = decompressive craniectomy.

patient demographics, Glasgow Coma Score and APACHE II (Acute Physiology and Chronic Health Evaluation II) score, were recorded. Treatment given before the DC, the trigger for surgical intervention, and ICP before and after surgery were also noted. Outcome data were collected on hospital mortality and on the length of stay in hospital and in the ICU. The discharge destination was noted. As this was a retrospective study, a formal Glasgow Outcome Score could not be obtained. As a substitute measure of functional outcome for survivors, the 6-month outcome was deemed to be "good" if they had returned to their own place of abode and "poor" if they required institutionalisation. For those who died, we noted the place and cause of death, the time from treatment withdrawal to death, and any organ donation made.

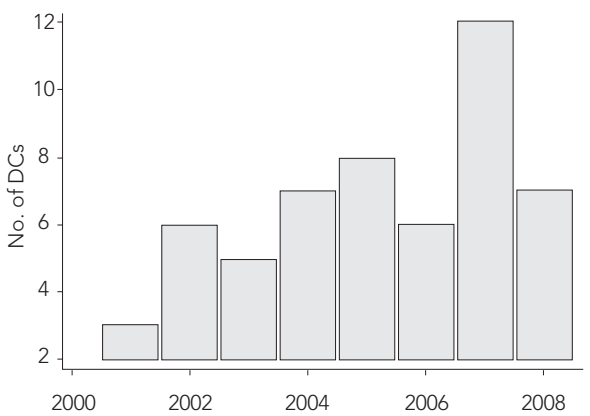
All patients were treated at the discretion of attending ICU and neurosurgical staff in conjunction with department guidelines. This included intubation and ventilation for airway protection and to avoid hypoxia and hypercapnia; blood pressure and circulatory support to maintain cerebral perfusion pressure; temperature control; glucose control; sedation and paralysis as deemed necessary; and reversal of anticoagulants and osmotherapy if appropriate. The decision to perform a DC and its timing were determined on clinical grounds by the attending neurosurgeon in consultation with ICU staff. The surgical procedure used for DC was at the discretion of the neurosurgeon, and included a duraplasty in all cases.

Table 1. Baseline characteristics of patients treated with decompressive craniectomy for acute non-traumatic indications (*n* = 54)

Characteristic	Number*
Female sex	31 (57%)
Mean age in years (SD; range)	46.5 (13.6; 16–79)
Diagnosis on admission	
Aneurysmal SAH	29 (54%)
WFNS grade:[11]	
1	6
2	5
3	2
4	8
5	8
Other intracranial haemorrhage	14 (26%)
AVM rupture	5
Hypertensive	6
Other	3
Ischaemic CVA	4 (7%)
Meningoencephalitis	3 (6%)
After elective neurosurgery	3 (6%)
Sagittal venous sinus thrombosis	1 (2%)
Mean GCS on admission (SD)	10 (4.2)
Mean APACHE II score (SD)	16.4 (6.6)

SAH = subarachnoid haemorrhage.
WFNS = World Federation of Neurosurgeons.
AVM = arteriovenous malformation. CVA = cerebrovascular accident.
GCS = Glasgow Coma Score.
APACHE II = Acute Physiology and Chronic Health Evaluation II.
* Number (%) of patients (except where otherwise specified).

Figure 2. Number of decompressive craniectomies (DCs) performed annually at Royal North Shore Hospital, 2001–2008*



* 2008 included only 6 months of data.

Summary statistics are given as mean and standard deviation for normally distributed variables, median and interquartile range (IQR) for non-normally distributed variables, and proportions where appropriate. The relationship between the numbers of procedures performed per year (from 2001 to 2007) was assessed with a simple linear regression model. Paired ICP data were compared with a paired *t* test. Proportions were compared with Fisher's exact test. All statistical analyses were performed using STATA software, version 10.1 (StataCorp, College Station, Tex, USA).

Table 2. Management of patients treated with decompressive craniectomy (DC) for acute non-traumatic indications ($n = 54$)

Management	No. of patients*
Management before DC	
Intracranial pressure monitoring device	37 (69%)
External ventricular drain	34 (63%)
Other	3 (6%)
Mechanical ventilation	50 (93%)
Mean CO_2 in mmHg (SD)	35.6
Temperature before DC in °C, mean (range)	36.0 (32.0–38.2)
Osmotherapy	45 (83%)
Mannitol	32 (59%)
3% saline	2 (4%)
Mannitol + 3% saline	11 (20%)
Mean serum sodium level† in mmol/L (range)	145 (131–176)
Thiopentone treatment	35 (65%)
Infusion‡	25 (46%)
Boluses	10 (19%)
Co-interventions during admission	
Intervention to secure aneurysm	28 (52%)
Clipping	19 (35%)
Coiling	9 (17%)
Nimodipine	33 (61%)
Tracheostomy	26 (48%)
Ventriculoperitoneal shunt	14 (26%)
Percutaneous endoscopic gastrostomy	10 (19%)
Therapeutic angiography	23 (43%)
Invasive haemodynamic monitoring	5 (9%)
Renal replacement therapy	1 (2%)

* Number (%) of patients (except where otherwise specified).
† Measured before DC.
‡ Five patients had an infusion before the procedure only, 10 after the procedure only, and a further 10 had an infusion before and after the procedure.

Results

The search of the ICU database retrieved 122 records. The results of the search and reasons for exclusion of patients are shown in Figure 1. After application of the inclusion and exclusion criteria, 54 patients remained in the study. Their baseline characteristics are shown in Table 1. Over half the patients were admitted after a subarachnoid haemorrhage (SAH). The full range of grades of SAH as determined by the World Federation of Neurosurgeons grading system were represented.[11] Most patients were women; eight patients were aged over 60 years, and three were over 70 years. Seventeen patients were admitted directly to Royal North Shore Hospital, and the other 37 were transferred to the hospital after receiving primary care at other institutions. Between 2001 and 2007, there was a significant increase in the mean number of patients receiving DC per year ($\beta = 1.1$, $P = 0.02$) (Figure 2).

Management and indications for decompressive craniectomy

The management of patients before a DC was performed is outlined in Table 2. An ICP monitoring device was in situ before DC in 37 of the 54 patients (69%), two of whom underwent two DC procedures. The method of choice was an external ventricular drain in 34 of these patients. Patients monitored included 26 of the 29 with SAH, all five with an arteriovenous malformation, all three who had undergone elective neurosurgery, the single patient with venous sinus thrombosis, and one of the four with a hypertensive cerebrovascular accident. The non-monitored patients were those admitted initially under non-neurosurgical teams,

Table 3. Trigger for decompressive craniectomy (DC), by diagnosis

	Trigger for DC*		
	Raised ICP	CT/clinical	At surgery
SAH ($n = 29$)	16	10	5
ICH, hypertensive ($n = 6$)	2	2	2
ICH, other ($n = 3$)	0	0	3
AVM ($n = 5$)	3	2	0
Ischaemic CVA ($n = 4$)	0	4	0
Meningitis ($n = 3$)	0	3	0
Post-surgery ($n = 3$)	2	1	0
VST ($n = 1$)	0	1	0

ICP = intracranial pressure. CT = computed tomography.
SAH = subarachnoid haemorrhage. ICH = intracranial haemorrhage.
AVM = arteriovenous malformation. CVA = cerebrovascular accident.
VST = venous sinus thrombosis.
* Number of patients. Values for different indications do not necessarily add to *n* as patients could have more than one indication for DC.

Table 4. Complications of decompressive craniectomy

Complication	Number
Bleeding, felt to be excessive	1
Infection	7
Duraplasty site (± CSF leak)	3
Replaced bone flap/acrylic plate	3
Abdominal bone flap site	1
Brain herniation through bony defect (not leading to imminent death)	2

CSF = cerebrospinal fluid.

who came to surgical attention only after catastrophic collapse. They were assessed as requiring emergency surgery rather than a more conservative approach.

Although 37 of the 54 patients underwent ICP monitoring before DC, medical records showed that high ICP was the catalyst for the procedure on only 23 of 56 occasions. A further 23 procedures were triggered primarily by suspicious clinical features and/or computed tomography findings. The remaining 10 DC procedures were not planned in advance but were undertaken at the time of surgery for an underlying problem (eg, aneurysm clipping, haematoma evacuation). The trigger for DC in each diagnostic group is listed in Table 3.

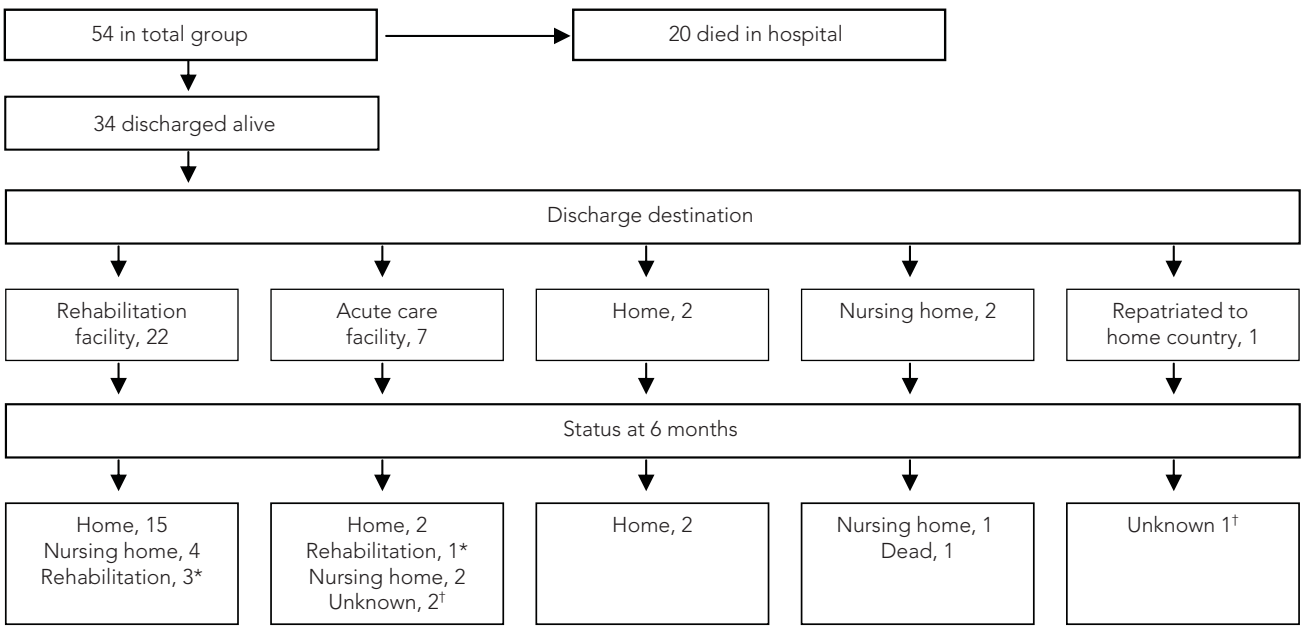
Decompressive craniectomy procedures

Over a quarter of patients underwent DC on the day of admission to hospital, and over half had the procedure within 2 days of admission. Some procedures were performed well into the hospital stay, with four being performed more than 2 weeks after admission (the latest at 31 days). These late DC procedures usually followed a second insult, such as a re-bleed. The type of DC performed was determined by the surgeon: 25 were done unilaterally on the right (presumed non-dominant), 16 unilaterally on the left (presumed dominant), seven were bifrontal, and eight were in the region of the posterior cranial fossa.

During their period in hospital, these patients consumed substantial health care resources. The median length of stay in the ICU was 16.5 days (IQR, 10–25 days; range, 2–45 days), and the median length of stay in hospital was 30.5 days (IQR, 12–63 days; range, 2–168 days). Over a fifth of patients required readmission to the ICU during their initial hospitalisation. Other interventions required are shown in Table 2. Two patients had an episode of resuscitated cardiac arrest.

The mean preoperative ICP in all patients with ICP monitors was 24.7 mmHg (SD, 10.5 mmHg; range, 7–54 mmHg). The mean initial postoperative ICP was 6.9 mmHg (SD, 4.6 mmHg; range, 0–24 mmHg), representing a significant reduction in mean ICP of 17.8 mmHg ($P < 0.001$ on paired t test).

Figure 3. Hospital outcome and 6-month outcome of patients after decompressive craniectomy



* The condition of two of these four patients was continuing to improve, and the other two patients were awaiting nursing home placement.
† At the time of hospital discharge, these patients were assessed as having "no rehabilitation potential".

Table 5. Six-month outcomes of 54 patients who underwent decompressive craniectomy

	Good outcome*	Bad outcome*	Dead*	Unknown*
Total group ($n = 54$)	19 (35%)	11 (20%)	21 (39%)	3 (6%)
By diagnosis				
Aneurysmal subarachnoid haemorrhage ($n = 29$)	6 (20%)	5 (17%)	15 (52%)	3 (10%)
Intracranial haemorrhage, hypertension ($n = 6$)	3 (50%)	2 (33%)	1 (17%)	0
Intracranial haemorrhage, other ($n = 3$)	2 (67%)	0	1 (33%)	0
Arteriovenous malformation ($n = 5$)	1 (20%)	2 (40%)	2 (40%)	0
Ischaemic cerebrovascular accident ($n = 4$)	3 (80%)	1 (20%)	0	0
Meningitis ($n = 3$)	1 (33%)	0	2 (67%)	0
Post surgery ($n = 3$)	2 (67%)	1 (33%)	0	0
Venous sinus thrombosis ($n = 1$)	1 (100%)	0	0	0
By type of decompressive craniectomy (DC)				
Non-dominant unilateral ($n = 23$)	9 (39%)	3 (13%)	9 (39%)	2 (9%)
Dominant unilateral ($n = 15$)	7 (47%)	4 (27%)	3 (20%)	1 (7%)
Bifrontal ($n = 7$)	2 (29%)	2 (29%)	3 (43%)	0
Post fossa/occipital ($n = 7$)	1 (14%)	2 (29%)	4 (57%)	0
Two procedures ($n = 2$)	0	0	2 (100%)	0
By trigger for DC†				
Intracranial pressure ($n = 21$)	9 (43%)	5 (24%)	6 (29%)	1 (5%)
Clinical/computed tomography ($n = 23$)	7 (30%)	5 (22%)	9 (39%)	2 (9%)
At surgery ($n = 10$)	3 (30%)	1 (10%)	6 (60%)	0
By timing of DC				
DC within 2 calendar days of admission to hospital ($n = 35$)	16 (46%)	6 (17%)	12 (34%)	1 (3%)
DC beyond 2 calendar days of admission to hospital ($n = 19$)	3 (16%)	4 (21%)	10 (53%)	2 (11%)

* Number (%) of patients. † Two patients had two procedures but only one outcome and were categorised according to the trigger for their primary procedure (clinical/computed tomography), rather than their second (intracranial pressure).

Outcomes

Complications of the procedure were recorded for 10 patients (Table 4). At 6 months, five of these 10 had a good outcome, four survived with a bad outcome and one had died.

Thirty-four of the 54 patients (63%) survived to hospital discharge, with the most common discharge destination being a rehabilitation facility (Figure 3). At 6-month follow-up, 30 were known to have survived, 19 of whom (63%) were assessed as having a good outcome. For all conditions apart from arteriovenous malformation, survivors were more likely to have a good than a bad outcome. Outcomes with respect to type of DC, trigger for and timing of DC, and diagnosis are presented in Table 5. A good outcome could still represent significant morbidity, with only two patients having no demonstrable deficit at 6 months — a 19-year-old woman who had returned to college study after recovering from meningitis, and a 27-year-old man who had returned to prison after a drug-induced intracranial haemorrhage. Persisting morbidity at

Table 6. Morbidity at 6-month follow-up

Deficit	Number*
Left hemiparesis/weakness	8
Right hemiparesis/weakness	3
Seizures	7
Speech problems	4
Memory problems	2
Vision problems	3
Required assistance with walking	1
Required assistance with activities of daily living	1
Impulsivity	2
Incoordination	1
Unspecified, but remaining on disability pension	1
No deficit	2

* Some patients reported more than one complaint.

6-month follow-up is summarised in Table 6. Patients aged over 60 years fared poorly, with a risk of more than 4 in 5 of experiencing severe disability or death. Although the risk of a bad outcome was lower in patients aged under 60 years (about 3 in 5), the difference was not statistically significant ($P = 0.24$).

Mortality

At 6-month follow-up there had been 21 deaths: 17 in the ICU, three in the ward and one after hospital discharge (a mortality rate of 39%). (The outcome of three patients was unknown.) Fourteen of the deaths in the ICU were the result of neurological factors, with 10 due to uncontrollable ICP despite decompression, and the other four due to treatment withdrawal or non-escalation of treatment in the face of a seemingly hopeless neurological prognosis. The other three ICU deaths were caused, respectively, by multiple organ dysfunction/sepsis, uncontrollable bleeding, and sudden cardiac arrest. Two ward patients died of infection with a non-escalation of treatment order, and one died of asystolic arrest.

Organ donation

Of the 14 patients who died of neurological causes in the ICU, two donated internal organs after brain death (one was diagnosed clinically, one on cerebral angiogram). Organ donation from a further patient was declined by the Australian Red Cross because of a lack of suitable recipients. One patient donated under the organ donation after cardiac death (DCD) protocol. Four patients were ineligible for donation because of family refusal or unavailability, and the remaining six patients had treatment withdrawn in the ICU (four of these were declared dead within 1 hour).

Discussion

The mortality rate in our sample was nearly 40%, reflecting the outcomes that may be expected when DC is employed in a heterogeneous group of patients. However, for most patients who survived, the outcome was favourable, with over 60% of survivors living at home at 6-month follow-up. Nevertheless, it was rare for patients to return to their full premorbid state of health and functioning. Complications of DC were frequent (occurring in almost 1 in 5 patients), but not associated with high mortality. Most deaths were from neurological causes. Organ donation from deceased patients based on clinical brain death criteria can be difficult because of the use of sedating agents. However, if DCD were widely adopted, many of these patients might become eligible to donate as a result of rapid death after withdrawal of treatment.[12]

In the non-trauma population, the best evidence for the effectiveness of DC is in patients with malignant middle cerebral artery infarction: a recent meta-analysis of three European RCTs involving a total of 93 patients revealed an increased survival benefit of the procedure, at a cost of moderate disability.[5] With the exception of ischaemic cerebrovascular accident, most indications for DC are supported by only weak evidence, mainly in the form of case reports and small case series, which are likely to overestimate the benefits of DC. For example, Schirmer and colleagues[3] reported a case series of 16 patients undergoing DC after SAH: 11 (69%) survived, and seven of the survivors had a favourable outcome. Adamo and Deshaies[8] described 13 patients who had undergone DC for raised ICP from encephalitis, with all 13 having a good or excellent outcome. Chen and colleagues[7] reported that eight of 11 patients (73%) who underwent DC after cerebellar infarction had a good outcome, and none of the patients died. Stefini and colleagues[13] described favourable outcomes in two out of three patients who had a DC following dural sinus thrombosis that resulted in coma and fixed pupils. All of these results are superior to the observed outcomes in our study. However, given the small numbers of patients involved, such comparisons may be unreliable.

The majority of our patients who underwent DC had a diagnosis of SAH. This diagnosis was associated with some of the worst outcomes, with fewer than 50% of these patients surviving, and only about half the survivors having a good outcome. This result is inferior to that of Schirmer et al,[3] who reported a 69% survival rate and a favourable outcome (assessed by modified Rankin score) in two-thirds of survivors in their study of 16 patients. However, their follow-up times varied and, for some patients, were as short as 39 days. They noted that DC carried out within 48 hours of SAH was associated with a better outcome than procedures performed later. Our data also suggest that patients who undergo DC early in their illness have better outcomes (both those with SAH and those with other conditions), although the numbers were too small to be definitive. D'Ambrosio et al[6] compared mortality and quality of life outcomes among 12 poor-grade SAH patients undergoing DC and 10 control patients from the same institution over a 7-year period. Mortality at 12 months was found to be similar in the two groups (about 40%). Extensive interviews with survivors revealed a poorer quality of life among those who underwent a DC compared with those treated more conservatively (five of nine survivors in the DC group were severely impaired compared with three of seven survivors in the control group). Although the numbers were small in this study, the authors concluded that DC was associated with poor quality of life and may not be in patients' best interests.

Our study exhibits the weaknesses of retrospective audits that rely on review of medical records: deficiencies in the database may mean that not all relevant patients were identified, data were not complete on all patients, patients were not questioned directly about quality of life and, to avoid making assumptions, the most objective measure available (place of abode) was chosen to determine outcome. We recognise that living circumstances are influenced by more than just medical factors, and encompass social, community and financial supports. However, for many young patients, the ability to live independently is likely to be an important outcome measure, and one that can be easily understood by patients and their families. As a retrospective study, we also could not assess the impact of selection bias on this cohort of patients, nor predict what the outcomes would have been if DC had not been performed.

In addition, our study was undertaken at a single centre that has an aggressive approach and extensive experience in managing patients with intracranial hypertension. Our results may not be generalisable to other institutions.

Even within our ICU, marked heterogeneity in treatment is obvious. This heterogeneity is due to several factors, including resource availability, differing surgical opinions, changes in practice over time, and lack of specific treatment protocols. Many patient crises occur after normal working hours, when medical personnel involved in patient care may lack the depth of knowledge needed for optimal management, leading to variations in treatment. Intensivists at Royal North Shore Hospital support the work of a range of surgeons with different thresholds for surgical intervention. This results in some patients having early, aggressive surgery and others having extensive medical interventions first. This surgical preference is difficult to influence, particularly in view of the lack of experimental evidence favouring one approach over another. Our ICU has written protocols for management of ICP in traumatic brain injury and general management of SAH, but not for management of non-trauma-related elevations in ICP per se. The lack of consensus about optimal management contributes to heterogeneity of treatment. Ideally, the availability of clear, experimentally proven management guidelines, agreed by all clinicians working within a unit, should minimise some of the observed heterogeneity in treatment, and might improve outcomes. Parallels can be drawn with the management of other ICU problems, notably acute respiratory distress syndrome, for which the publication of specific protocols[14] has standardised management, facilitating research and expanding knowledge of this condition.

Interestingly, at Royal North Shore Hospital, a similar number of DC procedures are performed for trauma-related and non-trauma-related brain injuries. Two large RCTs are currently being conducted on the effect of DC in the trauma population. More research is clearly needed in patients with severe intracranial hypertension unrelated to trauma.

The utility of DC may be assessed more easily by studying patient populations with a single diagnosis rather than a heterogeneous group, as described here. Patients with SAH are an obvious research target because of their relative frequency, young age and the potential for a significant number of years of life gained (possibly in a debilitated state). Outcomes for patients with SAH in our audit were dismal, with only 20% having a good outcome. This emphasises the urgent need for high-quality evidence of effectiveness.

Patients with ischaemic cerebrovascular accident, for which there is already good trial evidence of efficacy of DC, had among the best outcomes. Patients with other triggers for DC, such as intracranial hypertension (apart from ruptured arteriovenous malformation), elective neurosurgery or venous sinus thrombosis, also had good outcome rates of over 50%, warranting further research. However, as these conditions are less common, it is difficult to conduct RCTs. As a first step, a national or even international registry and prospective data collection may offer valuable insights into the effectiveness of DC on outcomes, and the patient populations most (and least) likely to benefit.

Conclusions

DC is an invasive rescue therapy for patients with severe brain insult and intractable intracranial hypertension. It has the potential to save lives, but also to leave people alive in a severely debilitated state. The place of DC in the management of patients with severe intracranial hypertension from non-trauma-related causes is yet to be definitively established.

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