Original Article

According to which factors in severe traumatic brain injury craniectomy could be beneficial

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Abstract

Background: To investigate the clinical outcome at 101 patients undergoing decompressive craniectomy (DC) after severe traumatic brain injury (TBI).

Methods: Age, Glasgow Coma Scale (GCS) at the time of intubation, and the intraoperative intracranial pressure (ICP) were recorded. Formal DC was performed in all cases and the square surface of bone flap was calculated in cm² based on the length and the width from computed tomography scan.

Results: The difference of good neurological recovery (Glasgow outcome score 4–5), between patients with ICP $\leq$20 mmHg, GCS $\geq$5, age $\leq$60 years, and bone flap $\geq$130 cm² and those with ICP >20 mmHg, GCS <5, age >60 years, and bone flap <130 cm², was statistically significant.

Conclusion: Although the application of DC in severe TBI is controversial and the population in this study is small, our study demonstrates the threshold of the specific factors (patient age, ICP and GCS on the day of the surgery and the size of the bone flap) which may help in the decision of performing DC. Furthermore, this study proves that the different combinations and mainly at the same time involvement of all prognostic parameters (age <60, GCS <5, bone flap $\geq$130 cm², and ICP $\leq$20 at time of DC surgery) allow a better outcome.

Key Words: Brain trauma, decompressive craniectomy, severe brain injury

INTRODUCTION

Decompressive craniectomy (DC) is an old surgical technique, with varied usefulness for a wide range of pathologies.[19] It has been documented that surgical interventions in the human skull were performed from people, even in the prehistoric times, motivated most possibly by religious rituals, magic, or even for healing purposes.[17,18,28,46] With the passage of time, the procedure of craniectomy became more efficient since physicians began to use more articulate, more accurate, and safer instruments. In ancient Greece, teaching and medical descriptions of Hippocrates (460–370 BC) included the concept of opening the cranial bone, in order to approach the underlying brain for therapeutic purposes.[9,34,42] In the early 19th century, the concept suggested by Monroe for the dynamic balance between

the three intracranial components was further supported by Kellie.[5] Since then, DC is widely used mainly as an empiric therapeutic intervention in malignant cerebral infarction, although some studies mention that worsens patients outcome,[4,45,49,54] and at intracranial hypertension (IH), following traumatic brain injury (TBI).[4,7,25,45,49,51,54] Craniectomy can clearly be life-saving in the presence of medically intractable elevations of intracranial pressure (ICP) and has been consistently demonstrated to reduce Intensive Care Unit (ICU) length of stay.[6,48] The idea of DC for TBI is to take off a part of skull bone and thus to give a more place to intracranial compartments.[12] In experimental models of TBI, it has been demonstrated that DC minimizes posttraumatic ICP increase and improves cerebral perfusion.[12] There are studies claiming that DC improves cerebral perfusion pressure and cerebral blood flow in head-injured patients.[29,50] Furthermore, when it is performed early, it reduces duration of stay in ICU and improves the Barthel Index Score.[1,3,16,20,21,26,29,35,36,41,43,44,58]

The main question in this procedure is whether the results justify the treatment as well as the associated complications and of course the functional outcome in surviving patients. The relationship between high ICP and poor outcome is very well documented.[13,31,33,38] Honeybul *et al.* reported that DC was associated with more unfavorable outcomes.[22] Many complications have been reported after DC such as herniation, bone defects, subdural effusion, hydrocephalus, and other factors that play role in unfavorable outcome.[23]

The purpose of this study was to analyze all those factors that play a key role in the outcome of patients who had undergone DC and lead to conclusions on whether and when this procedure can be beneficial.

MATERIALS AND METHODS

This is a retrospective study, with 101 patients undergoing DC after severe TBI and who had been submitted in our hospital during the last 5 years to reduce the ICP, were included. The study was approved by the Institutional Review Board of all the participating institutions. A signed written consent form was obtained from the participants or their legal representatives. The analysis of our data was performed according to the regulations of the current Health Insurance Portability and Accountability Act.

During 5-year period (2009–2013) in our department, 119 patients with severe TBI were admitted and from those 101 patients (84.9%), DC was performed. In 18 cases (15.2%) with severe TBI, IC*P* values were maintained under 12 mmHg with conservative methods (barbiturate coma, hyperventilation, hypertonic saline, and osmotic diuretics).

The mean age was 42.8 years (range 6–83 years). There were 81 (80.2%) men and 20 (19.8%) women.

In all patients, brain computed tomography (CT) scan was performed before surgery. The initial brain CT scan included contusions (8 cases – 8%), fractures (12 cases – 12%), acute subdural hematoma (37 cases – 37%), epidural hematoma (7 cases – 7%), intraparenchymal (21 cases – 21%), intraventricular (7 cases – 7%) or subarachnoid (5 cases – 5%), hemorrhage, and/or brain edema (30 cases – 30%). The most common mechanism of injury was a motor vehicle crash followed by falls. Glasgow Coma Scale (GCS) at the time of intubation and intraoperative ICP were recorded. In the majority of cases in 99 patients (98.9%), GCS was <8. In 2 cases (1.9%), GCS of admission was 12 and after a decrease in level of consciousness and emergent intubation, DC was performed due to values of ICP >18 mmHg.

The basic criterion for performing DC were the values of ICP >18 mmHg. Early (approximately 1 h after admission) DC was performed in 86 patients (85.9%), and in the rest 25 patients (14.1%) after failure of all the conservative methods, DC was performed between the 4th and 6th day.

Formal DC [Figure 1] was performed in all cases, and the square surface of bone flap was calculated in cm² based on the length and the width from CT scan [Figure 2]. In all patients, a combination of two broad spectrum antibiotics intravenous was given intraoperatively.

The clinical outcome was assessed with the Glasgow Outcome Score (GOS) score at 6 and 12 months follow-up, respectively [Figure 3, Table 1], and the statistical analysis was done using multivariate analysis of variance test.

RESULTS

In this study, following types of DC were performed: Right (48.2%), left (43.6%), and bilateral (8.2%).
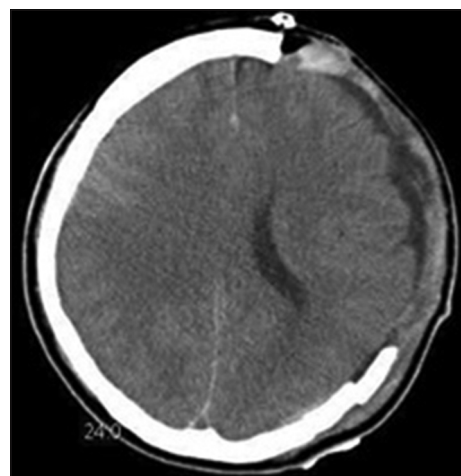

Figure 1: Computed tomography scan at patient with severe traumatic brain injury and right decompressive craniectomy

Figure 2: Three-dimensional reconstruction of the same patient

Figure 3: Patients Glasgow outcome score, 12 months after traumatic brain injury - decompressive craniectomy

Table 1: Total number of patients in each Glasgow outcome score category 6 and 12 months postoperatively

GOS	GOS 6 months	GOS 12 months
5	29	44
4	26	25
3	9	15
2	26	6
1	11	11

GOS: Glasgow outcome score

The most common complications during surgery were hemodynamic instability (15 cases – 15%) and hemorrhagic diathesis (10 cases – 10%). In two cases (1.9%), massive bleeding had occurred and in one of them, patient underwent hypovolemic shock and died. Other complications occurred postoperatively were bradycardia (2%), hypertension (1%), hypotension (1%), seizures (1%), hyperpyrexia (1.2%), difficulty in ventilation (1.2%), and rebleeding (1.2%). All these complications occurred either individually or in various combinations. The mortality, during surgery, was 1.9% (2 cases) and morbidity was 31.9% (32 cases) [Table 2].

At 69 patients (68.9%) who had an ICP ≤20 at the time of surgery, GOS was ≥4 after 12 months. In 26 (25.9%) elderly (age >60) patients, 11 patients (10.9%) had GCS ≤5, and their outcome was poor (GOS <4). From 55 patients where the bone flap was ≥130 cm², 36 of them (65.4%) had significantly better outcome according to GOS (≥4 after 12 months). However, in 10 patients who undergone a DC with bone flap ≤110 cm², only in 2 cases (20%) had a clinical improvement (GOS ≥4 after 12 months). The difference of good neurological recovery ([GOS 4–5] – threshold ≥4), between patients with ICP ≤ 20 mmHg, GCS ≥5, age ≤60 years, and bone flap ≥130 cm² and those with ICP >20 mmHg, GCS <5, age >60 years, and bone flap <130 cm², was statistically significant. For 6 and 12 months fol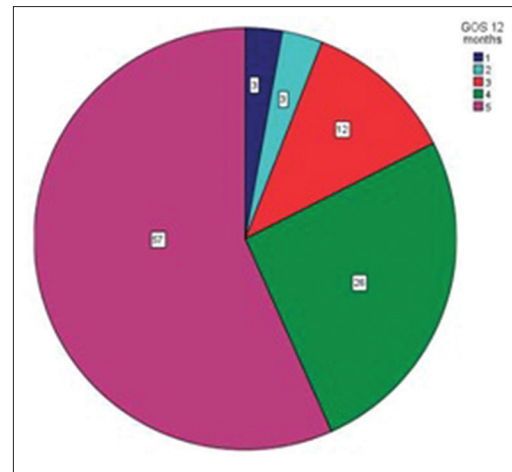low-up, the two-tailed $P < 0.0001$, respectively, and is considered to be extremely statistically significant. According to GOS [Table 3], the outcome was poorer with higher ICP and GCS <5. On the other hand, a bigger craniectomy and age ≤60, the recovery was better. The total number of patients in each GOS category at 6 and 12 months postoperative is presented in Table 1.

DISCUSSION

Diffuse brain swelling is the most common cause of morbidity and death after severe head injury in pediatric and adult patients.[32,47] In the last two decades, there has been increased attention in using DC as a procedure to control brain edema and elevated ICP after severe TBI.[1,2,11,30,37,39,43] However, the role of DC recommended in patients with severe TBI and refractory IH still remains controversial, mainly due its efficacy and complications such as infections (3–7%), communicating hydrocephalus (20.7%), subdural hygroma (26%), herniation (27.6%), and postoperative seizures (14%).[2,14,15,19,24,47,56] There is also a hypothesis by Cooper *et al.* that an increase in cerebral blood flow after removing the bone flap cause obstruction in the decompressed brain exacerbating the existing acute brain edema.[10] On the other hand, the focal increase in blood flow after DC may protect the brain from the secondary ischemic lesion.[19] Clinical data also indicate that DC reduces mortality and duration of stay in the care unit and improves the Barthel Index Score, especially when it is early performed.[1,3,16,20,21,26,29,35,36,41,43,44,58] The clinical outcome in severe TBI after DC varies from 7% to 70%.[27,40,55,59] Guerra *et al.* reported that up to 65% of patients with DC after severe TBI had a good recovery at 1 year.[19]

Despite these various studies, the effect of DC on clinical outcome after TBI is not yet clear. Although DC proved by DECRA study still remains questioning, there are suggesting an improvement in those patients.[57]

Table 2: Baseline characteristics of participants

Sex	Age	ICP preoperative	GSC preoperative	Bone flap size	GOS 6 months	GOS 12 months	Complications
A	22	20	5	130	4	5	Hemorrhagic diathesis
A	56	18	7	135	2	2	Rebleeding
A	64	15	5	130	5	5	
A	64	25	3	120	1	1	Hypovolemic shock, death
A	38	20	4	124	4	5	
A	63	20	4	125	2	2	
A	32	20	5	134	3	4	Hemodynamic instability
A	71	17	7	130	5	5	
Θ	16	25	3	136	2	4	
A	33	20	6	128	5	5	
A	27	20	5	137	2	4	
A	27	20	5	115	3	4	
Θ	54	25	3	130	2	3	
Θ	6	25	3	105	2	4	
A	72	25	3	110	2	2	Hemodynamic instability
A	52	25	4	135	2	3	
A	32	25	5	120	3	5	
A	7	25	5	135	3	4	
A	75	20	6	122	5	5	
A	12	50	3	138	2	3	Hemodynamic instability
A	12	20	6	116	4	4	
A	12	20	5	128	4	4	
A	12	25	3	137	2	3	
A	25	30	3	136	2	4	Hemodynamic instability
A	70	15	7	138	4	4	
A	25	30	6	130	4	5	
A	30	20	6	132	4	5	
A	18	10	8	122	5	5	
A	41	25	3	136	2	3	
A	30	20	5	130	4	5	
A	67	20	6	139	4	4	
A	33	20	6	119	4	5	
A	75	25	5	120	3	3	
A	71	15	7	132	5	5	
A	43	40	3	139	3	3	
A	49	50	3	110	2	3	
A	35	30	3	140	2	3	
A	56	20	5	131	4	5	Hypertension, seizure
A	69	30	6	130	5	5	
A	72	40	3	135	2	2	Hemorrhagic diathesis
Θ	70	20	5	120	3	4	Hemodynamic instability
A	22	10	8	136	5	5	
A	41	12	8	122	5	5	
A	54	15	7	138	5	5	
Θ	65	20	6	110	4	4	
Θ	14	20	5	114	4	5	Hypotension
A	28	30	5	132	4	4	Hemodynamic instability
A	37	40	4	138	2	3	
Θ	32	30	3	110	2	3	Hemodynamic instability
A	56	20	7	127	5	5	
Θ	44	25	4	137	2	4	Bradycardia

Contd...

Table 2: Contd..

Sex	Age	ICP preoperative	GSC preoperative	Bone flap size	GOS 6 months	GOS 12 months	Complications
A	29	20	5	134	4	5	
A	58	15	7	120	5	5	
Θ	8	15	7	118	5	5	
A	69	35	4	114	5	5	
A	34	10	8	130	5	5	
Θ	18	35	5	139	2	4	Hemodynamic instability
Θ	16	12	8	134	5	5	
A	76	15	8	114	5	5	Hemorrhagic diathesis
A	55	20	5	138	4	4	Hemodynamic instability
A	41	25	5	134	4	4	
Θ	59	25	5	136	4	5	
A	56	20	6	130	5	5	
A	22	25	5	136	4	5	Hemodynamic instability
A	45	25	5	132	4	5	
A	20	20	13	115	5	5	
A	66	15	8	136	5	5	
A	16	30	4	114	4	4	Allergy to pharmacy/cals
A	16	30	4	124	4	4	
A	62	20	6	122	5	5	
A	58	40	3	136	2	2	Hemodynamic instability, bradycardia
Θ	34	35	3	132	2	4	Hemodynamic instability
A	34	30	4	136	3	3	Hemodynamic instability
A	34	40	3	130	2	3	
A	72	50	3	128	2	2	Hemorrhagic diathesis
A	19	10	7	122	5	5	
A	50	15	12	128	4	5	
A	70	20	6	95	3	3	Hemodynamic instability
A	75	20	5	110	1	1	Death
A	17	4	8	120	5	5	
A	19	25	3	124	1	1	
A	27	14	3	120	2	3	Hemodynamic instability
A	55	10	7	138	5	5	
A	60	20	6	134	1	1	Hemorrhagic diathesis
Θ	36	15	8	114	5	5	
A	22	22	6	138	5	5	
Θ	83	20	5	126	5	5	
Θ	74	25	5	112	4	4	
A	80	20	6	132	1	1	Hemorrhagic diathesis
A	26	50	4	140	1	1	
A	18	25	5	139	2	4	Hyperpyrexia
Θ	56	40	7	137	4	5	
A	15	15	6	126	5	5	
Θ	16	30	3	135	2	4	Hemorrhagic diathesis
A	82	10	6	135	4	3	Difficulty in ventilation
A	19	30	4	137	1	1	
Θ	60	10	4	125	1	1	Hemorrhagic diathesis
A	22	40	3	130	1	1	Hemorrhagic diathesis
A	82	10	7	110	1	1	Massive bleeding
Θ	76	30	4	100	1	1	Hemorrhagic diathesis
A	39	10	8	130	5	5	

GOS: Glasgow outcome score, GCS: Glasgow coma scale, ICP: Intracranial pressure, A: Male, Θ: Female

Table 3: Glasgow outcome score

Grade	Explanation
Death	Severe injury or death without recovery of consciousness
Persistent vegetative state	Severe damage with prolonged state of unresponsiveness and a lack of higher mental functions
Severe disability	Severe injury with permanent need for help with daily living
Moderate disability	No need for assistance in everyday life, employment is possible but may require special equipment
Low disability	Light damage with minor neurological and psychological deficits

There are many prognostic factors affecting the outcome in severe TBI after DC such as age, lowest recorded GCS, presence of cranial fracture, absence of pupillary response/brainstem reflexes, respiratory insufficiency, refractory rise in ICP and the status of the basal cisterns or third ventricle on CT scan, the volume and location of the lesion, and the timing of surgery.[8]

The increased ICP is related with poor outcome after head injury, and ICP-guided therapy is commonly used.[52,53] In our data, the basic criterion for performing DC were the values of ICP >18 mmHg, and a better outcome (GOS ≥4 after 12 months) was achieved in 69 patients (68.9%), who had an ICP ≤20 at the time of surgery (threshold ICP ≤20).

The lowest recorded GCS and the worse outcome were also reported in other studies.[8,55] This cohort showed that patients with a threshold of GCS <5 in the intubation time, had a poorer outcome regardless of the early DC. The patient's age also seems to be related with the recovery after DC.[55] In our data, from 26 (25.9%) elderly/age >60/patients, 11 patients (10.9%) had GCS ≤5, and their outcome was poor (GOS <4). These results suggest that a threshold age >60 and GCS ≤5 is related with worsened outcome. Age always poses a moral dilemma for surgeon, but it seems that the age less than 60 years, in combination with other factors, provides a better chance of a good outcome. Age is not an absolute criterion for performing a craniectomy and certainly needs further studies to understand the various combinatorial factors such as physiological age, comorbidities, and potential to increase the average life, in order to determine the benefits. In this study there have been setting specific parameters, which easily can be known in any case of emergency TBI surgery and used as an easy guide to making difficult decisions.

In our study, 55 patients had undergone DC with bone flap ≥130 cm² and 36 of them (65.4%) had significantly better outcome according to GOS (≥4 after 12 months). On the other hand, in 10 patients with bone flap ≤110 cm², only 2 (≈20%) had a clinical improvement (GOS ≥ 4 after 12 months). This shows a strong correlation between the outcome and size of bone flap. In addition, this study proves that the different combinations and mainly at the same time involvement of all prognostic parameters (age <60, GCS <5, bone flap ≥130 cm² and ICP ≤20 at time of DC surgery) allow a better outcome ($P = 0.0001$ extremely statistically significant).

According to specific factors and their thresholds, our data can contribute to the decision of when to perform DC after severe TBI to be life-saving procedure and to minimize complications.

CONCLUSION

DC as a treatment option in patients with TBI has been a lot criticized and still remains controversial. Although studies such as DECRA have come up with results that consider DC as not a favorable option according to patients' outcome, other ongoing studies such as RESCUE-ICP are main to add some more light in the dark field of the best optional treatment. This study and its results tries to emphasize on specific factors under which DC could be beneficial and helps us decide not only if DC should be performed or not but also when and under which specific circumstances it should be performed.

Conflicts of interest
There are no conflicts of interest.

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Commentary

This paper continues a concept that is common in medicine that chronological age is a marker to be used in treatment. Chronological age is a biased view of aging across all modern cultures except those in which aging is a mark of respect and wisdom. Physiological age would be a better parameter to use. I challenge someone to develop this metric. Physiological age is a measure of the patients total body health. Chronological age does not measure this total body health but only a number in which are mixed many people in various stages of health. This physiological age would apply to all. It would apply to the very young with multisystem disease, who have little hope for recovery. It applies to all ages and avoids the bias that because someone is over 60 or 70, they have lived a full life and there is no use in prolonging it. Studies have reported that life expectancy will be 100 years for those born in the 21st century. Some cite 140 years as the expected life expectancy in the 21st century. Only a review of history will reveal that Hunter Gatherers lived until the age of 20 while during more civilized societies the ages extended to 40 years by the 1900s. In the past 100 years, life expectancy has doubled to 80 years and with some extension of that recently to 90 years. So, how does an arbitrary number of 60 of 70 apply to what will represent 30% of the population of many cultures but 2050. This concept makes no sense. Those now who are young and overweight (2/3 of the world population) will suffer earlier deaths from diabetes and hypertension and other diseases. Hence, I would expect that their physiological age will be higher than those who do not have these diseases or obesity. So, I predict that in the 21st century, we will see a subset of the young dying early and others living longer. Only a physiological age evaluation will make sense and add to the medical decisions governing treatment, no chronological age.

Most papers written using age do not consider this factor. Certainly people as they age have a higher chance of more diseases, but many are living well and contributing to society. Older people are more sensitive to drugs and must be treated as newborns with great care for their sensitivities to many treatments. So, to me papers that use an age as a cutoff without defining the health of the over 60/70 population are not valuable in guiding management decisions. That criticism applies to virtually all the studies written in the past decades.

It is time to start thinking differently about age and move into the 21st century on this subject of aging and medicine. This aging concept is a bias of societies worldwide. It will be rejected by the Boomers all over the world who are looking for a long productive life.

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