

# Decompressive Craniectomy for Traumatic Brain Injury: In-hospital Mortality-Associated Factors

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## Abstract

**Objective** Determine predictors of in-hospital mortality in patients with severe traumatic brain injury (TBI) who underwent decompressive craniectomy.

**Materials and Methods** This retrospective study reviewed consecutive patients who underwent a decompressive craniectomy between March 2017 and March 2020 at our institution, and analyzed clinical characteristics, brain tomographic images, surgical details and morbimortality associated with this procedure.

**Results** Thirty-three (30 unilateral and 3 bifrontal) decompressive craniectomies were performed, of which 27 patients were male (81.8%). The mean age was 52.18 years, the mean Glasgow coma scale (GCS) score at admission was 9, and 24 patients had anisocoria (72.7%). Falls were the principal cause of the trauma (51.5%), the mean anterior–posterior diameter (APD) of the bone flap in unilateral cases was 106.81 mm (standard deviation [SD] 20.42) and 16 patients (53.3%) underwent a right-sided hemicraniectomy. The temporal bone enlargement was done in 20 cases (66.7%), the mean time of surgery was 2 hours and 27 minutes, the skull flap was preserved in the subcutaneous layer in 29 cases (87.8%), the mean of blood loss was 636.36 mL, and in-hospital mortality was 12%. Univariate analysis found differences between the APD diameter (120.3 mm vs. 85.3 mm;  $p = 0.003$ ) and the presence of midline shift  $> 5$  mm ( $p = 0.033$ ).

**Conclusion** The size of the skull flap and the presence of midline shift  $> 5$  mm were predictors of mortality. In the absence of intracranial pressure (ICP) monitoring, clinical and radiological criteria are mandatory to perform a decompressive craniectomy.

## Keywords

- decompressive craniectomy
- intracranial pressure
- intracranial hypertension
- traumatic brain injury

## Introduction

Traumatic brain injury (TBI) is a serious pathology that conditions an increase in morbidity and mortality, with more than 50,000 deaths annually in developed countries.<sup>1</sup> Secondary damage due to cerebral edema, contusions, subdural hematoma (SDH), epidural hematoma (EDH), and others lead to a progressive increase in intracranial pressure (ICP), with consequent alteration in the brain compliance.<sup>2,3</sup>

Intracranial hypertension is related to a higher prevalence of disability and death if not treated. Guidelines propose a

step-wise treatment to control ICP, but when intracranial hypertension is refractory to medical or first-tier management, decompressive craniectomy (DC) is the treatment of choice.<sup>4</sup> Randomized controlled trials and guidelines have evaluated the benefits of DC over optimal medical treatment in cases of TBI with intracranial hypertension and recommend this procedure to improve neurologic outcomes and lower mortality rates.<sup>4-7</sup> Few studies in our country have issued this problem,<sup>8,9</sup> so we aimed to evaluate our experience of consecutive patients with severe TBI who underwent DC in our institution and analyze in-hospital mortality-associated factors.



## Materials and Methods

### Patient Selection

Between March 2017 and March 2020, 33 consecutive patients with the diagnosis of severe TBI underwent 33 decompressive craniectomies at the Hospital de Emergencias José Casimiro Ulloa from Lima, Perú. Clinical charts and brain CT scans were used to analyze demographics, clinical characteristics, tomographic findings, surgical details, procedure-related complications, and mortality associated with the procedure. The study was approved by the ethics committee of the hospital.

Demographics and clinical characteristics included age, sex, the mechanism of trauma, the presence of anisocoria, and the Glasgow coma scale (GCS) score at admission. The tomographic findings analyzed were the presence of acute SDHs and EDHs, midline shift > 5 mm, traumatic subarachnoid hemorrhage (SAH), cerebral contusions, skull fracture, and the Marshall classification. Surgical details included the type of craniectomy, the side of the craniectomy in unilateral cases, the anterior-posterior diameter (APD) in unilateral craniectomies, temporal bone removal (enlargement toward the skull base or zygomatic arch with drill or rongeur), blood loss, the subcutaneous layer placement of the bone flap, and the time of surgery.

Unilateral or bifrontal craniectomies were performed according to the type and location of the lesion and CT scans. ICP monitoring was not performed in any of the cases. For unilateral DC, a question mark incision and a frontotemporo-parietal bone flap with duroplasty was done. In cases of a bifrontal DC, a bicoronal incision with a flap from the frontal bone to the coronal suture with duroplasty was performed. All the procedures were catalogued as primary DC, and ICP monitoring was not performed.

### Statistical Analysis

Categorical variables were expressed as percentages, and numerical variables were expressed as means  $\pm$  SD. Differences between numerical variables were analyzed with t-student or Mann-Whitney tests, depending on its distribution, and the Fisher's test was employed for categorical variables. A *p* value < 0.05 was considered statistically significant. The software Stata v14.0 (StataCorp, College Station, Texas) was used for the analysis.

## Results

### Population Characteristics

Thirty-three decompressive craniectomies were analyzed, of which 30 were unilateral and three were bifrontal craniectomies. Males represented 81.8% of the cases and the mean age was  $52.2 \pm 20.1$  years (range 22 to 85 years). The principal mechanism of trauma was falls (51.5%), traffic accidents (36.4%), and hit by an object (12.1%). The mean GCS score at admission was 9, and 24 patients (72.7%) presented anisocoria at admission. Fifteen patients had a GCS  $\leq$  8 points (45.5%) (**► Table 1**).

### Tomographic Findings

The predominant tomographic findings were the presence of midline shift > 5 mm and a SDH in 90.1% and 87.9% of the cases, respectively.

Traumatic SAH, brain contusions and skull fractures were observed in 57.6%, 51.5% and 36.4% of the cases, respectively. The presence of an epidural hematoma was found in 6.1% of the cases.

All the patients were classified according to the Marshall Classification and all of them presented a score greater than 3. Thirteen patients were catalogued as a Marshall grade 3-4 and 20 patients as a Marshall 6. Three out of four patients who died were catalogued as Marshall 6 (75%) (**► Table 2**).

### Surgical Procedure Characteristics

Sixteen patients (53.3%) underwent a right-sided craniectomy and the mean APD of the unilateral craniectomy was  $106.8 \text{ mm} \pm 20.4 \text{ mm}$  (range 70.26 to 166.42 mm), the temporal bone was removed in 20 patients (66.3%) of the unilateral cases, the skull flap was preserved in the subcutaneous layer in 29 patients (87.8%), and the average time of the surgery was 2 hours and 27 minutes (**► Figs. 1 and 2**). The mean blood loss was  $636.4 \text{ mL} \pm 375.1 \text{ mL}$ .

### Complications and Mortality

Four patients (12%) presented cerebrospinal fluid (CSF) fistulas and three patients (9%) developed subcutaneous abdominal infections. The in-hospital mortality rate was four patients (12%).

### Univariate Analysis

When comparing both groups, there were no differences among the covariates, except for the mean APD of the skull flap, which was larger in patients who survived ( $120.3 \text{ mm}$  vs.  $85.3 \text{ mm}$ ; *p* = 0.003) and the presence of midline shift > 5 mm (*p* = 0.033) (**► Table 3**).

## Discussion

Decompressive craniectomy is a life-saving procedure in cases of TBI with intracranial hypertension. In this study, we report an in-hospital mortality rate of 12%, and mortality-associated factors found were the APD of the skull flap and the presence of midline shift greater than 5 mm.

Regarding the optimal management of TBI, guidelines recommend medical treatment with first-tier management, followed by the second-tier management, which includes DC, among other options, such as barbiturate coma.<sup>10</sup> Depending on the presence of ICP monitoring, if the DC is performed once, the diagnosis of TBI with intracranial hypertension is made; then, the procedure is termed primary DC and is usually performed within the first 24 hours. When ICP monitoring is available and intracranial hypertension is refractory to medical management, then the procedure is termed secondary DC. Current indications for DC are as follows: comatose patients with the presence of an acute SDH, severe brain swelling, midline shift > 5 mm, absence of basal cisterns due

**Table 1** Clinical and surgical-related characteristics of patients treated with decompressive craniectomy

Case	Age	Sex	Mechanism of trauma	Presence of anisocoria	GCS at admission	Surgical procedure	Side	APD (mm)	Temporal bone removal	Blood loss (mL)	Subcutaneous layer placement	Time of surgery (minutes)	Mortality
1	38	F	Traffic accident	Present	12	Unilateral craniectomy	Left	101.4	Yes	100	Yes	90	No
2	62	M	Traffic accident	Present	11	Unilateral craniectomy	Left	88.94	No	250	Yes	150	No
3	28	M	Traffic accident	Present	7	Unilateral craniectomy	Right	120.59	No	1500	No	120	No
4	33	M	Traffic accident	Present	9	Unilateral craniectomy	Left	133.25	Yes	1000	No	150	No
5	42	F	Fall	Absent	10	Unilateral craniectomy	Right	94.05	No	500	Yes	120	No
6	84	M	Fall	Present	5	Unilateral craniectomy	Left	88.43	No	300	Yes	70	Yes
7	71	M	Traffic accident	Present	6	Unilateral craniectomy	Right	112.93	Yes	500	Yes	120	No
8	23	M	Hit by rigid object	Present	8	Bifrontal craniectomy	-	-	-	400	Yes	255	No
9	78	M	Traffic accident	Present	9	Unilateral craniectomy	Left	113.27	Yes	200	Yes	90	No
10	85	F	Traffic accident	Present	5	Unilateral craniectomy	Right	106.23	Yes	1000	Yes	95	No
11	24	M	Fall	Absent	6	Unilateral craniectomy	Left	97.12	Yes	300	Yes	120	Yes
12	39	M	Fall	Present	12	Unilateral craniectomy	Right	116.04	Yes	1200	Yes	180	No
13	61	F	Fall	Present	5	Unilateral craniectomy	Left	121.5	No	700	No	140	No
14	26	M	Fall	Absent	10	Unilateral craniectomy	Left	127.29	Yes	1000	Yes	195	No
15	57	M	Fall	Present	10	Bifrontal craniectomy	-	-	-	300	Yes	113	No
16	38	M	Fall	Present	8	Unilateral craniectomy	Right	127.67	Yes	700	Yes	170	No
17	64	F	Traffic accident	Absent	14	Unilateral craniectomy	Right	122.69	Yes	200	Yes	106	No
18	36	M	Fall	Present	8	Unilateral craniectomy	Right	139.59	Yes	400	Yes	160	No
19	65	M	Fall	Present	8	Unilateral craniectomy	Right	123.58	Yes	900	Yes	170	No
20	66	M	Traffic accident	Present	5	Unilateral craniectomy	Left	132.84	Yes	1000	No	196	No
21	66	F	Fall	Present	10	Unilateral craniectomy	Right	108.37	No	700	Yes	170	No
22	35	M	Hit by rigid object	Present	5	Unilateral craniectomy	Right	131.18	Yes	400	Yes	170	No
23	22	M	Fall	Present	11	Unilateral craniectomy	Left	100.85	No	800	Yes	160	No
24	32	M	Traffic accident	Present	4	Unilateral craniectomy	Right	112.34	Yes	1000	Yes	150	No
25	22	M	Hit by rigid object	Absent	12	Unilateral craniectomy	Right	97.17	No	500	Yes	145	No
26	26	M	Fall	Present	9	Unilateral craniectomy	Right	166.42	Yes	350	Yes	165	No
27	68	M	Traffic accident	Absent	9	Bifrontal craniectomy	-	-	-	1500	Yes	235	Yes
28	46	M	Fall	Present	12	Unilateral craniectomy	Right	133.88	Yes	400	Yes	150	No
29	68	M	Fall	Present	7	Unilateral craniectomy	Left	148.92	Yes	1000	Yes	135	No
30	68	M	Traffic accident	Present	7	Unilateral craniectomy	Left	138.09	Yes	500	Yes	155	No
31	27	M	Fall	Present	12	Unilateral craniectomy	Right	99.77	No	300	Yes	170	No
32	51	M	Hit by rigid object	Absent	13	Unilateral craniectomy	Left	130.77	Yes	300	Yes	120	No
33	72	M	Fall	Absent	12	Unilateral craniectomy	Left	70.26	No	800	Yes	120	Yes

Abbreviations: APD, anterior-posterior diameter; GCS, Glasgow coma scale.

**Table 2** Tomographic characteristics of patients who underwent decompressive craniectomy

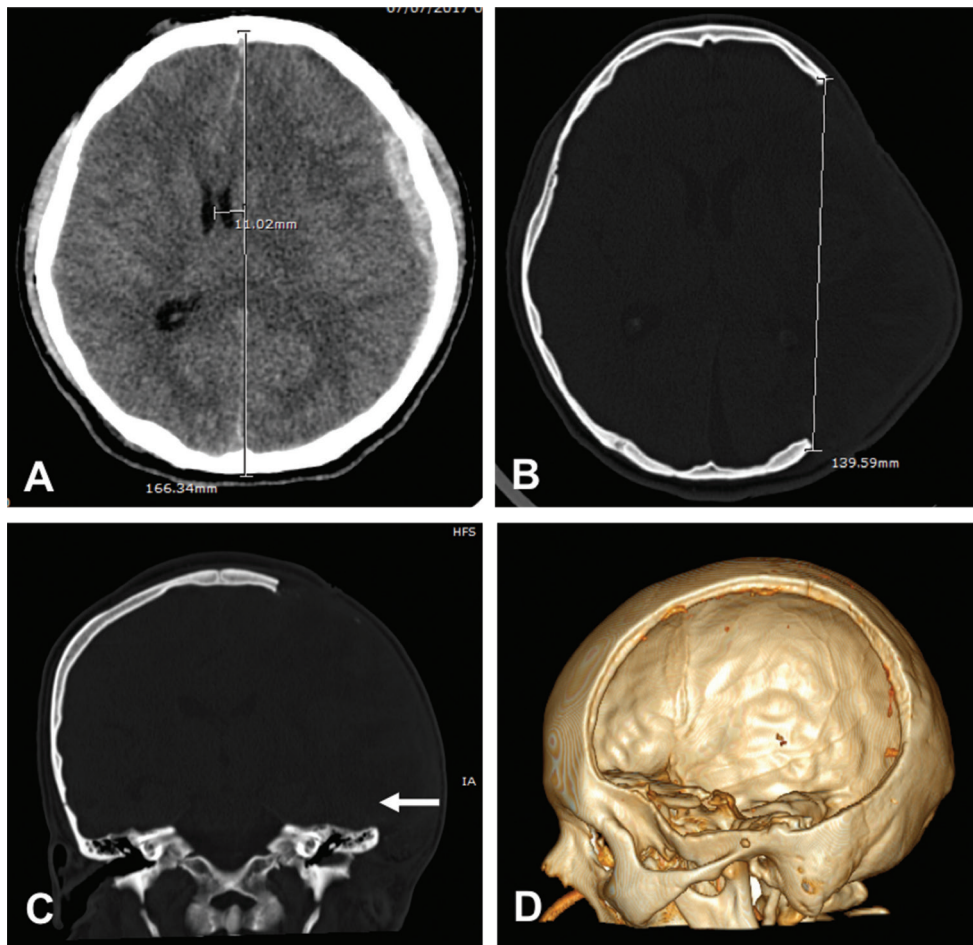
Patient	Marshall classification	SDH	EDH	Midline shift	Cerebral contusion	Traumatic SAH	Skull fracture
1	4	+	-	+	-	+	-
2	6	-	+	+	+	-	-
3	3	+	-	+	-	-	+
4	3	+	-	+	-	+	+
5	3	+	-	+	-	+	-
6	6	+	-	+	-	-	-
7	6	+	-	+	+	-	-
8	6	+	-	+	-	-	-
9	6	+	-	+	+	+	-
10	6	+	-	+	+	-	-
11	3	+	-	+	-	+	-
12	6	-	+	+	-	-	-
13	6	+	-	+	+	+	-
14	4	+	-	+	+	+	+
15	6	-	-	+	+	+	+
16	6	+	-	+	+	+	-
17	6	+	-	+	+	+	+
18	6	+	-	+	+	+	+
19	6	+	-	+	+	+	-
20	6	+	-	+	-	+	+
21	3	+	-	+	+	-	+
22	6	+	-	-	+	+	+
23	6	+	-	+	+	+	-
24	4	+	-	+	-	+	-
25	3	+	-	+	-	-	-
26	6	+	-	+	-	+	+
27	6	-	-	-	+	+	+
28	6	+	-	+	+	-	+
29	4	+	-	+	-	-	-
30	4	+	-	+	-	-	-
31	4	+	-	+	-	-	-
32	4	+	-	+	-	-	-
33	6	+	-	-	+	+	-

Abbreviations: EDH, epidural hematoma; SAH, subarachnoid hemorrhage; SDH, subdural hematoma

to a parenchymal hemorrhage or brain contusions with or without surrounding edema, and the presence of anisocoria.

Randomized controlled trials sought to determine the benefits of performing DC in patients with TBI. In the DECRA trial, bifrontal decompressive craniectomy was associated

with unfavorable outcomes when compared with medical therapy (70% vs. 51%) and no significant differences in mortality rates between surgical and medical groups were found at 6 months (19% vs. 18%).<sup>5,11</sup> In the RESCUEicp trial, decompressive craniectomy in patients with TBI and refractory



**Fig. 1** (A) Brain CT scan shows an acute subdural hematoma with midline shift. (B, C) Postoperative CT scan showing the diameter of the craniectomy with resection of temporal bone (arrow). (D) 3D reconstruction showing the defect.

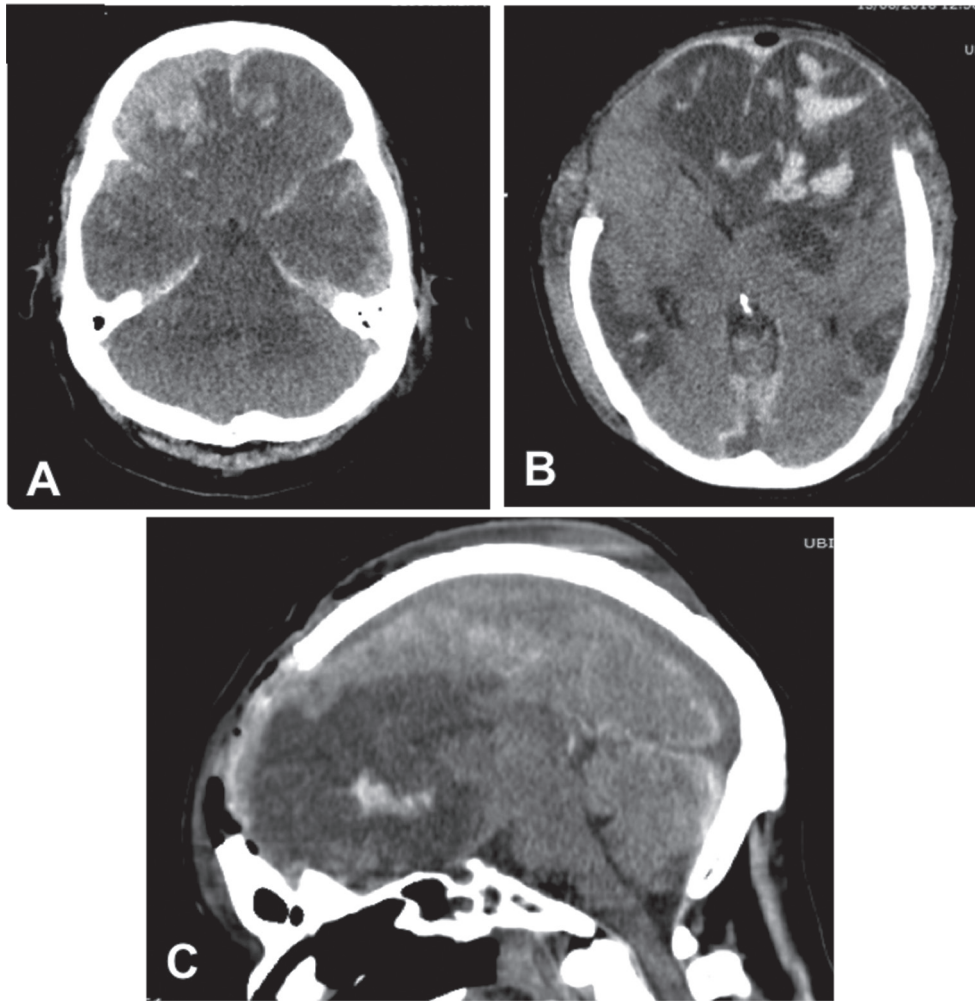
intracranial hypertension resulted in lower mortality and higher rates of severe disability at 6 months. A favorable outcome at 6 months (better on the GOSE) with surgery was obtained (42.8% vs. 34.6%,  $p = 0.12$ ) and mortality rates were significantly lower with surgery (26.9% vs. 48.9%)<sup>6</sup> The RESCUE-ASDH trial aims to address whether primary DC or craniotomy are the best strategies for patients with severe TBI who undergo evacuation of an acute SDH. Nevertheless, results from this trial are not yet available.<sup>12</sup> In addition, a Chinese trial found lower mortality rates (26.2% vs. 35.1%) and higher favorable outcomes (39.8% vs. 28.6%) in patients who underwent a standard DC (12 × 15 cm flap) compared with limited DC (6 × 8 cm flap).<sup>13</sup> Technical nuances to perform a DC have been reported.<sup>14</sup> The AP diameters of bone flaps range from 12 to 15 cm in unilateral craniectomies; <sup>15,16</sup> nevertheless, the ideal bone flap diameter should be larger than 15 cm to achieve an adequate decompression.<sup>17,18</sup>

Regarding the management of TBI in Perú, a developing country in South America, scarce publications were found.<sup>8,9,19</sup> One descriptive study in a public hospital evaluated 76 patients who underwent surgery due to TBI. Sixteen patients (21.1%) underwent DC in its two modalities

(unilateral or bifrontal), ICP monitoring was used in 12 cases (15.8%), and the mortality rate was 9 patients (11.8%).<sup>8</sup>

Despite the small sample, our analysis yielded important results. The size of the bone flap is an important predictor of mortality and good outcomes, as shown in previous studies.<sup>14,15,17,18</sup> The ideal APD to relieve the high ICP is 15 cm. However, four patients had an average diameter of 85.3 mm and all of them died. Patients were classified according to the Marshall tomographic scale and all were catalogued as Marshall  $\geq 3$ . Of the four dead patients, three had a Marshall 6 type of lesion. In-hospital mortality rates in our series is relatively lower compared with previous studies,<sup>20,21</sup> despite the lack of ICP monitoring. This could be explained because 55% of our series presented a GCS score  $> 8$  points on admission and the issue that 100% of the surgeries were primary DC. A combination of tomographic findings was found in the same patient. Midline shift was present in 90.1% of the cases, followed by the presence of a SDH in 87.9% of the cases.

The decision to perform a smaller or larger craniectomy was based on the surgeon's decision and radiological findings. In the case of a smaller craniectomy (mean 85 mm in



**Fig. 2** (A) Brain CT scan showing an acute subdural hematoma with frontal contusions and severe edema. (B–D) Postoperative bifrontal decompressive craniectomy.

APD), the total evacuation of the hematoma was followed by optimal medical management. We have to take into consideration the fact that all the procedures were primary DC, two of four patients who died had a midline shift  $> 5$  mm, and one patient underwent temporal bone enlargement. In addition, in this particular subgroup of patients when the surgery was done, the brain was not seriously edematous after hematoma evacuation.

According to the literature, factors associated with mortality are age, the low-GCS score at admission, the size of the craniectomy, effacement of basal cisterns, and severe midline shift.<sup>13,16,22–24</sup> Unfavorable outcomes reported were low-GCS scores on admission, postoperative hydrocephalus, tracheostomy, sphenoid fractures, and unchanged ICP.<sup>21,25,26</sup>

DC-related mortality rates ranged from 12 to 55%.<sup>16,20–22,24–27</sup> In-hospital mortality rates ranged between 32 to 55%,<sup>20,21,26</sup> whereas 30-day mortality rates ranged from 12 to 28.3%.<sup>16,22,24,27</sup> Laghari et al reported an in-hospital mortality rate of 25% at 3 months in their series. In addition, Khalili reported a mortality rate of 40.8% at 1-year follow-up.

Regarding procedure-related complications, our rate of CSF fistulas was high compared with the reported in the

literature (6% vs.12%).<sup>18</sup> Postoperative infection rates such as abdominal infections represent around 10%, similar to our 9% abdominal infection rate.<sup>18</sup>

This study has limitations. The small sample and the retrospective design did not allow to draw more robust statistical associations. None of the patients had ICP monitoring before, during, or after the surgery. Postoperative clinical outcomes were not assessed. Our institution is an emergency hospital where potentially surgical patients undergo emergent surgeries, and after their recovery, they are discharged to other institutions or to their homes. For this reason, follow-up was not feasible. Further investigations should be performed in developing countries regarding trauma and its surgical management.

## Conclusions

In our analysis, the mean diameter of the bone flap in unilateral craniectomies and the midline shift were associated within-hospital mortality. In centers without ICP monitoring, primary decompressive craniectomy should be performed according to clinical and radiological criteria.

**Table 3** Univariate analysis of mortality-associated factors following decompressive craniectomy

Variable	Alive n = 29	Dead n = 4	p-Value
Age	47.4 ± 19	62 ± 20.1	0.178
Sex			0.429
Male	23 (85.2)	4 (14.8)	
Female	6 (100)	0 (0)	
Trauma mechanism			0.781
Fall	14 (82.4)	3 (17.6)	
Traffic accident	11 (91.7)	1 (8.3)	
Hit by object	4 (100)	0 (0)	
Presence of anisocoria	23 (95.8)	1 (4.2)	0.052
Glasgow at admission	9 ± 2.8	8 ± 3.2	0.537
<b>Surgical characteristics</b>			
Type of surgery			0.330
Unilateral craniectomy	27 (90)	3 (10)	
Bilateral craniectomy	2 (66.7)	1 (33.3)	
Side of the craniectomy			0.09
Right	16 (100)	0 (0)	
Left	11 (78.6)	3 (21.4)	
APD of craniectomy (unilateral cases)	120.3 ± 18	85.3 ± 13.7	<b>0.003</b>
Removal of temporal bone	19 (95)	1 (5)	0.251
Blood loss*	500 (100–1500)	550 (300–1500)	0.956
SCL placement of bone flap	25 (86.2)	4 (13.8)	0.580
Time of surgery <sup>a</sup>	150 (90–255)	120 (70–235)	0.375
<b>Tomographic findings</b>			
Marshall at admission			0.481
Grade 3–4	12 (92.3)	1 (7.7)	
Grade 6	17 (85)	3 (15)	
Presence of subdural hematoma	26 (89.7)	3 (10.3)	0.420
Presence of epidural hematoma	2 (100)	0 (0)	0.769
Presence of midline shift > 5 mm	28 (93.3)	2 (6.7)	<b>0.033</b>
Presence of cerebral contusion	15 (88.2)	2 (11.8)	0.676
Presence of traumatic subarachnoid hemorrhage	16 (84.2)	3 (15.8)	0.426
Presence of cranial fracture	11 (91.7)	1 (8.3)	0.536

\*Mann–Whitney: median and ranges

### Conflict of Interest

None declared.

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