



# Decompressive Craniectomy and Shunt-Amenable Post-Traumatic Hydrocephalus: A Single-Center Experience

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■ **BACKGROUND:** Prior studies have shown that decompressive craniectomy may be an independent risk factor for the development of post-traumatic hydrocephalus (PTH). It is upon this background that we chose to conduct our single-center retrospective study to establish the possibility of an association between decompressive craniectomy and PTH.

■ **METHODS:** A retrospective review involving a database of all patients with traumatic brain injury was undertaken. All referrals and admissions with traumatic brain injury, as defined by the Mayo Classification, from January 2012 to May 2022, were included in the subsequent analysis. Statistical analysis was carried out using IBM SPSS version 28.0.1.

■ **RESULTS:** The mean age of the cohort was  $44.91 \pm 19.16$  with more males (82.3%) than females (17.7%). Vehicle incident/collision was the most common cause of traumatic brain injury. 84% of the cohort was alive at 30 days, 4% were noted to have an intracranial infection, and 3% underwent shunt insertion procedures, while 14% received decompressive craniotomies as part of their clinical management. There was a statistically significant association between undergoing decompressive craniectomy, and the development of PTH (odds ratio, 4.759 [95% confidence interval, 1.290–17.559];  $P = 0.019$ ). The presence of

intracranial infection and insertion of an external ventricular drain insertion were also independent predictors of developing PTH.

■ **CONCLUSIONS:** This study adds to the growing body of work regarding the immediate and long-term effects of the procedure. Although life-saving, PTH, needing shunt insertion, is one of the possible complications that surgeons and patients should be aware of.

## INTRODUCTION

Traumatic brain injury (TBI) is a pervasive phenomenon. It is the most common cause of death in patients under 40 years in England and Wales.<sup>1</sup> Head elevation, hyperventilation, seizure prophylaxis, hyperosmolar therapy, therapeutic cooling, surgical intervention for hematoma evacuation, and decompressive craniectomies (DCs) are modalities of management for TBI.<sup>2</sup> DCs are one of the strategies used when there is intractable intracranial hypertension, evidenced by uncontrollable intracranial pressure.<sup>3,4</sup> The procedure can be used in specific situations to prevent cerebral herniation and eventual death.<sup>5</sup>

Two recent multicenter randomized control trials, like the Trial of DC for traumatic intracranial hypertension (RescueICP trial), found that although DCs reduce the overall mortality, they

## Key words

- Brain trauma
- Decompressive craniectomy
- Post-traumatic hydrocephalus
- Severe traumatic brain injury
- Trauma
- Traumatic brain injury
- Ventriculoperitoneal shunt

## Abbreviations and Acronyms

- CSF:** Cerebrospinal fluid
- DC:** Decompressive craniectomies
- DECRA:** Decompressive Craniectomy trial
- EVD:** External ventricular drain insertion
- GCS:** Glasgow coma scale score
- GOS:** Glasgow outcome scale score
- ICU:** Intensive care unit
- PTH:** Post-traumatic hydrocephalus

**RESCUEicp trial:** Trial of decompressive craniectomy for traumatic intracranial hypertension

**TBI:** Traumatic brain injury

**VPS:** Ventriculoperitoneal shunt

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Citation: *World Neurosurg.* X (2023) 17:100138.

<https://doi.org/10.1016/j.wnsx.2022.100138>

Journal homepage: [www.journals.elsevier.com/world-neurosurgery-x](http://www.journals.elsevier.com/world-neurosurgery-x)

Available online: [www.sciencedirect.com](http://www.sciencedirect.com)

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resulted in higher rates of vegetative state, while the Decompressive Craniectomy trial (DECRA) reached a conclusion that DCs led to worse outcomes at 6 months despite reducing the length of stay in the intensive care unit and ventilatory support. These trials provide level-2 evidence regarding the utility of DC in TBI management. These are the main reasons the rate at which the procedure is done has reduced over time in many centers. Though potentially lifesaving, a DC procedure carries significant risk. Common complications attributable to DCs include postoperative hematomas, hemorrhagic progression of a contusion, infection, inflammation, and wound healing complications amongst others.<sup>6</sup>

Prior studies have shown that decompressive craniectomy may be an independent risk factor for the development of post-traumatic hydrocephalus (PTH).<sup>7-9</sup> A recent systematic review and meta-analysis by Mavorovounis et al. (2021)<sup>10</sup> found a clear relationship between DC and the occurrence of PTH. PTH typically presents with progressive dilatation of ventricles and accumulation of cerebrospinal fluid (CSF), in combination with clinical signs and symptoms.<sup>11</sup> This can cause a decline in the improvement and worsens the outcomes if not detected and managed early.<sup>12</sup> It is upon this background that we chose to conduct our single-center retrospective study to establish the possibility of an association between DC and PTH. We also aimed to identify the possible risk factors for the development of PTH in patients who had undergone DC procedures.

## METHODOLOGY

### Study Population

This study was carried out in a large tertiary neurosurgical center in England, which serves as the sole referral center for TBI management. A retrospective review involving a database of all patients with TBI admitted was undertaken. All referrals and admissions with severe TBI, as defined by the Mayo Classification,<sup>13</sup> from January 2012 to May 2022, were included in the subsequent analysis. Patients who died in the acute phase of trauma (1 week from injury) were excluded, in addition to those with incomplete data entries. Patients who had hydrocephalus before the severe TBI were excluded. The primary outcome of hydrocephalus was defined as the need for permanent CSF diversion (i.e., ventriculoperitoneal shunt).<sup>14</sup> This definition has been previously reported in literature. All patients were treated with the institutional protocol as guided by the Brain Trauma Foundation Guidelines.

### Data Collection

For each patient, data on the presence or absence of PTH was extracted. Information including age, sex, date of injury, types of injury sustained, the admitting Glasgow coma scale score, and the Glasgow outcome scale (GOS) score were extracted from the database. GOS was assessed at the discharge of the patient from the neurosurgical ward or death, whichever came first. Data on procedures such as DCs, craniotomies, external ventricular drain (EVD) insertion, and the presence/absence of intracranial infection were also recorded. As this was a retrospective analysis and patient information was anonymized, no specific patient consent was obtained for these purposes.

### Statistical Analysis

Statistical analysis was carried out using IBM SPSS version 28.0.1. In the first analysis, descriptive characteristics for the general cohort of patients with severe TBI were presented as mean and standard deviation for continuous variables and absolute count with frequencies for categorical variables. A univariate model involving fisher's exact test for dichotomous categorical variables and  $\chi^2$  for multinomial variables was used to test the different predictors against the outcome (shunt insertion). A multivariate analysis with logistic regression was then conducted with the predictors that had an association. Age was analyzed against shunt insertion using logistic regression in a univariate model, while other predictors like sex, mechanism of injury, the outcome at 30 days, Glasgow coma scale score at admission, the presence of intracranial infection, insertion of an EVD, and DC were tested against shunt insertion with the fisher's exact test/ $\chi^2$ . Associated predictors were then analyzed with logistic regression. The relationships were presented as odds ratios (OR) and a P-value of <0.05 was considered statistically significant with a 95% confidence interval (CI).

## RESULTS

Over 10 years, there were 806 patients who had severe TBI were admitted. 315 (39%) patients suffered mortality within the first week, and 33 (4%) patients had incomplete data, one patient had hydrocephalus with a shunt inserted prior to the severe TBI. A total of 457 patients met the eligibility criteria and were involved in this study. The mean age of the cohort was  $44.91 \pm 19.16$  with more males (82.3%) than females (17.7%). Vehicle incident/collision was the most common cause of TBI. 84% of the cohort was alive at 30 days, 4% were noted to have an intracranial infection, and 3% underwent shunt insertion procedures, while 14% received DCs as part of their clinical management. The most common outcome, with the GOS at discharge, was good recovery at 33%. The demographic characteristics are summarized in **Table 1**.

The reasons for shunting included improvement of symptoms, consciousness following insertion of an EVD (5), improvement in symptoms and/or consciousness level following large volume lumbar puncture (4), worsening clinical state despite endoscopic third ventriculostomy (1), progressive increase in ventricular size with decreased consciousness (1), improvement in symptoms following large subgaleal CSF collection drainage (1), and marked ventricular dilation and deterioration following the removal of EVD (1). The mean number of days from the exposure (decompressive craniectomy) to the outcome (shunt insertion) was 88 days, while the mean number of days from the initial traumatic insult to shunt insertion was 124 days. The earliest time a patient was shunted after the injury was 23 days, and the earliest onset of PTH after DC was 1 day. No patient was shunted within the first 7 days of admission.

Of those that had PTH, only 6 patients had a cranioplasty done. Of these 6, 5 of them had cranioplasties on or after the development of PTH, while only 1 case had cranioplasty before the insertion of a shunt. In total, 65 patients underwent DC over the study period, and 8 of them (12%), developed PTH. Of the predictors that were assessed independently, only decompressive craniectomy ( $P < 0.001$ ), Intracranial infection ( $P < 0.001$ ), and

**Table 1.** Baseline Demography/Surgical Data

Variable (N = 457)	Mean ( ± SD)/Absolute Count (%)
Age	44.91 ± 19.16
Sex	
Male	376 (82.3%)
Female	81 (17.7%)
Mechanism of Injury	
Fall more than 2m	75 (16.4%)
Blow(s) without weapon	65 (14.2%)
Fall less than 2m	135 (29.5%)
Vehicle incident/collision	166 (36.3%)
Stabbing	2 (0.004%)
Other	13 (2.8%)
Glasgow Outcome Scale	
Death	65 (14.2%)
Prolonged disorder of unconsciousness	7 (0.015%)
Severe disability	147 (32.1%)
Moderate disability	73 (16%)
Good recovery	151 (33%)
Not measured	1
Intracranial infection	19 (4%)
Shunt insertion	13 (2.8%)
Decompressive craniectomy	65 (14.2%)
Alive at 30 days	384 (84%)
Mean days from injury to shunt insertion	124.31 ± 163.7
Mean days from DC to shunt insertion	88 ± 54.67

SD, Standard Deviation; DC, Decompressive craniectomy.

EVD insertion ( $P < 0.001$ ) had statistically significant relationships with the development of PTH. These factors were then subjected to multivariable analyses. There was a statistically significant association between undergoing DC, and the development of PTH (OR, 4.759 [c, 1.290–17.559];  $P = 0.019$ ). The presence of intracranial infection and insertion of an EVD were also independent predictors of developing PTH. In this study, we also investigated for correlation between DC and EVD. We calculated the variance inflation factor, and our findings for both variables were 1.029. The correlation between EVD and DC was therefore minimal and did not affect our regression model. The results of the univariate and multivariate analysis are summarized in [Table 2](#).

## DISCUSSIONS

We aimed to examine the relationship between DC and PTH, and our study highlighted a significant association. The odds of

developing PTH requiring subsequent Ventriculoperitoneal (VP) shunt insertion in patients who had DCs as part of the management of severe TBI was approximately 4.8 compared to those who did not have DC (OR, 4.759 [95% CI, 1.290–17.559];  $P = 0.019$ ). This relationship between DC and PTH affirms the findings from previous studies, most notably<sup>10</sup> that assert a causal relationship between decompressive craniectomies and PTH. In practical terms, having undergone DC increases the occurrence of PTH, requiring subsequent VP shunt insertion for management. Our study noted that EVD insertion and the presence of intracranial infection were independent factors associated with PTH after severe TBI. The mean age of patients with severe TBI found in our study ( $44.91 \pm 19.16$ ) was similar to some other studies;  $45.5 \pm 21.3$ <sup>15</sup> and  $48.6 \pm 20.3$ .<sup>16</sup> Likewise, sex demographics were similar to that in the established literature.<sup>15–17</sup>

The incidence of PTH in our study was 3%. The incidence in literature, however, ranged between 0.7%<sup>17</sup> and 45% (although this was reduced to 11% when only severe hydrocephalus was considered).<sup>7,18</sup> Our investigation considered hydrocephalus in the context of patients that were felt to require a VP shunt insertion and hence may account for the lower incidence. Decompressive craniectomy has been associated with a higher chance of patients with TBI developing PTH,<sup>6,9,10</sup> and our findings corroborate this. Additional factors predisposing to PTH found in our study include intracranial infection and insertion of an EVD. These are unique findings and are the future of further work, as they were not noted in previous studies. Factors such as age and low presenting consciousness level,<sup>19</sup> were not found to be significant in our study. PTH has been associated with unfavorable neurological outcomes following TBI in more than 65% of patients in several series, resulting in longer hospital stays and a longer period of rehabilitation.<sup>20</sup> Several theories have been propounded on the possible causes of PTH following DCs, such as brain atrophy following diffuse axonal injury and disruption to CSF dynamics.<sup>21,22</sup>

The decompressive craniectomy-related factors that are tied to surgical decisions and timing, such as the distance of the medial edge of the craniectomy from the midline,<sup>23</sup> the size of the craniectomy,<sup>24</sup> and delayed cranioplasty<sup>25</sup> were not explored in this investigation. Future research is necessary to identify the extent to which these factors predispose patients who have had DC to PTH. Despite our comprehensive study, we had several limitations. Our data collection process involved going through individual patient records and documentation. Data used over a 10-year period may include variations in surgical approaches and practice. Similarly, management of severe TBI also changed over this period, evidenced by the decline in DC rates, due to research guiding critical care management of TBI. In our study design, we limited our definition of PTH to only patients who underwent permanent CSF diversion (shunt-placement), so this may potentially reduce the incidence of cases with PTH during data collection. The number of cases with PTH in our study is low, which is also a limitation towards drawing a generalizable conclusion. Although these limitations may impact the aspect of the study, our findings will contribute to the already existing body of work surrounding DCs and PTH.

**Table 2.** Univariate and Multivariate Analysis of the Different Predictors for Developing Shunt-Amenable Post-traumatic Hydrocephalus

Variable	P-Value	Variables Used in Multivariable Analysis	Multivariate Model OR (95% CI)	P-Value
Decompressive craniectomy	<b>&lt;0.001</b>	Decompressive craniectomy	<b>4.759 (1.290–17.559)</b>	<b>0.019</b>
Intracranial infection	<b>&lt;0.001</b>	Intracranial infection	<b>15.229 (3.700–62.688)</b>	<b>&lt;0.001</b>
EVD	<b>&lt;0.001</b>	EVD insertion	<b>9.249 (2.499–34.228)</b>	<b>&lt;0.001</b>
Age	0.308			
Sex	1.00			
Mechanism of injury	0.974			
Outcome at 30 days	0.408			
GCS score	0.848			

OR, Odds ratio; CI, Confidence interval; EVD, External ventricular drain.

The values in bold represent the statistically significant predictors used in the univariate and multivariate analysis.

## CONCLUSIONS

The use of decompressive craniectomy in the management of TBI has been extensively investigated in modern literature. This study adds to the growing body of work regarding the immediate and long-term effects of the procedure. Although lifesaving, PTH, needing shunt insertion, is one of the possible complications that the surgeons and patients should be aware of.

## CRedit AUTHORSHIP CONTRIBUTION STATEMENT

**Damilola Jesuyajolu:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Investigation, Data curation, Writing – original draft, Writing – review & editing, Project administration, Final approval. **Terngu Moti:** Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Final approval. **Zubair Abdulahi:** Investigation, Writing – original draft, Writing – review & editing, Final approval. **Adnan**

**Alnaser:** Investigation, Writing – review & editing, Final approval. **Ahmed Zanaty:** Investigation, Writing – review & editing, Final approval. **Tom Grundy:** Supervision, Conceptualization, Methodology, Writing – review & editing, Final approval. **Julian Evans:** Supervision, Conceptualization, Methodology, Writing – review & editing, Final approval.

## DECLARATION OF COMPETING INTEREST

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## ACKNOWLEDGMENTS

We would like to thank Mr. William Payne and Mr Simon Howard for assisting with material for this project.

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Received 30 June 2022; accepted 2 September 2022

Citation: *World Neurosurg*. X (2023) 17:100138.

<https://doi.org/10.1016/j.wnsx.2022.100138>

Journal homepage: [www.journals.elsevier.com/world-neurosurgery-x](http://www.journals.elsevier.com/world-neurosurgery-x)

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