Factors associated with shunt-dependent hydrocephalus after decompressive craniectomy for traumatic brain injury

Aditya Vedantam, MD,¹ Jose-Miguel Yamal, PhD,² Hyunsoo Hwang, MS,²
Claudia S. Robertson, MD,¹ and Shankar P. Gopinath, MD¹

¹Department of Neurosurgery, Baylor College of Medicine; and ²Department of Biostatistics, University of Texas School of Public Health, Houston, Texas

OBJECTIVE Posttraumatic hydrocephalus (PTH) affects 11.9%–36% of patients undergoing decompressive craniectomy (DC) and is an important cause of morbidity after traumatic brain injury (TBI). Early diagnosis and treatment of PTH can prevent further neurological compromise in patients who are recovering from TBI. There is limited data on predictors of shunting for PTH after DC for TBI.

METHODS Prospectively collected data from the erythropoietin severe TBI randomized controlled trial were studied. Demographic, clinical, and imaging data were analyzed for enrolled patients who underwent a DC. All head CT scans during admission were reviewed and assessed for PTH by the Gudeman criteria or the modified Frontal Horn Index $\geq 33\%$. The presence of subdural hygromas was categorized as unilateral/bilateral hemispheric or interhemispheric. Using L1-regularized logistic regression to select variables, a multiple logistic regression model was created with ventriculoperitoneal shunting as the binary outcome. Statistical significance was set at $p < 0.05$.

RESULTS A total of 60 patients who underwent DC were studied. Fifteen patients (25%) underwent placement of a ventriculoperitoneal shunt for PTH. The majority of patients underwent unilateral decompressive hemicraniectomy ($n = 46$, 77%). Seven patients (12%) underwent bifrontal DC. Unilateral and bilateral hemispheric hygromas were noted in 31 (52%) and 7 (11%) patients, respectively. Interhemispheric hygromas were observed in 19 patients (32%). The mean duration from injury to first CT scan showing hemispheric subdural hygroma and interhemispheric hygroma was 7.9 ± 6.5 days and 14.9 ± 11.7 days, respectively. The median duration from injury to shunt placement was 43.7 days. Multivariate analysis showed that the presence of interhemispheric hygroma (OR 63.6, $p = 0.001$) and younger age (OR 0.78, $p = 0.009$) were significantly associated with the need for a shunt after DC.

CONCLUSIONS The presence of interhemispheric subdural hygromas and younger age were associated with shunt-dependent hydrocephalus after DC in patients with severe TBI.

<https://thejns.org/doi/abs/10.3171/2017.1.JNS162721>

KEY WORDS posttraumatic hydrocephalus; shunt-dependent hydrocephalus; decompressive craniectomy; severe traumatic brain injury

POSTTRAUMATIC hydrocephalus (PTH) affects 11.9%–36% of patients undergoing decompressive craniectomy (DC) after traumatic brain injury (TBI).^{2,4,7,14} Hydrocephalus often develops more than a month after a patient undergoes DC²¹ and can be associated with poorer outcomes.¹⁷ Early diagnosis and treatment of PTH can prevent further neurological compromise in patients who are recovering from TBI.

The diagnosis of hydrocephalus in patients with large craniectomy defects remains a challenge. Ventriculomegaly after DC is not always indicative of hydrocephalus requiring treatment.¹⁷ The presence of subdural CSF collections, although suggestive of abnormal CSF circulation, may not be associated with clinical symptoms of hydrocephalus.^{1,24} It is therefore unclear if certain imaging features are more closely associated with the need for a ventriculoperitoneal

ABBREVIATIONS DC = decompressive craniectomy; GCS = Glasgow Coma Scale; IVH = intraventricular hemorrhage; PTH = posttraumatic hydrocephalus; SAH = subarachnoid hemorrhage; TBI = traumatic brain injury; VPS = ventriculoperitoneal shunt.

SUBMITTED October 29, 2016. **ACCEPTED** January 5, 2017.

INCLUDE WHEN CITING Published online June 16, 2017; DOI: 10.3171/2017.1.JNS162721.

shunt (VPS) in PTH. The aim of this study was to identify factors associated with shunt-dependent hydrocephalus in patients undergoing DC for TBI.

Methods

Study Sample

We analyzed prospectively collected data from a randomized controlled trial studying the effects of erythropoietin and blood transfusions on recovery after severe TBI (Epo Severe TBI trial; clinicaltrials.gov no. NCT00313716). For the present study, we selected enrolled patients who had undergone a DC after admission. Details of the study design and results of the randomized trial have been published previously.²⁰ The study was approved by the IRB at each participating institution. For the randomized controlled trial, a legally authorized representative provided written informed consent during the first year of the study, and after this the study was approved for and conducted under the conditions of the Exception From Informed Consent for Emergency Research. Patients with a closed head injury and unable to follow commands after resuscitation were enrolled within 6 hours of injury at a Level I trauma center. Patients with a Glasgow Coma Scale (GCS) score of 3 with fixed and dilated pupils, penetrating trauma, life-threatening systemic injuries, pregnancy, and severe preexisting disease were excluded. All patients were managed in an intensive care unit according to the Guidelines for the Management of Severe Head Injury (see Supplement 1 from Robertson et al.²⁰). The study was conducted from May 2006 to August 2012.

Surgery Characteristics

Decompressive surgery was performed at admission or at a delayed time point due to the presence of midline shift, contusions, cerebral edema, or intractable intracranial pressure. Unilateral decompressive hemicraniectomies of at least 15 cm in diameter were performed with the medial limit at least 2.5 cm lateral to the midline. Bifrontal DCs were performed with the posterior limit at the coronal suture. All cases underwent expansive duraplasty with an allograft. VPS placement was performed for a combination of clinical signs and radiographic features. For some patients, no definite change in clinical examination was noted, but considerable enlargement of ventricles was noted on serial head CT scans.

Data Collection

Demographic, clinical, and imaging data at admission, during the hospital stay, and at follow-up were used for this study. All CT scans after the DC were reviewed and assessed for PTH using the criteria described by Gude-man et al.⁵ (lateral and third ventricular enlargement, periventricular lucencies) or the modified Frontal Horn Index $\geq 33\%$ (Fig. 1).⁹ The presence of subdural hygromas was recorded according to location: ipsilateral, contralateral, bilateral, and interhemispheric (Fig. 2). In patients with bifrontal or bilateral fronto-temporo-parietal craniectomies, the hygroma was categorized by the side of the larger craniectomy defect.

FIG. 1. Measurement of the modified Frontal Horn Index ($= a/b$) on post-operative axial head CT scan after left fronto-temporo-parietal DC.

Statistical Analysis

Statistical analysis was performed using the R program (version 2.13.1, R Foundation for Statistical Computing). Univariate analysis was performed by comparing patients who underwent VPS placement and patients who did not require a VPS. Continuous variables were analyzed using a Welch 2-sample t-test and categorical variables were analyzed using the Fisher exact test. Using L1-regularized logistic regression to select variables, a multiple logistic regression model was created with ventriculoperitoneal shunting as the binary outcome. Statistical significance was set at $p < 0.05$.

Results

A total of 60 patients who underwent DC were studied. Fifteen patients (25%) underwent placement of a VPS for PTH. A fixed medium-pressure shunt valve was inserted in 8 patients (53.3%), and a programmable valve was inserted in 4 patients (26.7%). Details of the shunt valve were not available for 3 patients. Five patients required subsequent shunt revisions.

Baseline demographic, clinical, and imaging data are shown in Table 1. The majority of patients were male (86.7%), and patients undergoing a VPS placement after DC were significantly younger than those who did not undergo VPS insertion ($p < 0.001$). The majority of patients underwent DC within 24 hours of the injury (88.3%). Decompressive surgery was performed at a median of 2 hours after injury (range 1–222 hours). Data on indications for shunting were available for 12 of 15 patients who underwent shunt placement. In 6 patients, only radiological features of increased ventricle size were noted prior

FIG. 2. Serial axial head CT scans showing progressive development of right hemispheric and interhemispheric subdural hygromas after right fronto-temporo-parietal DC for TBI. This patient underwent VPS placement for PTH. The duration from injury to CT scanning was Day 7 (A), Day 11 (B), and Day 38 (C).

to shunt insertion. In 6 patients, a combination of clinical signs and increased ventricle size was observed. Clinical signs included increasing size of pseudomeningocele on the side of the craniectomy flap ($n = 3$) and worsened neurological examination ($n = 3$). There was no significant association between the transfusion thresholds ($p = 0.14$) or erythropoietin administration ($p = 0.23$) and the need for shunting. Outcome data for this cohort are presented in Table 2. There were 14 deaths in the cohort at a median duration of 15 days (range 3.4–180 days).

CT showed evidence of PTH in 43.3% of patients. The median size of interhemispheric hygromas was 6.93 mm (range 2.96–10.76 mm, $n = 18$). There was no significant difference in median size of interhemispheric hygromas between patients who underwent VP shunt insertion and those who did not (6.91 vs 6.93 mm, $p = 0.96$, Mann-Whitney U-test). The mean duration from injury to first CT scan showing a modified Frontal Horn Index $\geq 33.3\%$ was 16.4 ± 15.6 days. The mean times from injury to first CT scan showing hemispheric subdural hygroma and interhemispheric hygroma were 7.9 ± 6.5 days and 14.9 ± 11.7 days, respectively. The median duration from injury to shunt placement was 43.7 days (range 23.5–199 days). For patients who underwent a VPS insertion, cranioplasty was performed during the same admission in 10 patients at a median duration of 33.5 days (range 21.7–55.2 days). Cranioplasty was performed before insertion of a VPS in 8 patients (median duration 10 days, range 3–26.4 days) and simultaneously with shunt placement in 2 patients.

Multivariate analysis showed that the presence of interhemispheric hygroma ($p = 0.001$) and younger age ($p = 0.009$) were significantly associated with the need for a VPS after DC (Table 3).

Discussion

The present study found PTH in 43.3% of patients after DC for TBI and 25% of all patients required a VPS. Younger patients and patients with an interhemispheric hygroma on postoperative CT were more likely to undergo VPS placement after DC.

Subdural hygromas on CT imaging after DC have been reported in 16%–50% of patients.^{1,6,8,10,24} These hygromas have been thought to reflect impaired CSF circulation, although many hemispheric subdural hygromas show resolution on serial imaging.¹ In this study, only 37.8% of patients with hemispheric subdural hygromas required a VPS. Conversely, more than 50% of patients with an interhemispheric hygroma underwent placement of a VPS. CT first showed hemispheric subdural hygromas at an average of 7 days prior to interhemispheric subdural hygromas. It is possible that a greater derangement in CSF dynamics is needed to create an interhemispheric hygroma as compared to a hemispheric subdural hygroma. Kaen et al.¹² proposed that large interhemispheric hygromas represent the subacute hydrodynamic phase of cerebral swelling after DC, which may explain the delayed presentation of these CSF collections. The appearance of interhemispheric hygromas in the 2nd or 3rd week after a DC is a potential predictor for the development of symptomatic hydrocephalus.

A number of factors have been shown to be associated with PTH including low initial GCS score,⁷ traumatic subarachnoid hemorrhage (SAH), and intraventricular hemorrhage (IVH).²² Some authors have shown that traumatic SAH and IVH are not associated with PTH,^{12,18} and we did not find these factors to be predictive of the need for

TABLE 1. Demographic, clinical, and imaging data for 60 patients undergoing DC after severe TBI

Variable	Total	VPS Placement After DC		p Value
		Yes	No	
No. of patients	60	15	45	
Mean age in yrs (SD)	34.08 (11.76)	26.6 (7.1)	36.58 (12)	<0.001
Sex (%)				0.40
Male	52 (87)	12 (80)	40 (89)	
Female	8 (13)	3 (20)	5 (11)	
Mean GCS score* (SD)	6.2 (3.08)	5.4 (2.5)	6.5 (3.23)	0.18
SAH (%)				0.04
Yes	51 (85)	10 (67)	41 (91)	
No	9 (15)	5 (33)	4 (9)	
IVH (%)				>0.99
Yes	3 (5)	1 (7)	2 (4)	
No	57 (95)	14 (93)	43 (96)	
SDH (%)				>0.99
Yes	42 (70)	11 (73)	31 (69)	
No	18 (30)	4 (27)	14 (31)	
Cisterns (%)				0.18
Absent	11 (18)	2 (13)	9 (20)	
Compressed	36 (60)	12 (80)	24 (53)	
Present	13 (22)	1 (7)	12 (27)	
Midline shift (%)				0.35
None	13 (22)	4 (27)	9 (20)	
<5 mm	13 (22)	1 (7)	12 (27)	
5–15 mm	25 (42)	8 (53)	17 (38)	
>15 mm	9 (15)	2 (13)	7 (16)	
Decompressive surgery (%)				0.35
Bilateral FTP	7 (12)	3 (20)	4 (9)	
Unilateral FTP	46 (77)	12 (80)	34 (76)	
Bifrontal	7 (12)	0 (0)	7 (16)	
Type of decompressive surgery (%)				0.67
Primary (<24 hrs)	53 (88)	14 (93)	39 (87)	
Secondary (>24 hrs)	7 (12)	1 (7)	6 (13)	
Postop meningitis (%)				0.09
Yes	5 (8)	3 (20)	2 (4)	
No	55 (92)	12 (80)	43 (96)	
Postop imaging (%)				0.06†
Subdural hygroma				
Bilateral	7 (12)	4 (27)	3 (7)	
Unilateral	31 (52)	11 (73)	20 (44)	
Ipsilateral	26 (84)	8 (73)	18 (90)	
Contralateral	5 (16)	3 (27)	2 (10)	
None	22 (37)	0 (0)	22 (49)	
Interhemispheric hygroma (%)				<0.001
Yes	19 (32)	11 (73)	8 (18)	
No	41 (68)	4 (27)	37 (82)	
Modified Frontal Horn Index $\geq$ 33% (%)				0.07
Yes	26 (43)	10 (67)	16 (36)	
No	34 (57)	5 (33)	29 (64)	

FTP = fronto-temporo-parietal craniectomy; SDH = subdural hematoma.

Values are presented as the number of patients (%) unless otherwise indicated.

* At admission to the emergency room.

† Comparison between bilateral and unilateral subdural hygroma.

TABLE 2. Outcome data for patients undergoing DC after severe TBI categorized by shunt status

Outcome	Total (%)	VPS Placement After DC (%)		p Value
		Yes	No	
3-mo GOS score (n = 57)				
Favorable	4 (7.0)	0 (0)	4 (9.5)	0.56
Unfavorable	53 (92.9)	15 (100)	38 (90.5)	
6-mo GOS score (n = 55)				
Favorable	9 (16.4)	1 (7.1)	8 (19.5)	0.42
Unfavorable	46 (83.6)	13 (92.9)	33 (80.5)	
Death (n = 60)				
Yes	14 (23.3)	1 (6.7)	13 (28.9)	0.16
No	46 (76.7)	14 (93.3)	32 (71.1)	

GOS = Glasgow Outcome Scale.

a VPS. Many prior studies have investigated predictors of PTH, but have not specifically investigated predictors of shunt-dependent hydrocephalus as was done in this study.^{3,12,14,16,18,22} In the present study, younger patients were more likely to develop hydrocephalus requiring a VPS after DC. Low et al.¹⁶ found that younger age was associated with PTH, while others have shown a link between older age and PTH.^{11,22} Kan et al.¹³ found a high incidence (40%) of PTH requiring a VPS in children undergoing DC. High-energy mechanisms of injury, higher compliance of brain tissue,¹⁵ and lack of cerebral atrophy could contribute to an increased risk of symptomatic hydrocephalus in younger patients after DC.

The etiology of hydrocephalus after DC has been evaluated in prior studies. Disruption of CSF drainage due to arachnoid adhesions in the basal cisterns, loss of pulsatile intracranial CSF dynamics,²³ and impaired venous drainage into the sagittal sinus³ have been proposed as causative factors. De Bonis et al.³ reported a higher risk of hydrocephalus if the superior limit of craniectomy was < 2.5 cm from the midline. Although we did not have 3D reconstructed CT images to evaluate this finding, we did note that no patient with a bifrontal craniectomy required a VPS. In bifrontal craniectomies, we do not extend the bone flap posterior to the coronal suture, which limits exposure of arachnoid granulations and parasagittal draining veins to atmospheric pressure. Additionally, only 1 of 6 patients with a bifrontal craniectomy demonstrated a subdural hygroma on CT. These findings are further supported by the findings of Polin et al.,¹⁹ who performed bifrontal craniectomies extending 3–5 cm posterior to the coronal suture and showed a 28.6% risk of shunt-dependent hydrocephalus.

The present study was limited by small sample size and retrospective analysis. Although we found no significant difference in 6-month Glasgow Outcome Scale scores between the 2 groups, long-term follow-up is needed to establish the morbidity associated with VPS. Two patients in this series required shunt revisions for overshunting, and we note that pressure gradients do change over time for some of these patients. The use of programmable shunts in this patient population may improve our management of

TABLE 3. Multiple logistic regression model after variable selection

Variable	OR	95% CI	p Value
Age	0.78	0.66–0.94	0.009*
Interhemispheric hygroma	63.6	4.97–816.44	0.001*
Meningitis	9.92	0.48–203.07	0.14
SAH	0.89	0.07–11.4	0.93

* p < 0.05.

PTH, although this needs to be evaluated in future studies. Despite these limitations, we studied prospectively collected data in a homogenous data set and add to the limited literature available on shunting for PTH after DC for trauma.

Conclusions

The presence of interhemispheric subdural hygromas and younger age were associated with shunt-dependent hydrocephalus after DC in patients with severe TBI.

Acknowledgments

This study was supported by grant no. P01-NS38660 from the National Institute of Neurological Disorders and Stroke.

References

1. Aarabi B, Chesler D, Maulucci C, Blacklock T, Alexander M: Dynamics of subdural hygroma following decompressive craniectomy: a comparative study. **Neurosurg Focus** 26(6):E8, 2009
2. Choi I, Park HK, Chang JC, Cho SJ, Choi SK, Byun BJ: Clinical factors for the development of posttraumatic hydrocephalus after decompressive craniectomy. **J Korean Neurosurg Soc** 43:227–231, 2008
3. De Bonis P, Pompucci A, Mangiola A, Rigante L, Anile C: Post-traumatic hydrocephalus after decompressive craniectomy: an underestimated risk factor. **J Neurotrauma** 27:1965–1970, 2010
4. De Bonis P, Sturiale CL, Anile C, Gaudino S, Mangiola A, Martucci M, et al: Decompressive craniectomy, interhemispheric hygroma and hydrocephalus: a timeline of events? **Clin Neurol Neurosurg** 115:1308–1312, 2013
5. Gudeman SK, Kishore PR, Becker DP, Lipper MH, Girevenkulis AK, Jeffries BF, et al: Computed tomography in the evaluation of incidence and significance of post-traumatic hydrocephalus. **Radiology** 141:397–402, 1981
6. Guerra WK, Gaab MR, Dietz H, Mueller JU, Piek J, Fritsch MJ: Surgical decompression for traumatic brain swelling: indications and results. **J Neurosurg** 90:187–196, 1999
7. Honeybul S, Ho KM: Incidence and risk factors for post-traumatic hydrocephalus following decompressive craniectomy for intractable intracranial hypertension and evacuation of mass lesions. **J Neurotrauma** 29:1872–1878, 2012
8. Huang AP, Tu YK, Tsai YH, Chen YS, Hong WC, Yang CC, et al: Decompressive craniectomy as the primary surgical intervention for hemorrhagic contusion. **J Neurotrauma** 25:1347–1354, 2008
9. Huh PW, Yoo DS, Cho KS, Park CK, Kang SG, Park YS, et al: Diagnostic method for differentiating external hydrocephalus from simple subdural hygroma. **J Neurosurg** 105:65–70, 2006
10. Jiang JY, Xu W, Li WP, Xu WH, Zhang J, Bao YH, et al:

- Efficacy of standard trauma craniectomy for refractory intracranial hypertension with severe traumatic brain injury: a multicenter, prospective, randomized controlled study. **J Neurotrauma** 22:623–628, 2005
11. Jiao QF, Liu Z, Li S, Zhou LX, Li SZ, Tian W, et al: Influencing factors for posttraumatic hydrocephalus in patients suffering from severe traumatic brain injuries. **Chin J Traumatol** 10:159–162, 2007
12. Kaen A, Jimenez-Roldan L, Alday R, Gomez PA, Lagares A, Alén JF, et al: Interhemispheric hygroma after decompressive craniectomy: does it predict posttraumatic hydrocephalus? **J Neurosurg** 113:1287–1293, 2010
13. Kan P, Amini A, Hansen K, White GL Jr, Brockmeyer DL, Walker ML, et al: Outcomes after decompressive craniectomy for severe traumatic brain injury in children. **J Neurosurg** 105 (5 Suppl):337–342, 2006
14. Ki HJ, Lee HJ, Lee HJ, Yi JS, Yang JH, Lee IW: The risk factors for hydrocephalus and subdural hygroma after decompressive craniectomy in head injured patients. **J Korean Neurosurg Soc** 58:254–261, 2015
15. Kiening KL, Schoening W, Unterberg AW, Stover JF, Citerio G, Enblad P, et al: Assessment of the relationship between age and continuous intracranial compliance. **Acta Neurochir Suppl** 95:293–297, 2005
16. Low CY, Low YY, Lee KK, Chan SP, Ang BT: Post-traumatic hydrocephalus after ventricular shunt placement in a Singaporean neurosurgical unit. **J Clin Neurosci** 20:867–872, 2013
17. Marmarou A, Foda MA, Bandoh K, Yoshihara M, Yamamoto T, Tsuji O, et al: Posttraumatic ventriculomegaly: hydrocephalus or atrophy? A new approach for diagnosis using CSF dynamics. **J Neurosurg** 85:1026–1035, 1996
18. Poca MA, Sahuquillo J, Mataró M, Benejam B, Arikán F, Báguena M: Ventricular enlargement after moderate or severe head injury: a frequent and neglected problem. **J Neurotrauma** 22:1303–1310, 2005
19. Polin RS, Shaffrey ME, Bogaev CA, Tisdale N, Germanson T, Bocchicchio B, et al: Decompressive bifrontal craniectomy in the treatment of severe refractory posttraumatic cerebral edema. **Neurosurgery** 41:84–94, 1997
20. Robertson CS, Hannay HJ, Yamal JM, Gopinath S, Goodman JC, Tilley BC, et al: Effect of erythropoietin and transfusion threshold on neurological recovery after traumatic brain injury: a randomized clinical trial. **JAMA** 312:36–47, 2014
21. Stiver SI: Complications of decompressive craniectomy for traumatic brain injury. **Neurosurg Focus** 26(6):E7, 2009
22. Tian HL, Xu T, Hu J, Cui YH, Chen H, Zhou LF: Risk factors related to hydrocephalus after traumatic subarachnoid hemorrhage. **Surg Neurol** 69:241–246, 2008
23. Waziri A, Fusco D, Mayer SA, McKhann GM II, Connolly ES Jr: Postoperative hydrocephalus in patients undergoing decompressive hemicraniectomy for ischemic or hemorrhagic stroke. **Neurosurgery** 61:489–494, 2007
24. Yang XF, Wen L, Shen F, Li G, Lou R, Liu WG, et al: Surgical complications secondary to decompressive craniectomy in patients with a head injury: a series of 108 consecutive cases. **Acta Neurochir (Wien)** 150:1241–1248, 2008

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Gopinath, Vedantam, Robertson. Acquisition of data: Vedantam, Robertson. Analysis and interpretation of data: all authors. Drafting the article: Vedantam, Robertson. Critically revising the article: Gopinath, Vedantam, Yamal, Robertson. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Gopinath. Statistical analysis: Vedantam, Yamal, Hwang. Administrative/technical/material support: Gopinath, Robertson. Study supervision: Gopinath, Robertson.

Supplemental Information

Previous Presentations

Portions of this work were presented as an abstract at the 2017 AANS Annual Meeting in Los Angeles, California, April 22–26.

Correspondence

Shankar P. Gopinath, Department of Neurosurgery, Baylor College of Medicine, 7200 Cambridge, Ste. 9A, MS: BCM650, Houston, TX 77030. email: shankarg@bcm.tmc.edu.