REVIEW

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Development of Posttraumatic Hydrocephalus Requiring Ventriculoperitoneal Shunt After Decompressive Craniectomy for Traumatic Brain Injury: a Systematic Review and Meta-analysis of Retrospective Studies

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ABSTRACT

Background: Decompressive craniotomy (DC) is a known risk factor for the development of posttraumatic hydrocephalus (PTH) in the patients with traumatic brain injury (TBI). Herein, the present study reported the development of PTH requiring ventriculoperitoneal (VP) shunt after DC for TBI. **Methods**: Four databases (PubMed, Web of Science, Scopus, and Cochrane Library) were searched from 1983 to April 2018. The studies evaluating the prevalence of PTH requiring VP shunt after DC in the patients with TBIwere selected without language restriction. A random-effects meta-analysis using event rate (ER) and 95% confidence intervals(CIs), was runby RevMan5.3 software. **Results**: Out of 355 studies obtained from the databases, 25 studies were included and analyzed in the meta-analysis. The studies included 2402 patients undergoing DC for TBI, 354 of whohad PTH. The pooled ER of hydrocephalus in the patients undergoing DC for TBI was 17.7% [95%CI: 13.2 to 23.4%; P<0.001]. In addition, the pooled analysis showed that ER of hydrocephalus was 13% in adults [95%CI: 9 to 18.5%; P<0.001] and 37.6% in children [95%CI: 27.79 to 48.7%; P=0.029; I^2=0%]. **Conclusion**: The present study demonstrated that DC after TBI was associated with the development of PTH, especially in children compared to adults.

Keywords: **Traumatic brain injury, decompressive craniotomy, hydrocephalus, ventriculoperitoneal shunt.**

1. INTRODUCTION

Traumatic brain injury (TBI) is a leading cause of death and disability worldwide. More than 90% of the burden is shared bylow - and middle-income countries (1). Decompressive craniotomy (DC) is a surgical method performed to immediately reduce intracranial pressure (ICP) (2). DC is a known risk factor for the development of posttraumatic hydrocephalus(PTH) in the patients with TBI (3).PTH affects 11.9% - 36% of patients undergoing DC (4), is an important cause of morbidity after TBIand affects the patients' long-term outcomes (5). PTH has been recognized since Dandy's report in 1914 (6). The cause of hydrocephalus development after DC is considered to be multi-factorial, and risk factors associated with PTH still remain un-clear (7). The treatment of PTH in patients who undergo DC is a difficult problem to solve. Shunt operation with or without cranioplasty may be done simultaneously aiming to correct the underlying problems. Therefore, it is important to prevent the PTH for the good outcomes of the patients with DC (8). The purpose of this study was to evaluate the development of PTH requiring ventriculoperitoneal (VP) shunt after DC for TBI.

2. MATERIALS AND METHODS

Search strategies

Four databases (PubMed, Web of Science, Scopus, and Cochrane Library) were searched using key terms "hydrocephalus" and "decompressive craniectomy"and ("head trauma"or"traumatic head"or"head inju-

The first author, publication year	Country	Study Design	No. of patients undergoing DC	No. of patients with Posttraumatic Hydrocephalus	Mean initial (preoperative or admission) Glasgow Coma score	Mean age/range of patients undergoing DC, year	%male in patients undergoing DC
Yang, 2003 (18)]	China	Retrospective	68	20	-	-	-
Aarabi, 2006 (10)	USA	Retrospective cohort	50	5	3-15	25.3/>18	66
Kan, 2006 (11)	USA	Retrospective cohort	51	20	4.6	6.6/<18	64.7
Jagannathan, 2007 (12)	USA	Retrospective	17	5	4.6	11.9/2-19	65
Choi, 2008 (8)	Korea	Retrospective	55	13	9.2	49/>30	-
Morgalla, 2008 (21)	Germany	Retrospective	33	4	≤8	36.3/13-60	60.6
Yang, 2008 (19)	China	Retrospective	108	10	Range: 3 to >9	44.3/<18 to >60	68.5
Aarabi, 2009 (13)	USA	Retrospective cohort	54	7	6.6	Median: 32 /16-68	83.3
Ban, 2010 (16)	Korea	Retrospective	89	10	7.2	51.4/4-82	88.8
Honeybul, 2010 (23)	Australia	Retrospective cohort	41	4	≤8	32.1/-	83
Honeybul, 2011 (24)	Australia	Retrospective	164	23	-	-	-
Malmivaara, 2011 (25)	Finland	Retrospective cohort	54	6	≤8:83% > 8:17%	37 years/13-65	81.5
Su, 2011(26)	Taiwan	Retrospective	149	35	≤8	-	-
De Bonis, 2013 (3)	Italy	Retrospective cohort	64	19	7.3	37.9/16-80	79.7
Saade, 2014 (27)	Brazil	Retrospective	56	6	4/5 critical:51.7%& >5: 27: 48.3%	-/18-65	83.9
Sedney, 2014 (14)	USA	Retrospective	20	2	3.8	37.8/≥ 18	90
Zeiler, 2014 (28)	Canada	Retrospective	20	4	6.5	44.1/19-72	75
Grille, 2015 (29)	Uruguay	Retrospective	64	4	7	31/-	79
Ki, 2015(17)	Korea	Retrospective	92	24	Range: 3 to >8	52.8/-	74
Pechmann, 2015 (20)	Germany	Retrospective cohort	12	5	4.5	8.5/2-14	67
Sinha, 2015 (30)	India	Retrospective cohort	944	69	≤8	Median:32/-	82.7
Yuan, 2015 (20)	China	Retrospective cohort	62	16	-	50/>18	-
Kinoshita, 2016 (31)	Japan	Retrospective cohort	39	6	7	-/≥60	71.8
Jehan, 2017 (15)	USA	Retrospective cohort	33	3	Median: 9	48.8/>18	69.7
Kim, 2017 (5)	Korea	Retrospective	63	34	-	53.7/7-85	77.8

Table 1: The characteristics of studies included in meta-analysis (n=25). Abbreviation: DC; decompressive craniectomy

ry"or"brain injury"or"brain trauma"or"traumatic brain"). The databases were searched from 1983 to April 2018.

Study selection and selection criteria

The studies on the prevalence of PTH requiring VP shunt after DC in patients with TBI were selected without language restriction. The studies were selected for analysis if they a) were retrospective studies; b) included patients with TBI for any reason; c) showed the prevalence of PTH after DC alone; d) included patients with any age; e) diagnosed hydrocephalus by computed tomography scan, and f) included patients with any Glasgow Coma Score (GCS).

Data extraction

One author (M.S) checked all studies and selected the eligible ones. Then, the author extracted the relevant data, including the first author, publication year, country, number of patients undergoing DC, number of patients with hydrocephalus, GCS of patients, age/range of pa-

tients, and percentage of males in patients undergoing DC. Another author (R.F) re-checked the data and disagreements were resolved via conversation by both. The definition of hydrocephalus was based on the study of Honeybul and Ho (9).

Statistical analyses

A random-effects meta-analysis using event rate (ER) and 95% confidence intervals (CIs) was done by Review Manager 5.3 (RevMan 5.3, The Cochrane Collaboration, Oxford, United Kingdom).I^2 statistic was used to determine heterogeneity between the studies, and it was considered heterogeneous if P<0.1, and P-value (2-sided) less than 0.05 was considered statistically significant in other analyses. The publication bias was assessed through funnel plot analysis using Begg's and Egger's tests.
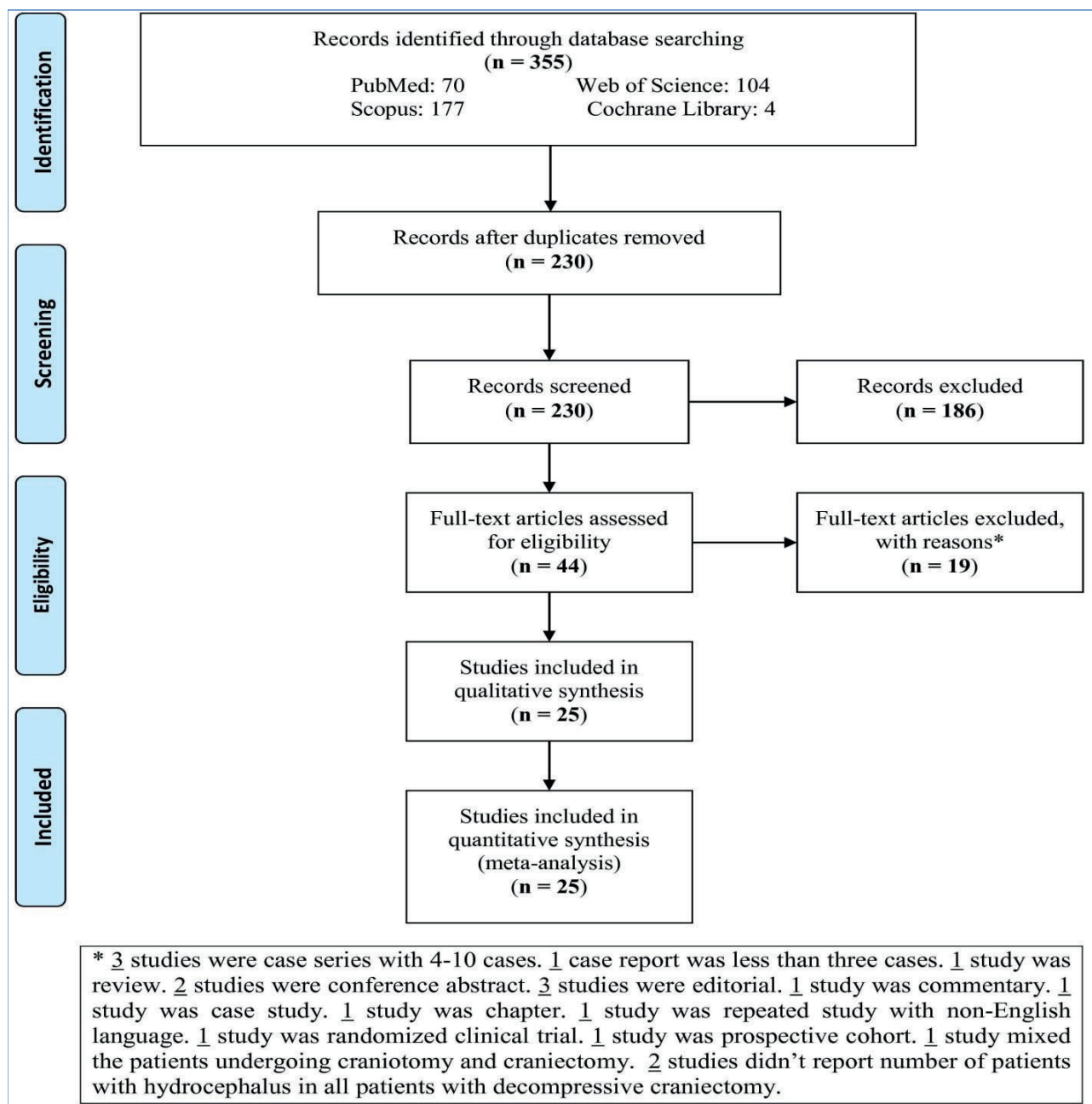
Identification

Records identified through database searching
(n = 355)
PubMed: 70   Web of Science: 104
Scopus: 177   Cochrane Library: 4

Screening

Records after duplicates removed
(n = 230)

Records screened
(n = 230)

Records excluded
(n = 186)

Eligibility

Full-text articles assessed
for eligibility
(n = 44)

Full-text articles excluded,
with reasons*
(n = 19)

Included

Studies included in
qualitative synthesis
(n = 25)

Studies included in
quantitative synthesis
(meta-analysis)
(n = 25)

* 3 studies were case series with 4-10 cases. 1 case report was less than three cases. 1 study was review. 2 studies were conference abstract. 3 studies were editorial. 1 study was commentary. 1 study was case study. 1 study was chapter. 1 study was repeated study with non-English language. 1 study was randomized clinical trial. 1 study was prospective cohort. 1 study mixed the patients undergoing craniotomy and craniectomy. 2 studies didn't report number of patients with hydrocephalus in all patients with decompressive craniectomy.

Figure 1. The flowchart of the study

3. RESULTS

Out of 355 studies retrieved from the databases, after removing the duplicate studies and excluding the irrelevant ones, the full-texts of 44 studies were assessed for eligibility. Nineteen studies were excluded with reasons (Figure 1). At last, 25 studies were included and analyzed in the meta-analysis.

The characteristics of 25 studies included in meta-analysis are shown in Table 1. Six studies (10-15)were reported from the USA, four studies (5,8,16,17) from Korea, three studies (18-20) from China, two studies (21, 22) from Germany, two studies (23, 24) from Australia, and one study from Italy (3), Finland (25), Taiwan (26), Brazil (27), Canada (28), Uruguay (29), India (30), and Japan (31). The studies included 2402 patients undergoing DC for TBI, 354 of who had PTH. Preoperative or admission GCS, mean age/range, and percentage of males in the patients undergoing DC are shown in Table 1. In all studies, the percentage of males was higher than females.

Event rate of hydrocephalus (without age restriction)

The pooled ER of PTH in the patients undergoing DC for TBI was 17.7% [95%CI: 13.2 to 23.4%; P<0.001] and I^2=86.6% (Figure 2).

Event rate of hydrocephalus (adult vs. children)

The pooled analysis showed that ER of PTH was 13% in adults [95%CI: 9 to 18.5%; P<0.001; I^2=74.7%] and 37.6% in children [95%CI: 27.79 to 48.7%; P=0.029; I^2=0%] (Figure 3). Therefore, ER of PTH in children undergoing Dc for TB was around three times more than adults.

Publication bias

Egger's and Begg's tests did not show any publication bias in each analysis (Figure 4).

4. DISCUSSION

TBI is one of the most common causes of death among young people in the industrialized countries (32). This meta-analysis showed that the ER of PTH in patients with TBI and undergoing DC was significantly high (17.7%). In addition, the ER of PTH was higher in children than adults (37.6% vs. 13%).

Among the studies included in meta-analysis, Grille et al. (29) reported the lowest rate (6.3%) and Kim et al. (5) reported the highest rate (54%). The low rate of hydrocephalus in Grille's study (29) was perhaps due to under diagnosis or utilization of different diagnostic criteria according to international references, confirmed by the study of Honeybul and Ho (24). But in the study of Kim et al.,(5) among the coexisting hemorrhages at the first admission, the maximal thickness of traumatic subdural hemorrhage and the extent of midline shift were significantly larger in the group with PTH compared to the group without PTH, and another study confirmed the extent of midline shift (3). The study of Honeybul and Ho (9) found that the development of hydrocephalus was associated with low admission GCS score and subdural hygroma rather than craniotomy close to the midline. Complications following DC for TBI were found to occur at specific times, and the poor GCSscore (≤ 8) or the severity of brain injury (11, 16, 23) and the older age (≥ 65) were found to show the high incidence of hydrocephalus (16). Also, extended craniectomy and repeated operation might play a role in the development of PTH in patients receiving DC (8). It was hypothesized that hydrocephalus might be dependent on *cerebrospinal fluid* (CSF) dynamic alterations (8, 33), especially in the venous reabsorption phase (33).

Therefore interhemispheric subdural hygroma may represent an epiphenomenon following DC close to the midline, and that subdural hygroma can be considered an expression of some alteration of CSF dynamics that may precede the appearance of hydrocephalus (3). One study showed that in patients with severe head trauma undergoing DC, hydrocephalus was associated with a large craniectomy area and contralateral subdural hygroma (17). Leaving the bone flap out at that time appeared to help controlI CP, but was associated with an increased incidence of PTH and wound complications (11). One
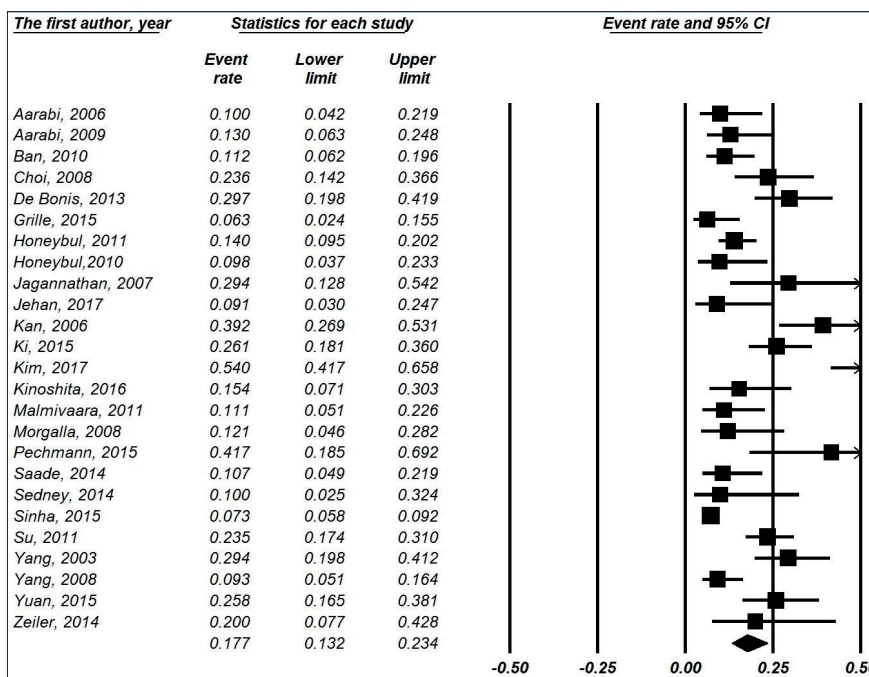

Figure 2. Forest plot of random-effects of event rate of posttraumatic hydrocephalus in all patients of each age undergoing decompressive craniectomy.
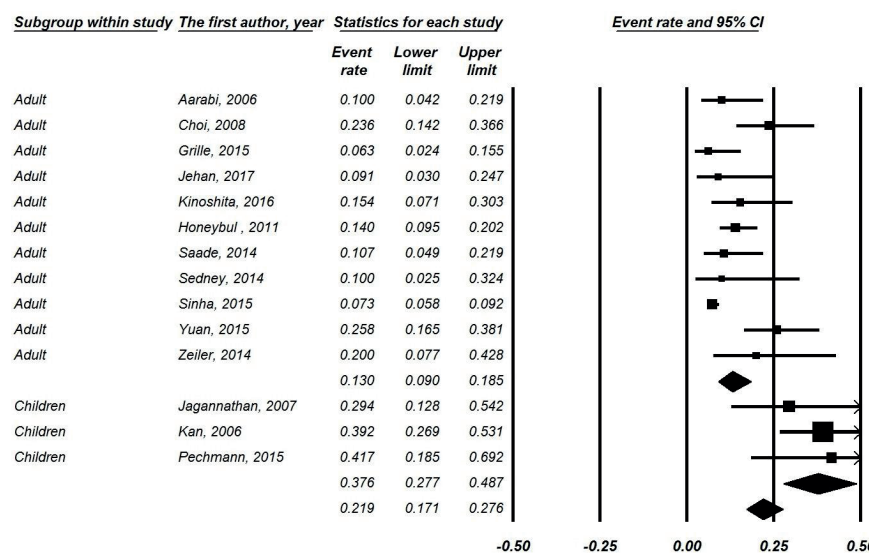

Figure 3. Forest plot of random-effects of event rate of posttraumatic hydrocephalus in adults and children undergoing decompressive craniectomy.

study (9) reported that timing of cranioplasty was not significantly associated with hydrocephalus requiring a VP shunt, but maximum ICP prior to decompression had a significant correlation with hydrocephalus. Therefore, DC causes alterations of CSF and high ICP that these changes can increase the risk of postoperative hydrocephalus.

A randomized controlled trial showed that younger age was associated with shunt-dependent hydrocephalus after DC in a recent study by Vedantam et al. (4) The presence of interhemispheric subdural hygroma and younger age were associated with shunt-dependent hydrocephalus after DC in patients with severe TBI. Low et al. (34) found that younger age was associated with PTH, while others have shown a link between older age and
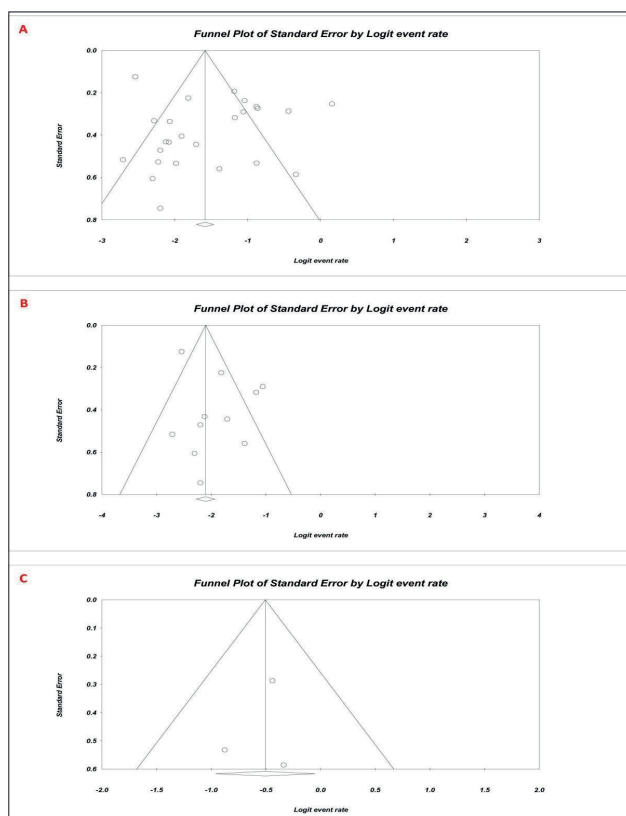
Figure 4. Funnel plot of event rate of posttraumatic hydrocephalus in (A) all studies, (B) adults, and (C) children undergoing decompressive craniectomy.

PTH (35, 36). High-energy mechanisms of injury, higher compliance of brain tissue (37), and lack of cerebral atrophy could contribute to an increased risk of symptomatic hydrocephalus in younger patients after DC (4). A prospective cohort among the patients that survived long enough showed the higher incidence of hydrocephalus requiring VP shunt in patients who had bilateral DC compared to unilateral DC (21% vs. 9%; P>0.05) (38). Therefore, GCS score, alterations of CSF, ICP, and age may play significant roles in the development of PTH in patients receiving DC.

Limitations

The age range, GCS, and time of follow-up, DC procedure, and type of trauma were different between the studies.

5. CONCLUSIONS

The present study demonstrated that DC after TBI was associated with the development of PTH especially in children compared to adults that several factors can impact on the incidence of PTH. Therefore, randomized controlled clinical trials are needed to confirm these conclusions by controlling these factors affecting the development of PTH.

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- **Conflict of interest:** We have no conflicts of interest to disclose.

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