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Prevalence of hydrocephalus in the patients with traumatic brain injury: A systematic review and meta-analysis

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Review Article

Abstract

BACKGROUND: The purpose of this study was determination of the prevalence of post-traumatic hydrocephalus (PTH) in patients who had traumatic brain injury (TBI) worldwide.

METHODS: Four electronic databases including Scopus, PubMed, Embase, and Web of Science were searched in this meta-analysis. The random-effects model was applied for the pooled effect size of $I^2 > 50\%$. Subgroup analysis was done to evaluate the heterogeneity, and the Egger's test was used to test the asymmetry of the funnel plots in order to assess the publication bias.

RESULTS: A total of 48 studies with 11624 patients were evaluated. The pooled prevalence of PTH was 13% [95% confidence interval (CI): 11.0-15.0] and according to decompressive craniectomy (DC) surgery was 22.0% (95% CI: 18.0-26.0). This result among patients with severe TBI (sTBI) was 16.0% (95% CI: 13.0-19.0) and it was higher in the developed countries. The prevalence of PTH was generally higher in studies with a sample size lower than 100 (21.0%) and was generally lower in studies conducted between 1990 to1999 (4.0%). These results were not too different according to the study design.

CONCLUSION: It is recommended to design a prospective clinical study in order to explain the true dynamics and circulation of the cerebrospinal fluid (CSF) after DC. Moreover, there is a need to evaluate the cost-effectiveness of DC in reducing the intracranial pressure in comparison with other available options. In fact, performing the clinical studies with higher quality in less developed countries could provide more reliable related results to achieve a true global conclusion.

KEYWORDS: Traumatic Brain Injury; Hydrocephalus; Decompressive Craniectomy; Meta-Analysis; Prevalence; Severe Head Injury

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Introduction

Traumatic brain injury (TBI) is an important source of health and medical concern in all societies.[1] In most countries, it is the most important cause of mortality and disability in the young people. Nowadays, the incidence of TBI is rising in low- and middle-income countries because of the increase in the motor vehicle accidents.[2] Based on the World Health Organization (WHO) report, traffic-related accidents will be the third most prevalent cause of disease and injury by 2020 throughout the world.[3] TBI-induced neurological damages

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are divided into primary injury (at the time of impact) or secondary injury (afterwards). Secondary injury is the leading cause of mortality after TBI.[4] Hydrocephalus is among the important posttraumatic secondary injuries.[5] It is characterized by the imbalance between production and resorption of the cerebrospinal fluid (CSF), which could cause the ventricular dilatation (ventriculomegaly) or enlargement of the subarachnoid space.[6]

Dandy reported about the presence of first clinical case of post-traumatic hydrocephalus (PTH) in 1914.[7] If PTH cannot be diagnosed or treated, it may result in the increase in the rate of possible mortality after TBI.[8,9] Besides, PTH is one of the causes of regression in the rehabilitation of the patients with TBI and it can lower final long-term cognitive and functional outcomes if it becomes prolonged before final treatment. On the other hand, PTH is a treatable secondary damage of TBI and timely intervention could improve the final outcome in these patients.[8,10] Up to now, many reports have been published about the patients with PTH but despite the importance of this issue, there is no comprehensive study on the worldwide prevalence of the PTH in the patients with TBI. Given the importance of this complication, this study is designated and implemented to determine the global prevalence of hydrocephalus in patients who had TBI.

Methods

Our meta-analysis was done in compliance with the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines.[11] We expected to identify the studies on the prevalence of hydrocephalus in the patients with TBI. This systematic review and meta-analysis was conducted by searching the papers in the four electronic databases including the Web of Science, Scopus, PubMed, and Embase. A general list of terms including the Medical Subject Headings (MeSH) terms on the hydrocephalus together with terms related to the brain injury was used.

Our searching sources consisted of health and interdisciplinary databases, grey literature sources, manual searching, and reference lists in the publications identified from other mentioned sources. The EndNote© software (version 7, Thomson Reuters, Philadelphia, PA, USA) was used to import search results.

Inclusion and exclusion criteria: In this study, the papers were excluded based on the language (only English language papers were included). All the studies concerning the hydrocephalous caused by the head trauma were included in the study. The studies that had used the qualitative methods were also excluded from the study.

Headings and certain papers were reviewed by two reviewers through discussing the hydrocephalus together with the terms related to TBI for the abstract review. All the listed headings were directly inserted into the EndNote software. Then, duplicate data were eliminated. In the abstract review step, all the studies on hydrocephalus not caused by the head trauma were excluded. Then, the whole text was reviewed to classify the studies. Herein, all the reviewed papers were completely analyzed, and particular papers were identified. Furthermore, a cross-search was carried out to identify any further related papers.

Data extraction and quality assessment: Selection of study and extraction of data were done by HF and AS evaluated the process over data extraction. The eligible data were extracted and tabulated by re-reading the information of the chosen papers including the authors, year(s) of conduction, year of publication, country where the study was done, study methods, sampling method, target population (pediatrics, adults, geriatrics, or all), number of patients undergoing the decompressive craniectomy (DC), study methods, mean age/age range (year), number of patients with TBI, and number of TBI patients with hydrocephalus.

The methodological quality of the papers was evaluated using a checklist (quality assessment checklist for prevalence studies) adapted from the study by Hoy et al.[12] According to this scale, the studies are graded with respect to the nine methodological criteria, with a total possible score of 9.

Statistical analysis: The Stata software (version 14.2, Stata Corporation, College Station, TX, USA) was used to calculate the pooled prevalence of hydrocephalus in the patients with TBI and subgroups analysis was also performed in various variables. The I^2 statistic with a cutoff of 50% was used to determine the heterogeneity between the studies. Random-effects model was applied for the pooled effect size of $I^2 > 50\%$.[13] The Stata software was also utilized to generate the forest plots about the pooled prevalence, with 95% confidence interval (CI). In this study, Egger's test was applied to test the asymmetry of the funnel plots in order to assess the publication bias, and subgroup analysis was done for the presence of heterogeneity. Sensitivity analysis was done to assess the dependency of overall estimate on a single study. We used the ArcGIS software to map the prevalence of hydrocephalus in the patients with TBI according to the country.

Results

According to the search results, among 4265 studies, 115 studies were included by excluding the duplicate papers (n = 1280), and the titles and abstracts that met the inclusion criteria for the meta-analysis were scanned. A total of 48 papers were selected for investigating the prevalence (Figure 1).

Table 1 shows the selected information about the included papers. A total of 48 studies with 11624 patients (ranging from 12 to 2374 per study) were evaluated in this meta-analysis.

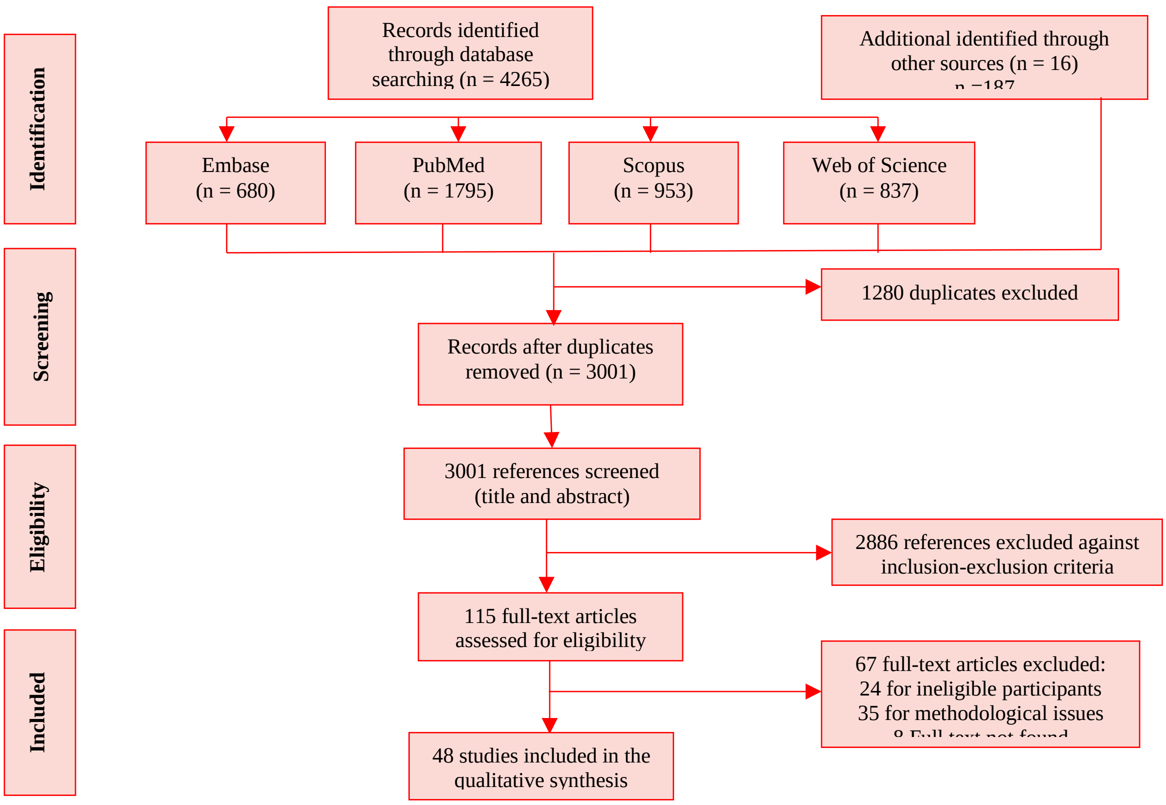

Figure 1. Flow diagram showing the different phases of searching for relevant publication

Table 1. Characteristics of included studies

The first author, publication year	Year of survey	Country	Study design	Target population	Sampling method	Trauma patients (sample size)	Type of trauma injury	No. of patients undergoing DC	No. of patients with hydrocephalus
Beauchamp K, 2010[14]	2003-2007	USA	N/A	N/A	Census	69	N/A	N/A	14
De Bonis P, 2013[15]	2007-2011	Italy	N/A	All	Census	64	Closed TBI	64	19
Chen H, 2017[16]	2012-2015	China	Retrospective	Adult patients	Census	527	N/A	N/A	57
Chen L, 2016[17]	2004-2008	China	Retrospective	All	Census	44	Motor vehicle accident	N/A	3
d'Avella D, 2003[18]	1997-1999	Italy	Clinical trial	All	Census	24	N/A	24	11
De Bonis P, 2010[19]	2006-2009	Italy	Retrospective	All	Census	26	Road accidents	26	9
Demircivi F, 1993[20]	1985-1990	Turkey	Retrospective	All	Census	89	Traumatic subarachnoid hemorrhage	N/A	2
Di G, 2018[21]	2013-2016	China	Retrospective	All	N/A	121	N/A	121	23
Cardoso ER, 1985[22]	1976-1981	Scotland	Retrospective	All	Census	2374	Severe head injury	N/A	17
Faleiro R, 2008[23]	2003-2005	Brazil	Retrospective	N/A	Census	89	Severe, moderate, mild TBI	89	7
Fotakopoulos G, 2016[24]	2009-2013	Greece	Retrospective	N/A	Census	126	N/A	126	20
Ganesh S, 2013[25]	1996-2007	USA	Prospective, cross-sectional, observational	All	Census	157	N/A	N/A	44
Groswasser Z, 1988[9]	1981-1985	Israel	N/A	N/A	N/A	335	Severe cranio-cerebral injury	N/A	13
Honeybul S, 2010[26]	2006-2007	Australia	Retrospective	N/A	Census	41	Severe head injury	41	4
Honeybul S, 2011[27]	2004-2009	Australia	Retrospective	All	Census	164	N/A	164	23
Honeybul S, 2014[28]	2004-2012	Western Australia	Cross-sectional	All	Census	270	Severe TBI	N/A	33

Table 1. Characteristics of included studies (continue)

The first author, publication year	Year of survey	Country	Study design	Target population	Sampling method	Trauma patients (sample size)	Type of trauma injury	No. of patients undergoing DC	No. of patients with hydrocephalus
Jovanovic MJ, 2015[29]	N/A	Serbia	Case-control	All	N/A	97	N/A	N/A	8
Kaen A, 2010[30]	2000-2006	Spain	Retrospective	N/A	Census	73	Severe head injury	73	20
Kan P, 2006[31]	1996-2005	USA	Retrospective	Children	Census	51	Severe TBI	51	14
Khan Z, 2012[32]	2009-2010	Pakistan	Retrospective	N/A	Census	154	Bomb blast head injuries	N/A	5
Ki HJ, 2015[33]	2007-2014	Korea	Retrospective	All	Census	92	N/A	92	24
Kim H, 2017[34]	2005-2016	Korea	N/A	N/A	Census	63	Acute traumatic SDH	N/A	34
Kishore PR, 1978[35]	N/A	USA	Cross-sectional	N/A	N/A	29	N/A	N/A	4
Low CY, 2013[36]	1999-2006	Singapore	Retrospective	All	Census	871	Road traffic accident	N/A	23
Lv LQ, 2011[37]	2007-2008	China	Cross-sectional	All	Census	79	N/A	N/A	13
Mazzini L, 2003[38]	1995-2000	Italy	Prospective	All	N/A	140	N/A	N/A	14
Murshid WR, 1998[39]	1986-1993	Saudi Arabia	Retrospective	All	Census	633	Minor head injuries	N/A	2
Nasi D, 2018[40]	2003-2011	Italy	Retrospective	All	Census	190	N/A	190	37
Pachatouridis D, 2013[41]	2005-2010	Greece	Retrospective	All	N/A	63	N/A	63	23
Pechmann A, 2015[42]	2005-2013	Germany	Retrospective	Children	Census	12	Car accident , fall from height, and toboggan accident	N/A	5
Phuenpathom N, 1999[43]	1993-1996	Thailand	Retrospective	All	Census	1080	Severe, moderate, mild TBI	N/A	17
Hu Q, 2018[44]	2013-2016	Italy	Retrospective	All	Census	183	N/A	183	50
Roka YB, 2008[45]	1999-2005	Nepal	Retrospective	All	Census	43	Road traffic accident	N/A	9
Ryan ME, 2017[46]	N/A	USA	Retrospective	All	Census	388	N/A	N/A	24

Table 1. Characteristics of included studies (continue)

The first author, publication year	Year of survey	Country	Study design	Target population	Sampling method	Trauma patients (sample size)	Type of trauma injury	No. of patients undergoing DC	No. of patients with hydrocephalus
Sakr S, 2016[47]	2008-2011	Egypt	Prospective	All	N/A	30	Outcome after gunshot wounds	N/A	5
Silva Neto AR, 2019[48]	2014-2015	Brazil	Retrospective	All	Census	50	N/A	50	17
Shi SS, 2011[49]	2004-2008	China	Retrospective	All	Census	389	N/A	N/A	48
Su TM, 2011[50]	2005-2008	Taiwan	Retrospective	N/A	Census	13	Severe TBI	13	6
Su TM, 2019[51]	2008-2014	Taiwan	Retrospective	All	Census	143	N/A	N/A	43
Sun S, 2018[5]	2012-2017	China	Retrospective	All	Census	1125	Severe, moderate, mild TBI	N/A	116
Takeuchi S, 2013[52]	N/A	Japan	Retrospective	N/A	N/A	23	N/A	23	11
Tian HL, 2008[53]	2002-2004	China	Retrospective	All	Census	301	Motor vehicle collisions	N/A	36
Vadivelu S, 2016[54]	2001-2010	USA	Retrospective	Children	Census	28	N/A	N/A	2
Whyte J, 2013[55]	N/A	USA, Germany, and Denmark	N/A	All	Randomized	184	N/A	N/A	10
Yang XF, 2008[56]	1998-2005	China	Retrospective	All	Census	108	Traffic accident	108	10
Yilmazlar S, 2005[57]	1997-2003	Turkey	N/A	All	N/A	30	Traffic accident	N/A	1
Yoon SY, 2017[58]	2004-2103	Korea	Retrospective	Children under 24 months	Census	60	Fall	N/A	2
Yuan Q, 2015[59]	2009-2013	China	Retrospective	All	Census	379	N/A	172	64

N/A: Not available; SDH: Subdural hematoma; DC: Decompressive craniectomy; TBI: Traumatic brain injury

All the studies were published from 1991 to December 2019. Among them, 21 studies had investigated the patients from Asian countries, 14 studies had investigated the patients from European countries, 10 studies were from American countries, 2 studies were from Australasian countries, and 1 study was from North African countries. The related details were also presented in table 1. The pooled prevalence of hydrocephalus in the patients with TBI was equal to 13% (95% CI: 11.0-15.0) in all the 48 studies consisting of 11624 participants, with respect to the primary definition for hydrocephalus in the patients with TBI in each study. A statistically significant heterogeneity was observed between the studies (I^2 = 95.4%, P < 0.001), but there was no evidence of funnel plot asymmetry (Egger's test, P > 0.05) (Figure 2).

Prevalence of hydrocephalus in the patients with TBI according to the DC surgery: 18 studies (15, 19, 21, 23, 24, 26, 27, 30, 31, 33, 40, 41, 44, 48-50, 52, 56) reported hydrocephalus in patients with TBI according to DC surgery with total population of 1626. The pooled prevalence was 22.0% (95% CI: 18.0-26.0) with statistically significant heterogeneity between studies (I^2 = 78.7%, P < 0.001) but no evidence of funnel plot asymmetry or other small study effects (Egger's test, P > 0.05) (Figure 3).

Prevalence of hydrocephalus among the patients with severe TBI (sTBI): 21 studies (9, 15, 22, 25-31, 33, 35-38, 40, 42, 48-50, 52) reported hydrocephalus in the patients with sTBI with total population of 5501.

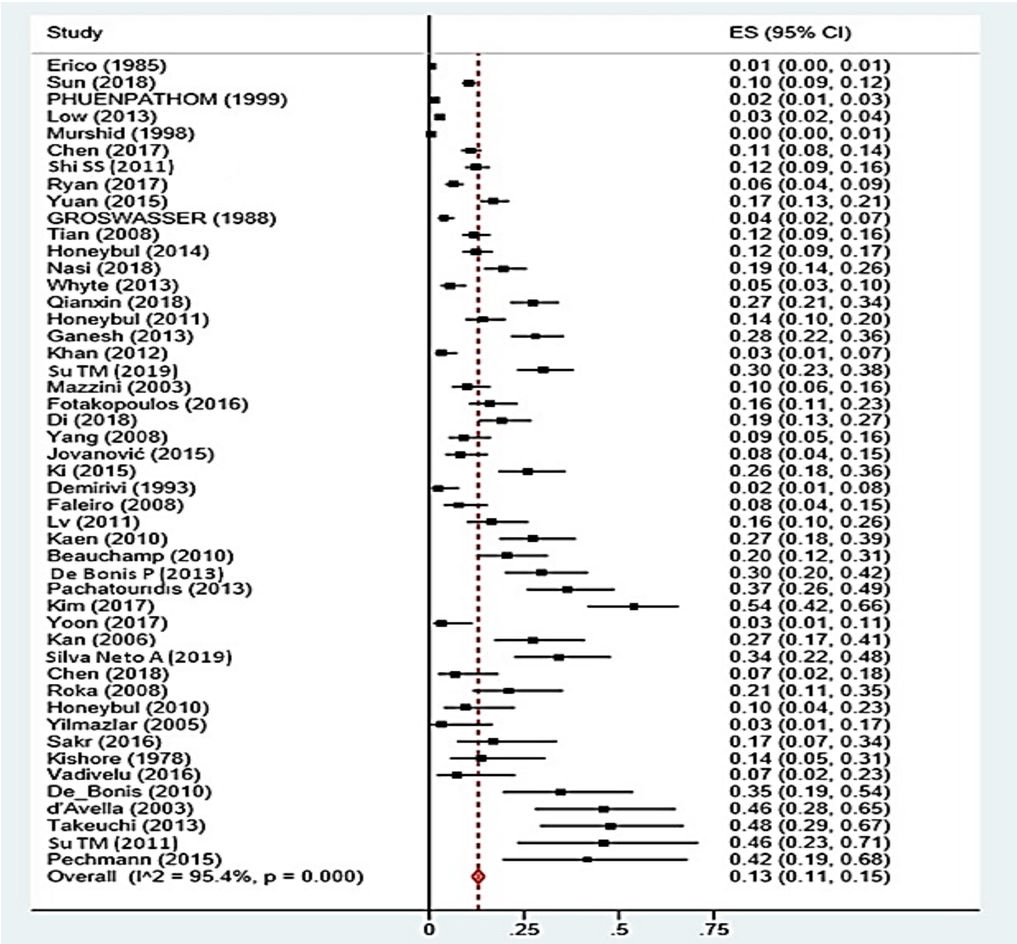

Figure 2. Forest plot for the overall estimate of the prevalence of hydrocephalus in the patients with traumatic brain injury (TBI)

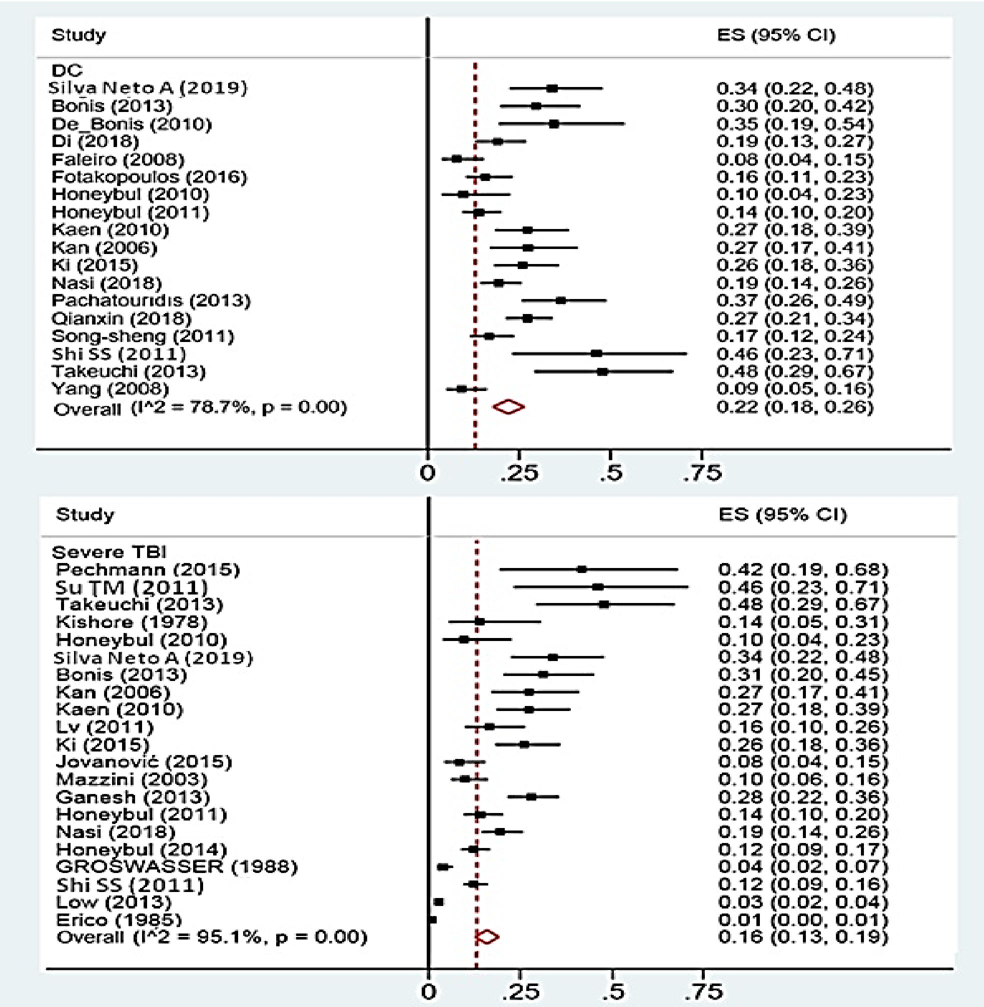

Figure 3. Prevalence of hydrocephalus in the patients with traumatic brain injury (TBI) according to the decompressive craniectomy (DC) surgery

The pooled prevalence was 16.0% (95% CI: 13.0-19.0) with statistically significant heterogeneity between studies (I^2 = 78.7%, P < 0.001) but no evidence of funnel plot asymmetry or other small study effects (Egger's test, P > 0.05) (Figure 3).

Global prevalence of hydrocephalus in patients with TBI: The majority of studies were conducted in the Southeast Asian or European countries. There were a few studies from North Asian and North African countries. Table 2 presents the pooled prevalence of hydrocephalus in the patients with TBI according to the geographical location. There was a statistically significant heterogeneity between the studies in all these analyses, but the results of pooled prevalence according to the geographical location showed the highest prevalence in the European countries (19.0%). Figure 4 shows the pooled prevalence with respect to the country.

Prevalence of hydrocephalus in the patients with TBI according to the study year: Among the eligible studies, 9 were conducted between 1990 and 1999 (9, 18, 20, 22, 25, 31, 38, 39, 43), 13 between 2000 and 2010 (14, 17, 23, 26, 30, 36, 40, 45, 49, 53, 54, 56, 57), and 26 between 2011 and December 2019 (5, 15, 16, 19, 21, 24, 26, 28, 29, 32-35, 37, 41, 42, 44, 46-48, 50-52, 55, 58, 59).

Table 2. Pooled prevalence of hydrocephalus in the patients with traumatic brain injury (TBI) according to the geographical location

	Number of studies	Number of subjects	Pooled prevalence	95% CI	I^2 (%)	P for I^2
All studies	48	11624	13.0	11.0-15.0	95.4	< 0.001
American	10	1315	15.0	10.0-20.0	< 50.0	< 0.001
Australasian	2	205	13.0	8.0-18.0	N/A	N/A
European	14	3491	19.0	13.0-25.0	< 50.0	< 0.001
Middle East Asian	3	1122	2.0	0.0-5.0	N/A	N/A
North African	1	30	17.0	7.0-34.0	N/A	N/A
North Asian	1	43	21.0	11.0-35.0	N/A	N/A
South East Asian	17	5418	13.0	11.0-15.0	< 50.0	< 0.001

CI: Confidence interval; N/A: Not applicable, too few studies to assess heterogeneity

The prevalence of hydrocephalus in the patients with TBI was generally lower in the studies conducted between 1990-1999 (4.0%), compared to those conducted from 2000 to 2010 (12.0%) and 2011 to December 2019 (18.0%) (Table 3).

Prevalence of hydrocephalus in the patients with TBI according to the sample size: Among the eligible studies, 25 were conducted among a sample size lower than 100 (14, 15, 17-20, 23, 26, 29-31, 33-35, 37, 41, 42, 45, 47, 48, 50, 52, 54, 57, 58), 20 studies were done with a sample size between 100-1000 patients (5, 9, 17, 21, 24, 25, 27, 28, 32, 36, 38-40, 44, 46, 49, 53, 55, 56, 59), and 3 studies were done among a sample size lower than 1000 (5, 22, 43). The prevalence of hydrocephalus in the patients with TBI was generally higher in the studies conducted with a sample size lower than 100 (21.0%), in proportion to other studies (Table 3).

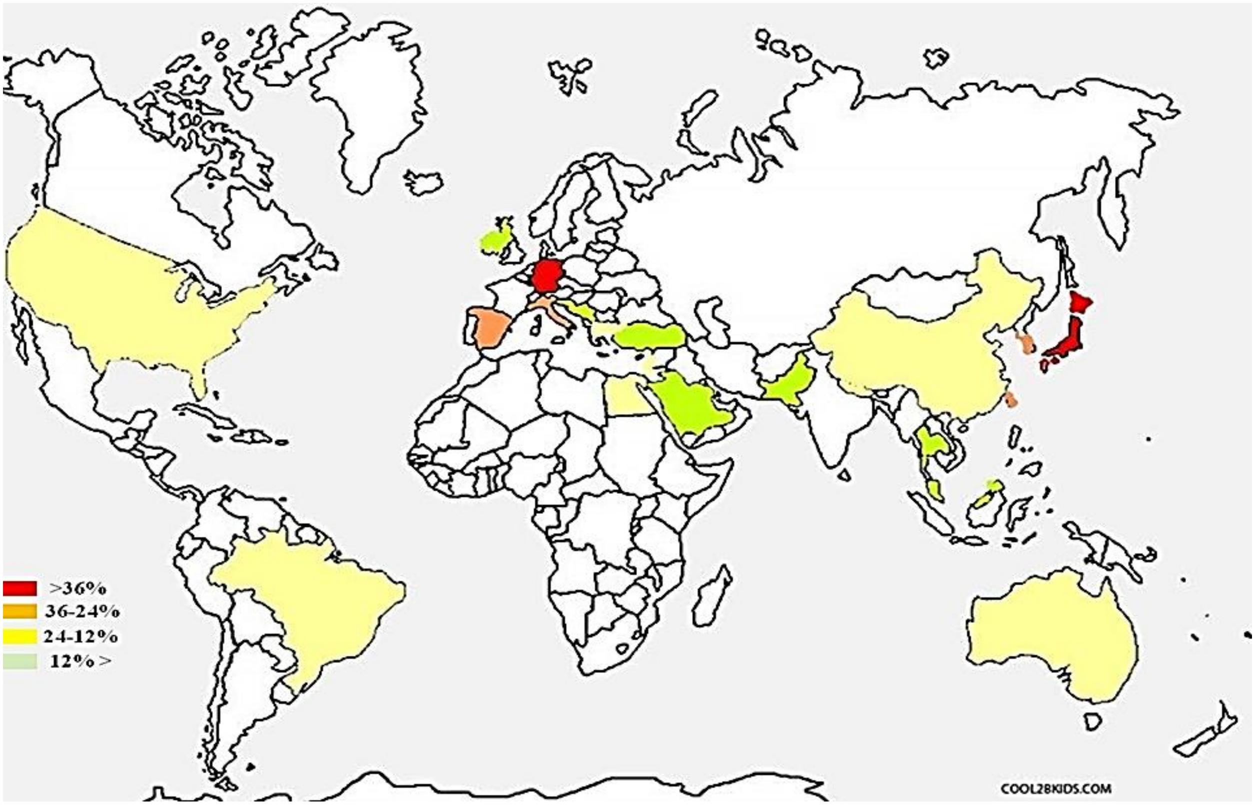

Figure 4. Prevalence of hydrocephalus in the patients with traumatic brain injury (TBI) according to the country

Table 3. Pooled prevalence of hydrocephalus in the patients with traumatic brain injury (TBI) according to the year of survey, sample size, and study design

	Number of studies	Number of subjects	Pooled prevalence	95% CI	I^2 (%)	P for I^2
All studies	48	11624	13.0	11.0-15.0	95.4	< 0.001
Year of survey						
1990-1999	9	4883	4.0	2.0-6.0	93.7	< 0.001
2000-2010	13	2399	12.0	8.0-16.0	90.5	< 0.001
2011-2020	26	4342	18.0	15.0-22.0	90.6	< 0.001
Sample size						
< 100	25	1282	21.0	16.0-26.0	88.9	< 0.001
100-1000	20	4572	12.0	9.0-15.0	96.5	< 0.001
> 1000	3	5763	4.0	1.0-7.0	N/A	N/A
Study design						
Retrospective	33	9899	12.0	10.0-14.0	95.9	< 0.001
Observational	2	311	7.0	4.0-9.0	N/A	N/A
Cohort	2	294	13.0	10.0-17.0	N/A	N/A
Prospective or cross-sectional	6	418	12.0	8.0-16.0	0.0	0.520

CI: Confidence interval; N/A: Not available

Prevalence of hydrocephalus in the patients with TBI according to the study design: There were 33 studies that reported the prevalence through retrospective studies (5, 15-17, 20-24, 26, 27, 30, 31, 33, 36, 39-46, 48-54, 56, 58, 59) and 6 were prospective or cross-sectional studies (25, 28, 29, 35, 37, 38). The prevalence of hydrocephalus in patients with TBI was not too different according to study design (Table 3).

Discussion

PTH is considered as an important injury that could influence the rehabilitation outcome and final prognosis of the patients with TBI.[8,10] If PTH is not properly treated or diagnosed, the patients with TBI will have lower functional outcome, and higher morbidity or even higher mortality rate will occur.[8]. In our study, worldwide prevalence of PTH in the patients with TBI was obtained as 13%. However, under the influence of TBI severity and type of treatment option, its prevalence was equal to 16% in the patients with sTBI and it was equal to 22% in the patients who underwent DC. Similar to our results, numerous reports supported a strong association between the PTH occurrence and sTBI in up to 70% of patients with PTH.[60,61] In the patients with sTBI, although benign ventriculomegaly is a common complication with an incidence rate of up to 86%, the prevalence of PTH requiring treatment is lower (less or about 10%).[60,62] The related literature indicates that the incidence of PTH occurring concomitant with the DC widely varies from less than 10% up to 50%.[6,53] Some hypotheses could support higher incidence of PTH in the patients with TBI who underwent DC. Firstly, the change in the CSF dynamics and circulation pathways after craniectomy could cause an imbalance between CSF formation and the altered CSF reabsorption.[63] Secondly, it has been revealed that there is an association between the sTBI and higher incidence of PTH. On the other hand, DC is performed mostly in the patients with sTBI.[8] As a result, PTH is more likely to occur in the patients who underwent DC. In addition, some reports have indicated the role of repeated operations in occurrence of PTH concomitant with DC.[64]

In our study, prevalence of PTH was higher in the developed countries compared to other countries, so that the mean prevalence of PTH in European countries was equal to 19%. Even in some of European countries as well as developed East Asian countries, e.g., Japan, South Korea, and Taiwan, the prevalence of PTH was more than 36%. As a result, the results of this meta-analysis revealed a higher prevalence of TBI in the developed countries compared to the least-developed countries (LDCs) although based on the literature, there is a higher prevalence of TBI in latter ones in terms of road traffic collisions.[65] This difference could be due to some issues in association with the LDCs, e.g., sampling procedure and variable diagnostic protocols for PTH during the study period such as lack of similarity for definition of PTH and variable inclusion criteria in the related literature.[53] In addition, in the LDCs, the patients with mild TBI are not well admitted and finally, they are underdiagnosed; the patients with the injuries caused by low-velocity road traffic accidents, falls, and sport-related concussions are classified into this group.[65] Another reason for this difference could be a less availability of more detailed documented information about the patients with TBI in the LDCs and undeveloped countries.[66] On the other hand, the availability of neuroradiologic diagnostic tools also contributes to publication of a true report on the prevalence and prognosis of PTH.[67] Further, herein, high quality published researches were used based on our study design; thus, it is possible that some LDCs-related studies have been excluded due to not meeting our inclusion criteria. Therefore, the results of the study may be influenced by the information obtained from the LDCs.

Considering the sample size of the studies, results of this meta-analysis revealed a higher prevalence of PTH in the studies with less than 100 included patients in comparison with other studies. This finding should be cautiously interpreted as there is a possibility of selection bias or maybe the surveys have been performed in a highly selected group of the patients with sTBI. Finally, according to the study year, an obvious increase was observed in the prevalence of PTH in the recent years that seems to be as a result of improvement, advances, and availability of the diagnostic neuroradiologic tools in the studied countries.[67]

Conclusion

The results of the present study revealed that the prevalence of PTH was higher in the patients with sTBI (16%) and patients who underwent DC (22%) compared to its worldwide mean prevalence (13%). Especially, performing DC in the patients with TBI is highly correlated with higher prevalence of PTH. As a result, it is recommended to design a prospective clinical study in order to explain the true dynamics and circulation of the CSF after DC. Besides, there is a need to evaluate the cost-effectiveness of DC in reducing the intracranial pressure compared to other available options such as barbiturate coma, external ventricular drain insertion, transient hyperventilation, mannitol administration, etc. Finally, it is noteworthy that performing the clinical studies with higher quality in the LDCs could provide more reliable related results to achieve a true global conclusion.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgments

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