Bifrontal–Parietal Ratio: A Novel Risk Factor for Cerebrospinal Fluid Overdrainage after Ventriculoperitoneal Shunting

Chonnawee Chaisawasthomrong[1] Kriangsak Saetia[1]

[1] Division of Neurosurgery, Department of Surgery, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand

Address for correspondence Kriangsak Saetia, MD, Division of Neurosurgery, Department of Surgery, Ramathibodi Hospital, Mahidol University, Bangkok 10400, Thailand
(e-mail: kriangsak.saetia@windowslive.com).

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Abstract

Objective This study aimed to examine potential risk factors associated with cerebrospinal fluid overdrainage after ventriculoperitoneal (VP) shunting.

Materials and Methods We retrospectively examined the medical records of hydrocephalus patients who underwent VP shunting at a single institution between January 2011 and December 2017 and had a minimum 3-year follow-up. Variables studied included age, gender, hydrocephalus etiology, symptoms, shunt valve, ventricular catheter entry point, and neurosurgical history, including history of external ventricular drainage. Radiographic variables included Evans index, bicaudate index, callosal angle, measurements of frontal lobe thickness, and bifrontal–parietal ratio.

Results Among the 182 study patients, 11 experienced overdrainage. Age, gender, etiology, symptoms, and surgical history did not significantly differ between patients who experienced overdrainage and those who did not. Evans index, bicaudate index, and callosal angle did not significantly differ between the groups. Measurements of frontal lobe thickness and bifrontal-–parietal ratio were significantly lower in the overdrainage group.

Conclusion Bifrontal–parietal ratio may be useful to predict overdrainage after VP shunt surgery.

Keywords
- bifrontal–parietal .ratio
- cerebrospinal fluid overdrainage
- ventriculoperitoneal shunt

Introduction

Hydrocephalus is a common condition with many different causes, such as trauma, tumor, infection, vascular disease, degenerative disease, and congenital malformation. Ventriculoperitoneal (VP) shunting is commonly employed to treat hydrocephalus in adults and children. Each year in the United States, ~69,000 patients are admitted to the hospital because of hydrocephalus and 39,000 hydrocephalus surgeries are performed, most commonly VP shunting.[1] Although VP shunting in hydrocephalus patients improves neurological function and reduces mortality and morbidity, it is associated with potential complications,[2–5] such as overdrainage, underdrainage, infection, and shunt malfunction. These complications may require multiple surgical procedures over a patient's lifetime.[6]

Since cerebrospinal fluid (CSF) drainage requirements vary between patients, shunting can result in over- or underdrainage. Previous overdrainage studies have reported different

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incidence rates and identified few overdrainage risk factors. One study of shunted posttraumatic hydrocephalus patients found a 23.4% incidence of overdrainage in the first year after surgery.[7] However, a study of idiopathic normal pressure hydrocephalus patients found only a 5% incidence of overdrainage; high body mass index and lumbar puncture opening pressure >160 mm H_2O were contributing factors.[8] A study of human immunodeficiency virus (HIV)-negative patients with cryptococcal meningitis found that longer interval between meningitis onset and shunting and longer interval between hospitalization and shunting were significantly associated with overdrainage; age, gender, CSF analysis, and specific shunt device were not.[9] To assist neurosurgeons in preventing complications and surgical planning, this study aimed to investigate potential overdrainage risk factors, such as surgical history, surgical procedure, and diagnostic imaging findings.

Materials and Methods

We retrospectively examined the medical records of hydrocephalus patients who underwent VP shunting at Ramathibodi Hospital, Mahidol University, Bangkok, Thailand between January 2011 and December 2017 and had a minimum 3-year follow-up. The selection of a shunt valve type depended on surgeons' preference. All conventional valve types utilized in this study were medium pressure. For all programmable shunt valves, the initial configuration was set to medium pressure (15–20 mm H_2O), followed by subsequent adjustments based on follow-up computed tomography (CT) scans and clinical evaluations during outpatient visits. Patients with incomplete or missing records, those unable to communicate, and patients who died within 3 years of shunting were excluded. Medical charts, operative reports, imaging studies, and clinical follow-up evaluations were reviewed to record patient data. Demographic and clinical data included age, gender, hydrocephalus etiology, and clinical presentation. Surgical data included shunt system, entry point of ventricular catheter, history of external ventricular drainage, and neurological surgery history. Radiographic data included preoperative head CT or preoperative brain magnetic resonance imaging (MRI) measurements obtained using Synapse software version 4.4.210 (Fujifilm Thailand, Bangkok, Thailand). Evans index was defined as the ratio of maximum width of the frontal horns of the lateral ventricles to the maximum internal diameter of the skull at the level of the foramen of Monro (►**Fig. 1**). Bicaudate index was defined as the ratio of the width of the lateral ventricles at the level of the head of the caudate nucleus to the distance between the inner tables of the skull at the same level (►**Fig. 2**). Callosal angle was defined as the angle between the lateral ventricles measured on a coronal image perpendicular to the anterior commissure–posterior commissure plane at the level of the posterior commissure (►**Fig. 3**). In addition, we introduce three new radiographic measurements of hydrocephalus, including bifrontal summation, bifrontal average, and bifrontal–parietal ratio. These parameters represent frontal cortex thickness that might correlated with brain atrophy before surgery. Bifrontal summation was defined as the sum of the thicknesses of both frontal cortices on axial and coronal views at the level of the foramen of Monro (4 measurements). Bifrontal average was defined as bifrontal summation/4. Bifrontal–parietal ratio was defined as the ratio of bifrontal summation to the maximal internal diameter of the skull at the same level (foramen of Monro) on an axial view (►**Fig. 4**). Patients were

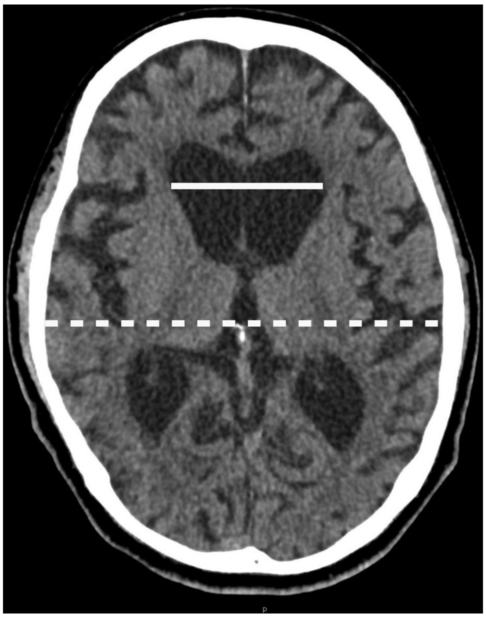

Fig. 1 Evans index was defined as the ratio of maximum width of the frontal horns of the lateral ventricles to the maximum internal diameter of the skull at the level of the foramen of Monro. The straight line indicates the maximum thickness of the frontal horns of the lateral ventricles. The dashed line indicates the maximum internal diameter of the skull.

Fig. 2 Bicaudate index was defined as the ratio of the width of the lateral ventricles at the level of the head of the caudate nucleus to the distance between the inner tables of the skull at the same level. The straight line indicates the width of the lateral ventricles. The dashed line indicates the distance between the inner tables of the skull.

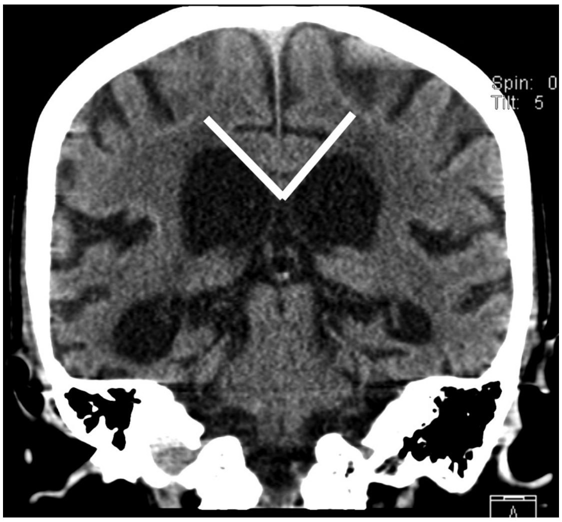

Fig. 3 Callosal angle was defined as the angle between the lateral ventricles measured on a coronal image perpendicular to the anterior commissure–posterior commissure plane at the level of the posterior commissure (straight lines).

diagnosed with overdrainage if they developed symptoms of intracranial hypotension (positional headache, altered consciousness, nausea, and vomiting) or chronic subdural hematoma on CT or MRI (►**Fig. 5**). All patients' radiographic measurements were evaluated by single author. Patients diagnosed with slit ventricle syndrome were not included in the study.

Statistical analyses were performed using Stata software version 14 (StataCorp, College Station, Texas, United States). Data were compared between overdrainage and nonoverdrainage groups using the Student's *t*-test or Mann–Whitney's *U* test for continuous variables and the chi-square or Fisher's exact test for categorical variables. A $p < 0.05$ was considered significant.

Fig. 5 Bilateral chronic subdural hematoma on computed tomography and magnetic resonance imaging indicating ventriculoperitoneal shunt overdrainage.

Results

Demographic and clinical data in patients with and without overdrainage after initial shunt placement are shown in ►**Table 1**. Age, gender, and clinical presentation did not significantly differ between the overdrainage and no overdrainage groups. Overdrainage occurred in a higher proportion of pediatric patients (age $<$15 years) than adult patients, but the difference was not significant. Hydrocephalus etiologies and surgical procedure data did not significantly differ between the groups (►**Tables 2** and **3**, respectively).

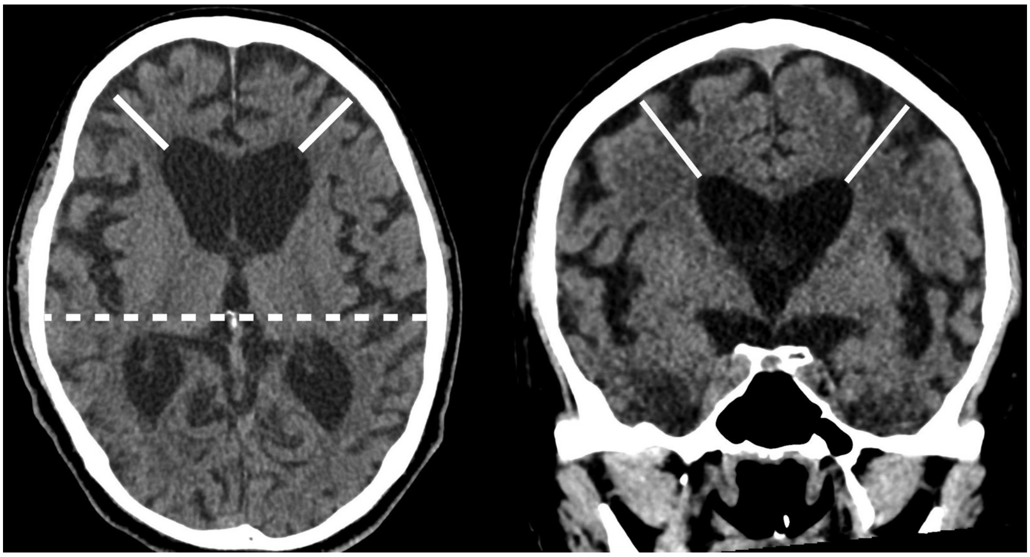

Fig. 4 Bifrontal summation was defined as the sum of the thicknesses of both frontal cortices on axial and coronal views at the level of the foramen of Monro (straight lines). Bifrontal average was defined as the mean length of the four lines. Bifrontal–parietal ratio was defined as the ratio of bifrontal summation to the maximal internal diameter of the skull at the same level on an axial view (dashed line).

Table 1 Demographic and clinical data

Data	Total (*n* = 182)	No overdrainage (*n* = 171)	Overdrainage (*n* = 11)	*p*-Value
Gender, *n* (%)				
Male	88 (48.35)	85 (96.59)	3 (3.41)	0.149
Female	94 (51.65)	86 (91.49)	8 (8.51)	
Age (y), mean ± SD	45.26 ± 28.31	45.28 ± 27.97	44.89 ± 34.67	0.965
Pediatric (<15 y)	39 (21.43)	35 (89.74)	4 (10.26)	0.253
Adult (≥15 y)	143 (78.57)	136 (95.10)	7 (4.90)	
Clinical presentation, *n* (%)				
Difficulty walking	30 (16.48)	27 (90)	3 (10)	0.394
Headache	27 (14.84)	26 (96.30)	1 (3.70)	0.999
Retardation	6 (3.30)	6 (100)	0	0.999
Memory loss, dementia	14 (7.69)	13 (92.86)	1 (7.14)	0.596
Altered consciousness	47 (25.82)	45 (95.74)	2 (4.26)	0.731
Nausea and vomiting	1 (0.55)	1 (100)	0	0.999
Ataxia	5 (2.75)	4 (80)	1 (20)	0.270
Increased head circumference	14 (7.69)	12 (85.71)	2 (14.29)	0.203
CSF leakage and pseudomeningocele	9 (4.95)	9 (100)	0	0.999
Vision loss	5 (2.75)	5 (100)	0	0.999
Imaging progression of hydrocephalus	14 (7.69)	13 (92.86)	1 (7.14)	0.596

Abbreviations: CSF, cerebrospinal fluid; SD, standard deviation.

Table 2 Hydrocephalus etiologies

Data	Total (*n* = 182)	No overdrainage (*n* = 171)	Overdrainage (*n* = 11)	*p*-Value
Tumor, *n* (%)				
No	129 (70.88)	121 (93.80)	8 (6.20)	0.889
Yes	53 (29.12)	50 (94.34)	3 (5.66)	
Trauma, *n* (%)				
No	168 (92.31)	158 (94.05)	10 (5.95)	0.596
Yes	14 (7.69)	13 (92.86)	1 (7.14)	
Infection, *n* (%)				
No	178 (97.80)	167 (93.82)	11 (6.18)	0.999
Yes	4 (2.20)	4 (100)	0	
Vascular, *n* (%)				
No	136 (74.73)	126 (92.65)	10 (7.35)	
Yes	46 (25.27)	45 (97.83)	1 (2.17)	
Congenital, *n* (%)				
No	158 (86.81)	149 (94.30)	9 (5.70)	0.641
Yes	24 (13.19)	22 (91.67)	2 (8.33)	
Degenerative, *n* (%)				
No	141 (77.47)	134 (95.04)	7 (4.96)	0.271
Yes	41 (22.53)	37 (90.24)	4 (9.76)	

Table 3 Surgical procedure data

Data	Total ($n = 182$)	No overdrainage ($n = 171$)	Overdrainage ($n = 11$)	*p*-Value
History of external ventricular drainage, *n* (%)				
No	138 (75.82)	127 (92.03)	11 (7.97)	0.068
Yes	44 (24.18)	44 (100)	0	
Neurosurgical history, *n* (%)				
No	82 (45.05)	75 (91.46)	7 (8.54)	0.201
Yes	100 (54.95)	96 (96)	4 (4)	
Ventricular catheter entry site, *n* (%)				
Frontal	157 (86.26)	149 (94.90)	8 (5.10)	0.286
Keen's point	22 (12.09)	19 (86.36)	3 (13.64)	
Occipital	3 (1.65)	3 (100)	0	
Shunt valve type, *n* (%)				
Programmable	71 (39.01)	64 (90.14)	7 (9.86)	0.112
Conventional	111 (60.99)	107 (96.40)	4 (3.60)	

Although none of the overdrainage group patients underwent external ventricular drainage before shunting, this was not significantly different from the proportion of patients who did not undergo preoperative drainage in the overdrainage group (0 vs. 8.66%; $p = 0.068$). Neurosurgical history, ventricular catheter entry point, and shunt valve type did not significantly differ between the groups. Seven of 71 patients who received a programmable shunt valve (9.86%) developed overdrainage; one of these required subdural hematoma evacuation. Among the conventional valve patients, 4 of 111 (3.60%) developed overdrainage; all received low pressure valves and required surgery.

Evans index, bicaudate index, and callosal angle did not significantly differ between the overdrainage and no overdrainage groups. Bifrontal average was significantly lower in the overdrainage group (19.92 ± 9.43 vs. 26.91 ± 5.30 mm; $p = 0.034$). Bifrontal summation was also significantly lower in the overdrainage group (79.68 ± 37.73 vs. 107.64 ± 21.21 mm; $p = 0.034$). Furthermore, bifrontal–parietal ratio was significantly lower in the overdrainage group (0.58 ± 0.27 vs. 0.82 ± 0.15; $p = 0.015$). Subanalyses of the same parameters with patients grouped by age demonstrated that differences in bifrontal average and bifrontal summation between the overdrainage and no overdrainage groups were significant in pediatric patients but not in adults. However, the bifrontal–parietal ratio was significantly different between groups in both children and adults (►**Table 4**).

Table 4 Radiographic data

Data	Total ($n = 182$)	Non-overdrainage ($n = 171$)	Overdrainage ($n = 11$)	*p*-Value
Evans index, mean ± SD	0.36 ± 0.07	0.35 ± 0.06	0.37 ± 0.11	0.745
Bicaudate index, mean ± SD	0.33 ± 0.08	0.32 ± 0.07	0.40 ± 0.19	0.207
Callosal angle, mean ± SD	113.00 ± 20.46	113.25 ± 19.20	109.09 ± 35.93	0.711
Bifrontal average, mean ± SD	26.49 ± 5.84	26.91 ± 5.30	19.92 ± 9.43	0.034
Bifrontal summation, mean ± SD	105.95 ± 23.36	107.64 ± 21.21	79.68 ± 37.73	0.034
Bifrontal–parietal ratio, mean ± SD	0.81 ± 0.17	0.82 ± 0.15	0.58 ± 0.27	0.015
Pediatric, mean ± SD, $n = 39$				
Bifrontal summation	83.38 ± 29.38	87.94 ± 26.41	43.41 ± 25.60	0.003
Bifrontal average	20.84 ± 7.34	21.98 ± 6.60	10.85 ± 6.40	0.003
Bifrontal–parietal ratio	0.67 ± 0.21	0.71 ± 0.18	0.33 ± 0.18	0.000
Adult, mean ± SD, $n = 143$				
Bifrontal summation	112.11 ± 16.93	112.71 ± 16.26	100.41 ± 25.82	0.256
Bifrontal average	28.03 ± 4.23	28.18 ± 4.06	25.10 ± 6.46	0.256
Bifrontal–parietal ratio	0.85 ± 0.13	0.85 ± 0.12	0.73 ± 0.19	0.013

Abbreviation: SD, standard deviation.

Discussion

Overdrainage of CSF is a common complication of VP shunt surgery and can present with slit ventricle syndrome, symptoms of intracranial hypotension, or subdural fluid collections or hematoma.[9–12] In our study of 182 hydrocephalus patients who underwent VP shunting, 11 (6.0%) developed overdrainage, which is consistent with previously reported rates ranging between 5 and 12%.[9,11] Etiology of hydrocephalus in these 11 patients was degenerative disease in 4, tumor in 3, congenital disease in 2, trauma in 1, and vascular in 1.

A previous study of HIV-negative patients who underwent shunting after cryptococcal meningitis found no difference in age between patients who experienced overdrainage and those who did not (57.7 ± 15.6 vs. 51.2 ± 18.9 years; $p = 0.43$).[9] We also found no age difference (44.89 ± 34.67 vs. 45.28 ± 27.97 years; $p = 0.965$). Similarly, gender and clinical presentation were not associated with overdrainage, in agreement with previous studies. Our study also examined neurosurgical history, including history of external ventricular drainage, and ventricular catheter entry site and found no association with overdrainage.

Shunt valve type was not significantly associated with overdrainage either, as in a previous study.[13] Although we found a considerably higher rate of overdrainage in patients who received a programmable valve compared with those who received a conventional valve, the difference was not significant. However, programmable valves allow pressure adjustment to correct overdrainage without surgery, unlike conventional valves, which require valve replacement. Additionally, we found no association of Evans index, bicaudate index, or callosal angle with overdrainage. Ventricular size does not appear to be a risk factor for overdrainage.

Brain atrophy due to advanced age and rapid loss of CSF resulting from lumbar puncture can predispose to tearing of bridging veins in the subdural space and cause subdural hematoma.[13–15] VP shunting dramatically decreases volume of CSF in the ventricular system. Therefore, we examined the association of frontal cortex thickness with overdrainage, which has not been previously studied.

To define brain atrophy, we introduce new radiological parameters including bifrontal summation, bifrontal average, and bifrontal–parietal ratio. Although these parameters were not yet validated as markers for brain atrophy, we hypothesized that these parameters representing frontal cortex thickness might correlated with shunt overdrainage.

Frontal cortex thickness, as measured by bifrontal summation and bifrontal average, was significantly lower in the overdrainage group. Since children and adults have different brain sizes, subanalyses of these age groups were performed. Bifrontal summation and bifrontal average measurements were significantly different between the groups in children but not in adults. We are uncertain regarding this discrepancy. Further studies will help clarify this issue.

However, the bifrontal–parietal ratio was significantly different between the groups in both children and adults. This suggests that bifrontal–parietal ratio could be a good measure of overdrainage risk in all age groups.

Previous studies suggested that bicaudate index is associated with cerebral atrophy and cognitive function.[16,17] However, our study did not show correlation between bicaudate index and shunt overdrainage. The difference between bifrontal–parietal ratio and bicaudate index on shunt overdrainage might explain by the area of brain measurement. Bifrontal–parietal ratio was measured at the thinnest part of frontal cortex, whereas bicaudate index was not. We hypothesized that thinner brain cortex might represent higher risk of shunt overdrainage.

The authors tried to determine an optimal cutoff value of bifrontal–parietal ratio to predict overdrainage by receiver operating characteristic (ROC) analysis. Unfortunately, the area under ROC curve was only 0.24 because of small number of overdrainage group. Therefore, we could not recommend an optimal cutoff value of bifrontal–-parietal ratio to predict overdrainage.

Advantages of our study include long follow-up period and analysis of surgical history and diagnostic imaging parameters. In addition, we have introduced bifrontal summation and bifrontal average as measurements of frontal cortex thickness, as well as bifrontal–parietal ratio that were found to be risk factors for overdrainage. However, several limitations should be noted. The study was retrospective in nature and the patients had heterogeneous causes of hydrocephalus. There was also heterogeneity in study population including pediatric and adult patients. In addition, our results may have been affected by technical surgical factors, as the surgeries were performed by multiple surgeons. Furthermore, only one researcher performed the radiographic measurements, which may have introduced information bias. Future studies with larger sample size involving multiple observers to analyze intra- and interobserver reliabilities are warranted.

Conclusion

Bifrontal–parietal ratio was associated with VP shunt overdrainage, while age, gender, presentation, etiology, shunt valve type, surgical history, and radiographic ventricular size were not. This measurement may be useful to predict overdrainage after shunting. Further studies are warranted.

Ethics Approval

This study was approved by the Human Research Ethics Committee, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Thailand.

Funding
None.

Conflict of Interest

None declared.

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References

1 Stone JJ, Walker CT, Jacobson M, Phillips V, Silberstein HJ. Revision rate of pediatric ventriculoperitoneal shunts after 15 years. J Neurosurg Pediatr 2013;11(01):15–19

2 Aldrich EF, Harmann P. Disconnection as a cause of ventriculoperitoneal shunt malfunction in multicomponent shunt systems. Pediatr Neurosurg 1990-199116(06):309–311, discussion 312

3 Braga MH, Carvalho GT, Brandão RA, Lima FB, Costa BS. Early shunt complications in 46 children with hydrocephalus. Arq Neuropsiquiatr 2009;67(2A):273–277

4 Choudhury AR. Avoidable factors that contribute to the complications of ventriculoperitoneal shunt in childhood hydrocephalus. Childs Nerv Syst 1990;6(06):346–349

5 Elisevich K, Mattar AG, Cheeseman F. Biodegradation of distal shunt catheters. Pediatr Neurosurg 1994;21(01):71–76

6 Keucher TR, Mealey J Jr. Long-term results after ventriculoatrial and ventriculoperitoneal shunting for infantile hydrocephalus. J Neurosurg 1979;50(02):179–186

7 Sun T, Yuan Y, Zhang Q, et al. One-year outcome of patients with posttraumatic hydrocephalus treated by lumboperitoneal shunt: an observational study from China. Acta Neurochir (Wien) 2018; 160(10):2031–2038

8 Khan QU, Wharen RE, Grewal SS, et al. Overdrainage shunt complications in idiopathic normal-pressure hydrocephalus and lumbar puncture opening pressure. J Neurosurg 2013;119(06):1498–1502

9 Hung CW, Lin WC, Chang WN, et al. Risk factors and outcomes of cerebrospinal fluid overdrainage in HIV-negative patients with cryptococcal meningitis after the ventriculoperitoneal shunting procedure. J Microbiol Immunol Infect 2018;51(04):545–551

10 Weprin BE, Swift DM. Complications of ventricular shunts. Tech in Neurosurg 2001;7(03):224–242

11 Pudenz RH, Foltz EL. Hydrocephalus: overdrainage by ventricular shunts. A review and recommendations. Surg Neurol 1991;35 (03):200–212

12 Kondageski C, Thompson D, Reynolds M, Hayward RD. Experience with the Strata valve in the management of shunt overdrainage. J Neurosurg 2007;106(2, Suppl):95–102

13 Ringel F, Schramm J, Meyer B. Comparison of programmable shunt valves vs standard valves for communicating hydrocephalus of adults: a retrospective analysis of 407 patients. Surg Neurol 2005; 63(01):36–41, discussion 41

14 Ross DA, Olsen WL, Ross AM, Andrews BT, Pitts LH. Brain shift, level of consciousness, and restoration of consciousness in patients with acute intracranial hematoma. J Neurosurg 1989; 71(04):498–502

15 Foelholm R, Waltimo O. Epidemiology of chronic subdural haematoma. Acta Neurochir (Wien) 1975;32(3-4):247–250

16 Bermel RA, Bakshi R, Tjoa C, Puli SR, Jacobs L. Bicaudate ratio as a magnetic resonance imaging marker of brain atrophy in multiple sclerosis. Arch Neurol 2002;59(02):275–280

17 Brickman AM, Honig LS, Scarmeas N, et al. Measuring cerebral atrophy and white matter hyperintensity burden to predict the rate of cognitive decline in Alzheimer disease. Arch Neurol 2008; 65(09):1202–1208