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Transcranial Doppler and Cerebrospinal Fluid Flow Study in Normal Pressure Hydrocephalus

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Objective : The authors analyze prospectively the result of transcranial doppler(TCD) in normal pressure hydrocephalus and compared its cerebral blood flow parameters to radionuclide cerebrospinal fluid(CSF) flow study, postoperative brain computed tomography(CT) findings and clinical outcome, and studied the relationship betweeen cerebral hemodynamics and clinical performance.

Methods : Twenty five patients with hydrocephalus undertook pre- and post-operative TCD but only preoperative CSF flow study was performed. Mean flow velocity(Vm), pulsatility index(PI) and resistance index(RI) were assessed through TCD and changes in ventricle size and cortical gyral atrophy were checked through brain CT.

Results : Postoperative hydrocephalus showed an increase in Vm(ACA P=0.037, MCA P=0.034), decrease in PI(ACA P=0.019, MCA P=0.017) and decrease in RI (ACA P=0.017, MCA P=0.021) compared to preoperative TCD parameters in the postoperative improvement group. In the postoperative improvement group, postoperative TCD parameters correlated with CSF flow study grade (Vm : R^2=-0.75, PI : R^2=0.86, RI : R^2=0.78) and ventriculocranial ratio change correlated with PI change (R^2=0.73). The convexity gyral atrophy and initial TCD parameters showed close relationship to outcome.

Conclusion : PI and RI can be used as an indicator of post operative prognosis, and with the addition of CSF flow study values, can also be used as a tool to predict pre-op and post-op patient status and successful shunt surgery.

KEY WORDS : Hydrocephalus · Transcranial doppler · CSF flow study · Pulsatility index · Resistance index.

Introduction

Hydrocephalus is a common neurosurgical problem. It leads to changes not only in cerebral blood flow by displacement, deformation, stretching, or decrease in the calibre of cerebral vessels[1,2,4], but also in vascular resistance and cerebral perfusion pressure, which is the driving force for cerebral microcirculation[1,5,10]. Cerebral blood flow velocities(CBFV) in the major arteries of the circle of Willis can be measured by pulsed transcranial Doppler(TCD) with a low ultrasound frequency of 2 MHz[1,4]. TCD is commonly accepted as a method for evaluation of intracranial arterial stenosis or occlusions and of arterial vasospasm after subarachnoid hemorrhage[2,20,27,28].

One of the techniques used to detect disturbed CSF circulation in hydrocephalus is radionuclide cerebrospinal fluid(CSF) flow study with intrathecal injection of radioactive isotope. The usefulness of radionuclide CSF flow study in selected patients with presumed hydrocephalus for shunting remains controversial. Some publications on hydrocephalus described the test as useful in proving additional information, but many others found that the predictive accuracy of radionuclide CSF flow study was low or even did not use the test. Despite this, radionuclide CSF flow study remains one of the most popular test in CSF hemodynamics of hydrocephalus, because most clinicians think radionuclide CSF flow study is better than brain CT in making a therapeutic decision.

In this study, we compared the cerebral blood flow parameters obtained from preoperative and postoperative transcranial doppler with clinical outcome and studied its relationship with radionuclide CSF flow study and also with the changes in CBF parameters of the diverse clinical symptoms and CT findings found after surgery.

Materials and Methods

Twenty five patients with hydrocephalus who underwent either ventriculo-peritoneal or lumbar-peritoneal shunt from January, 2002 to December, 2003 were selected. Impr-

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Table 1. Severity of symptoms grade

Grade	Gait disturbance	Cognitive impairment	Urinary incontinence
0	Normal	Normal	Normal
1	Caution gait minimal	Attentional or memory deficit	Sporadic incontinence
2	Considerable unstable gait	Considerable deficit oriented to situation	Frequent incontinence
3	Unaided gait not possible	Nor marginally oriented	No control

Table 2. Outcome by improvement index

Improvement index	No. of patients	% of patients
0.00	4	16
0.33	3	12
0.50	6	24
0.67	4	16
0.75	5	20
0.83	2	8
1.00	1	4

Improvment index= sum of improvement / sum of preoperative severity (0.00 = no/only minimal improvement to 1.00 = excellent improvement of all preoperative cardinal symptoms)

Table 3. Grading of cerebrospinal fluid flow study by RI cisternography (Tc-99m DTPA)

Grade	Ventricular filling	Flow over the convexity	No. of patients	% of patients
I	No	Yes	0	0
II	Yes; out by 24hr	Yes	2	8
III	Yes; persistent at 24hr	Yes	7	28
IV	Yes; persistent at 24hr	No	16	64

ovement of symptoms after shunting was assessed by classifying the 3 cardinal symptoms, gait disturbance, cognitive impairment, and urinary impairment as Grade 0 to 3 (Table 1), and comparing the preoperative and postoperative changes. Degree of improvement was obtained using the improvement index. The improvement index is acquired by dividing the sum of the severity grades checked before operation by the sum of the improvement grades. Patients with an improvement score of greater than 50% were included in the improvement group and patients with less than 50% or no improvement were selected as the non-improvement group (Table 2). For example, if the sum of the preoperative grade of all cardinal symptoms was 4, and a grade improvement of 1 was seen in each symptom, the improvement index is calculated as 3/4(0.75).

Improvement index= sum of improvement / sum of preoperative severity.

Statistical data was assorted by SPSS(10.0 English version, U.S.A), and a p-value of less than 0.05 obtained through the student t-test and regression analysis was named statistically significant.

Transcranial doppler

TransScan 3D (EME NCOLET, Gemerny) of 2MHz frequency was used to evaluate the preoperative and postoperative cerebral blood flow of the major arteries in the circle of Willis and the internal carotid artery. The mean flow velocity(Vm), pulsatility index(PI) and resistance index(RI) of both middle cerebral arteries were assessed 7 days prior to, and after surgery, as follows;

PI=Peak systolic velocity-End diastolic velocity / Mean flow velocity.

RI=Peak systolic velocity-End diastolic velocity / Peak systolic velocity.

Radionuclide CSF flow study

Radionuclide CSF flow study was performed in all patients using a lumbar injection of Tc^{99m}-diethylenetriaminepentaacetic acid(DTPA). Sequential lateral and posterior scintiscan of the head were obtained with a scintillation gamma camera at 1, 3, and 24 hours after injection. The intracranial isotope activity at each interval were analyzed by an experienced observer

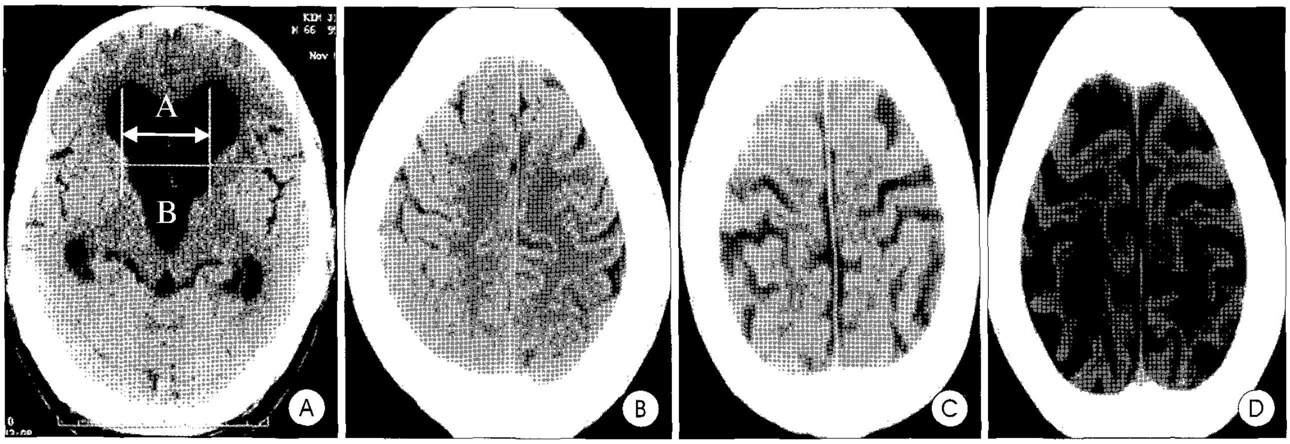

Fig. 1. Brain computed tomography finding in hydrocephalus (A : ventricular size. B,C,D : cortical gyal atrophy). Ventriculocranial ratio=A/B,C,D. Convexity gyral atrophy. B : non, C : moderate, D : severe.

and designated according to their feature into grade I of grade IV defined groups (Table 3). No side effects were observed in the patients who underwent the procedure.

Brain computed tomography

Brain CT was performed preoperatively and postoperatively, and the ventricular size and degree of brain atrophy were assessed. Ventricular size was calculated as the ratio between the largest width of the frontal horns behind the basal ganglia at the level of the foramen of Monro, and the internal diameter from inner table to inner table at this level. Brain atrophy was divided in to three groups according to sulcal-gyral patterns of convexity (Fig. 1).

Results

Subject

Of the 25 selected patients, 16 were male, and 9 were female. Patient age ranged from 56 to 69 years, with an average of 62.25. Causes of hydrocephalus were trauma (11, most common), post stroke (10), congenital (2), and unknown (2). 17 of the 25 patients underwent ventriculo-peritoneal shunt, while 8 received a lumbo-peritoneal shunt.

Main symptoms

Patients presenting cardinal symptoms of greater than Grade 2 were as follows; 18 cases (72%) with gait disturbance, 10 cases (40%) of cognitive impairment, and 18 cases (72%) of urinary incontinence (Table 4). 18 cases (72%) were classified into the symptom improvement group after surgery.

Transcranial doppler in hydrocephalus patients

The preoperative data of the symptom improvement group showed a decrease in Vm, and an increase in PI and RI, which was statistically significant (p=0.042).

When comparing preoperative and postoperative parameters, the symptom improvement group showed a statistically significant postoperative increase in Vm of the ACA and MCA, with a value of 40.35±7.62cm/ sec(P=0.037) and 41.24±6.54cm/ sec(P=0.034), respectively. Postoperative PI scores decreased; ACA was 0.72±0.08(P=0.019) and the MCA 0.61±0.07(P=0.017). Post-operative RI scores also decreased with a mean value of 0.59±0.11(P=0.017) in the ACA and 0.65±0.11(P=0.021) in the MCA. However, the Vm (ACA : P=0.093, MCA : P= 0.075), PI(ACA : P=0.081, MCA : P=0.064) and RI(ACA : P=0.076, MCA : P=0.067) of the non-improvement group did not show a statistically significant difference before and after surgery (Table 5).

Comparison of radionuclide CSF flow study with transcranial doppler finding

Through the radionuclide CSF flow study, 2 patients was grouped as Grade 2, 7 as Grade 3, and 16 as Grade 4. Our study showed that greater symptom improvement was seen in patients with higher preoperative ventricular reflux grade. When comparing the TCD scores of each grade, Vm of the symptom improvement group was 45.32±4.26cm/sec in grade 2, 39.21±5.12cm/sec in grade 3, and 36.38±5.41cm/sec in grade 4, showing a statistically significant negative correlation (R^2= 0.75). However,

Table 4. Pre-operative symptoms

Grade	Gait disturbance		Cognitive impairment		Urinary incontinence	
	No.*	%**	No.	%	No.	%
0	1	4	7	28	1	4
1	6	16	8	32	6	24
2	15	60	8	32	13	52
3	3	12	2	8	5	16

* No.: Number of patients, **%: percents of patients, ** Preoperative severity 0= normal to 3 severly impaired

Table 5. Transcranial doppler parameter in hydrocephalus

Symptom improvement	TCD value	Artery			
		Pre-op		Post-op	
		ACA	MCA	ACA	MCA
(+)*	Vm	34.56±5.16	37.46±7.58	40.35±7.62	41.21±6.54
	PI	0.93±0.12	0.95±0.14	0.72±0.08	0.61±0.07
	RI	0.69±0.09	0.72±0.09	0.59±0.11	0.65±0.11
(−)**	Vm	40.35±7.62	41.24±6.54	41.54±9.25	41.81±7.25
	PI	0.82±0.08	0.88±0.10	0.83±0.14	0.87±0.11
	RI	0.56±0.08	0.52±0.08	0.53±0.07	0.54±0.11

* Pre-op vs Post-op ACA Vm P=0.037, PI P=0.019 RI P=0.017, MCA Vm P=0.034, PI P=0.017 RI P=0.021, ** Pre-op vs Post-op ACA Vm P=0.093, PI P=0.081 RI P=0.076, MCA Vm P=0.075, PI P=0.064 RI P=0.067

Table 6. Cerebrospinal fluid flow study grade vs. initial transcranial doppler parameters

Grade	Improvement* (Patient No.)	TCD(ACA)			TCD(MCA)		
		Vm (cm/sec)	PI	RI	Vm (cm/sec)	PI	RI
Grade II	+(1)	45.32±4.26	0.86±0.08	0.54±0.11	47.29±3.41	0.74±0.12	0.50±0.13
(2)	−(1)	43.21±4.12	0.74±0.09	0.51±0.14	43.27±4.25	0.72±0.13	0.52±0.26
Grade III	+(5)	39.21±5.12	1.05±0.15	0.56±0.19	38.65±2.44	0.86±0.35	0.55±0.12
(7)	−(2)	40.23±4.24	0.84±0.14	0.53±0.11	44.36±2.96	0.85±0.21	0.52±0.17
GradeIV	+(12)	36.38±5.41	1.13±0.16	0.61±0.15	36.25±2.58	0.90±0.15	0.62±0.14
(16)	−(4)	42.15±4.32	0.91±0.07	0.58±0.11	32.39±3.25	0.91±0.17	0.54±0.13

* (+) : Symptom improved postoperatively, (−) : symptom not improved postoperatively. CSF flow grade vs.TCD parameters. (+) grade vs. Vm R^2=−0.75, grade vs. PI R^2=0.86, grade vs. RR^2=0.78 (−) grade vs. Vm R2=−0.63, grade vs. PI R^2=0.61, grade vs. RI R^2=0.64

while non-improvement group also demonstrated a decrease in mean flow velocity with a higher grade, there was no statistically significant correlation (R^2= 0.63). The PI and RI of the symptom improvement group was 0.86 ±0.08 and 0.54±0.11 in grade 2, 1.05±0.15 and 0.56±0.19 in grade 3, 1.13±0.06 and 0.61±0.15, respectively. This showed a positive correlation of an increase in the two parameters according to an increase in grade (PI : R^2= 0.86, RI : R^2= 0.78). The PI and RI of the non-improvement group decreased with an increase of grade, but no significant correlation was seen (PI : R^2= 0.61, RI : R^2= 0.64) (Table 6).

When comparing the CSF tapping pressure obtained during lumbar puncture for CSF flow study with the TCD parameters, an increase in PI and RI scores was seen with an increase the CSF pressure in both improvement and non-improvement groups. The improvement group especially showed a statistically significant correlation. (Symptom improvement group PI : R^2= 0.79, RI : R^2= 0.59, Non-improvment group PI : R^2= 0.47, RI : R^2= 0.42) (Fig. 2).

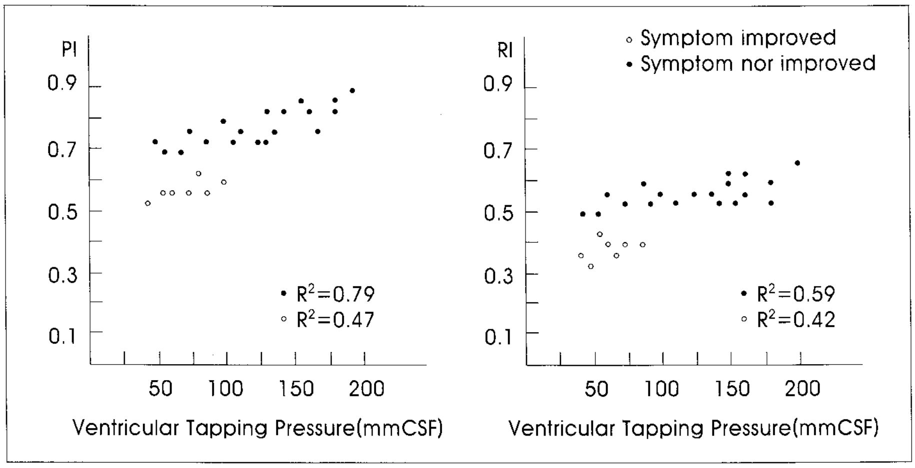

Fig. 2. Ventricular tapping pressure vs. initial transcranial doppler parameters.

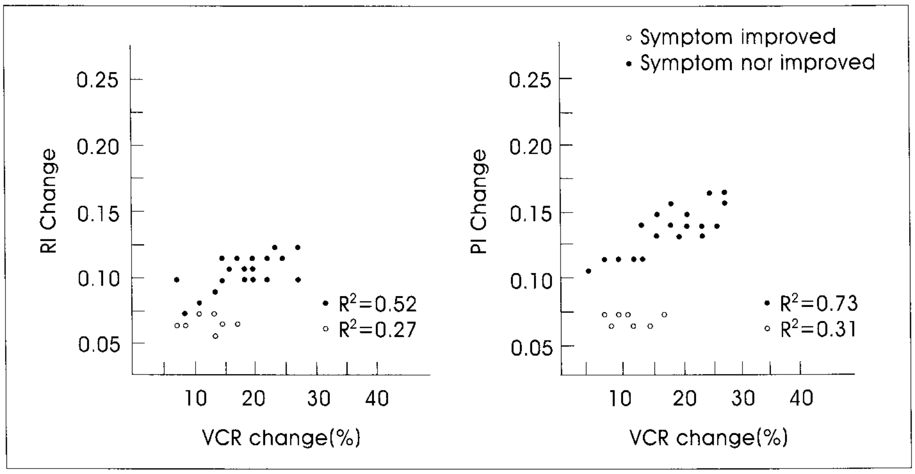

Fig. 3. Ventriculocranial ratio change vs. transcranial doppler parameters.

Table 7. Convexity gyral atrophy vs. initial transcranial doppler parameters

Cortical atrophy (Patient No.)	Improvement* (Patient No.)	TCD(ACA) Vm (cm/sec)	TCD(ACA) PI	TCD(ACA) RI	TCD(MCA) Vm (cm/sec)	TCD(MCA) PI	TCD(MCA) RI
Non	+(6)	39.15±5.33	1.09±0.12	0.74±0.10	37.51±4.21	1.11±0.12	0.55±0.14
(6)	−(1)	44.32±3.52	0.71±0.08	0.53±0.09	44.22±4.58	0.75±0.13	0.52±0.16
Moderate	+(6)	41.21±4.58	1.05±0.11	0.65±0.12	38.65±4.44	0.98±0.25	0.59±0.09
(10)	−(2)	43.23±4.26	0.72±0.12	0.53±0.13	43.44±5.86	0.75±0.11	0.52±0.12
Severe	+(5)	43.88±4.58	0.88±0.12	0.61±0.11	40.14±3.55	0.92±0.15	0.54±0.15
(9)	−(4)	42.25±4.22	0.69±0.17	0.52±0.07	42.25±4.24	0.70±0.07	0.51±0.15

* (+) : Symptom improved postoperatively, (−) : symptom not improved postoperatively. Cortical atrophy degree vs. TCD Parameters. (+) degree vs. Vm R^2=0.55, degree vs. PI R^2=−0.72, degree vs. RI R^2=−0.69. (−) degree vs. Vm R^2=0.43, degree vs. PI R^2=−0.48, degree vs. RI R^2=−0.40

Comparison of brain CT findings with TCD parameters

Postoperative change in ventricular size was assessed using the ventricle and inner table ratio. A decrease in ventricular size in the symptom improvement group correlated with the changes in PI scores acquired through transcranial doppler (R^2= 0.73). However, no correlation was seen in the non-improvement group (R^2= 0.31). The RI scores also decreased as the ventricular size decreased in the symptom improvement group and the non-improvement group but was not statistically significant (Fig. 3). Patients with more severe cortical gyral atrophy showed an increase in Vm and a decrease in PI and RI, and also exhibited poor symptom improvement. When comparing TCD parameters with cortical gyral atrophy in the symptom improvement group, a decrease in PI and RI values were seen in patients with more severe atrophy. and this correlation was statistically significant (PI R^2= 0.72, RI R^2= 0.69) (Table 7).

Discussion

The diagnosis and treatment of hydrocephalus in adults is not often a straightforward task. It is complicated by diagnostic uncertainties and by treatment failures, and sorting out the small fraction of patients with true hydrocephalus is difficult, since no diagnostic test is available that shows a high degree of accuracy in the majority of patients[5]. Furthermore, the presence of hydrocephalus does not necessarily indicate that a good clinical response to ventricular shunting will be achieved. Irreversible brain injury caused by long-term ventricular dilatation, as well as the inability to reduce intraventricular pressure and ventricular volume effectively without complications, may not allow improvement in some patients with true hydrocephalus even after ventricular shunting procedures.

TCD

During the past decade continuous and pulsed wave Dopplers have been used extensively for accurate evaluation of extracranial arterial obstructive lesions.

TCD technique was developed and described by Aaslid et al.[1] By insonating through a "temporal ultrasonic window" blood velocity recordings from the anterior circulation were possible in 95% of the normal population and their normal values were reported. Temporal ultrasonic window, which lies above the zygomatic arch, was used and the patients were evaluated in a supine position. TCD has the advantage of being non-invasive, easily handled at the bedside, and working in real time. TCD monitoring has already been advocated as screening procedure in patients with NPH[3,4,17]. Monitoring of CBF with the TCD technique, however, has several limitations and possible sources of errors. Variability of TCD velocities depends strongly on the skill of the investigator and the angle of insonation[17]. Inaccurate measurements of flow velocities in hydrocephalus patients have also been shown to result from vessel distortion, which may increase the angle of insonation[11]. In the present study, all data were acquired by the same investigator, which should reduce at least the interindividual bias and decrease variability. And PI and RI are a better index as it is a ratio of two velocities read by the same transducer. This helps to reduce the errors mentioned above. Weiner et al.[32] reported experimental evidence showing an adverse effect of ventriculomegaly on CBF, apparently by displacement, deformation, stretching, and decrease in the calibre of cerebral arteries and also demonstrated dilatation of cerebral blood vessels after ventricular drainage. Changes in the TCD signal induced by ventricular shunting have been reported by Homburg et al.[15]. These authors found that PI rapidly decreased to normal values during ventricular tapping and CSF drainage, and they proposed an exponential relationship between PI and ICP. Some authors have found no alterations in cerebral hemodynamics after shunt therapy[5,7,14,19], whereas others found significant improvement in cerebral blood flow[8,10] and cerebrovascular reactivity[6,12,13], and a reduction in PI [11]. Quinn and Pople[26] recorded the PI in children with blocked shunts and showed that a raised PI in such patients returned to values comparable with the control group after shunt revision. A remarkable observation in our study was the decrease in blood flow velocities in patients with and without clinical improvement after shunt surgery, suggestive for a possible postoperative normalization in intraparenchymal pressure and concomitant relaxation of large arteries. In a recent study, Vajda et al.[30] suggested that the TCD-determined PI is a useful noninvasive indicator for stoma patency in children and adults with occlusive hydrocephalus treated by endoscopic fenestration of the third ventricle floor. PI values in the 22 patients studied showed a statistically significant decrease 5 days after surgery, as compared to preoperative values[29-31]. The results reported by Vajda et al.[30] were confirmed in our study, where the comparison of mean TCD indices with ICP values in all 29 hydrocephalic patients resulted in statistically significant differences in PI and RI before and after shunting. Also, a significant positive correlation was calculated between RI and ICP and a positive, but no statistically significant correlation was found between PI and ICP[24,25,27,28]. Nadvi et al.[23] used TCD as a non-invasive method for evaluating shunt function and found a significant reduction in pulsatility index after shunt.

Radionuclide CSF flow study

There has been some change in the choice of methods used to confirm the suspected diagnosis of NPH. Radionuclide CSF flow study, which was a routine method for decades. Ouvrier et al.[24] offered a general perspective on value of CSF scanning in hydrocephlaus patients. In this study isotope is injected into lumbar subarachnoid space, and its passage into the brain and ventricles is visualized. Others studied severity grading and necessity of shunts in communication hydrocephalus patients by undergoing isotope CSF flow studies using Tc 99mm-DTPA. They reported that while all grade I cases did not need shunting, all grade II and IV cases excluding one grade III case revealed progession of hydrocephalus and needed shunting[16,18,21,22]. Ouvrier et al.[24] observed that an improved surgical outcome was noted if ventricular reflux persisted for 48 hours or more and the lack of ascent of radinucleotide to the convexity by 48 hours. The main reasons that Isotope CSF flow study is still valuable is to decrease the diagnostic uncertainty remaining after clinical and CT assesment, especially when the effect of one or CSF taps was inconclusive[9]. According to a report by Black et al.[5], if the finding is "positive" (greater than gradeIII) in a isotope CSF flow study, treatment and diagnosis of hydrocephalus may be helpful. However Petersen et al.[25] suggested that Isotope CSF flow study does not improve the diagnostic accuracy of combined clinical and CT criteria in patients with hydrocephalus. In our study, a greater amount of symptom improvement was seen in higher grades, and a statistically significant correlation was found between grade and PI, RI scores. Therefore, even if there were no symptom improvement, higher grades in the isotope CSF flow study, compared to the TCD parameters, correlated with an increase in the PI and RI scores, which reflect the cerebral hemodynamics. Further study is indicated, but through our study, we can argue that isotope CSF flow study can also be used as a preoperative evaluation modality in hydrocephalus patients.

Brain computed tomography

Findings on the CT scan (significant ventricular enlargement, convexity gyral atrophy) contributed individually and collectively to selection of patients for surgery[20]. Borgesen and Gjerris[7] suggested that good clinical outcome after a shunting procedure could be achieved in the face of cortical atrophy. However in our study, a greater symptom improvement was seen after surgery in patients with larger ventricular size and less convexity gyral atrophy. This also correlated with TCD parameters. Therefore, preoperative brain CT findings is another factor needed to select patients for operation.

Conclusion

We believe that analysis of TCD parameters with radionuclide CSF flow study and brain CT findings can help to predict the surgical outcome of hydrocephalus patients.

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