MRI Study of Morphologic Features and CSF Hydrodynamics to Predict Ventriculoperitoneal Shunt Responsiveness in Normal Pressure Hydrocephalus

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Background: *Selection of shunt responsive normal pressure hydrocephalus (NPH) patients using MRI findings is controversial.*
Objective: *To evaluate findings on conventional MRI and CSF flow study as predictors for shunt responsiveness in NPH patients.*
Material and Method: *The retrospective study of 33 NPH patients with MRI CSF flow measurement was conducted. Conventional MR imaging of these patients were evaluated and scored, and CSF flow parameters were analyzed to determine the significant predictive parameters for clinical outcome of shunt responsiveness. Clinical evaluation was according to the idiopathic normal pressure hydrocephalus grading scale (iNPHGS) before and after the operation. The most improved clinical score during follow-up time (at least 1 year) was counted for evaluation. The distinct improvement was determined as improvement of total iNPHGS equal or more than 3 scores.*
Results: *Thirty-three NPH patients with gait disturbance underwent VP shunting. Cognitive impairment and urinary incontinence were found in 30 patients. Twenty-one patients show overall improvement. None of conventional MRI feature showed relation with the clinical outcome except severe white matter change (Fazekas grade 2 to 3), which showed negative influence to improvement. CFS parameters that can predict shunt responsiveness were mean velocity $\geq$27 mm/s, peak velocity $\geq$62 mm/s, and CSF flux $\geq$0.22 mm^3/s with sensitivity of 70%, 76.2%, 66.7% and specificity of 80%, 75%, 60% respectively. There was no statistically significant difference of disproportionately enlarged subarachnoid-space hydrocephalus (DESH) finding and shunt responsiveness in nineteen cases of iNPH.*
Conclusion: *Severity of white matter change and CSF flow analysis could predict shunt-responsive cases. The hyperdynamic CSF flow as the specific value in our institution can confidently diagnose NPH and predict the marked improvement after VP shunting.*

Keywords: *Normal pressure hydrocephalus (NPH), Ventriculoperitoneal shunt (VPS), Shunt responsiveness, MRI*

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Normal pressure hydrocephalus (NPH) is a clinical triad symptom of gait disturbance, urinary incontinence, and cognitive impairment as characterized by Hakim and Adam in 1965[1]. In pathophysiological terms, NPH has been defined as an imbalance of cerebrospinal fluid formation and absorption that produce a net accumulation of fluid in the ventricular system[2]. The imaging character is dilated ventricular system with the normal range of CSF opening pressure on lumbar puncture. Generally, NPH is classified into idiopathic and secondary NPH which occurs after the known cause such as subarachnoid hemorrhage, head trauma, and meningitis. Due to the incidence of NPH increases corresponding with aging society, some conditions can cause overlap symptoms such as dementia in Alzheimer's disease, gait disturbance in Parkinsonism, or psychomotor abnormality due to psychotic cause. Besides the conditions mimic NPH symptoms, brain atrophy in elderly also makes difficulty to diagnose hydrocephalus confidently on imaging.

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The important of NPH is that its clinical symptoms can be reversible by CSF shunting surgery. Shunting in the patients with secondary NPH usually improve the symptoms with low incidence of complications[3]. Concerning guidelines for management of idiopathic NPH (iNPH), the definite diagnosis of idiopathic NPH is made when there is improvement of the symptoms after shunt diversion[4]. The pre-operative selection of the patient who should get benefit from CSF shunting is essential to prevent complications from unnecessary surgery.

Pre-operative diagnosis of iNPH consists of clinical symptoms, imaging tools, and CSF evaluation. The most clinical presentation is gait abnormality reported in 94.2 to 100%[4-6]. Cognitive impairment was reported about 69 to 88.3% and urinary incontinence in 54 to 76.7%[4].

CSF tap test and CSF drainage test are also used for pre-operative prediction of shunt outcome with high positive predictive value but low sensitivity and specificity[4]. CSF drainage test shows higher accuracy than CSF tap test. But both are invasive procedure and may cause complication such as infection[4].

Many characteristics on imaging were used for diagnosis of hydrocephalus such as more than 0.3 of Evans' index (the ratio of maximum width of frontal horns to the maximum width of inner table skull), tightness of high convexity with dilated sylvian fissure, narrowing of posterior cingulate sulcus, and mean callosal angle of 90°.

Sherman and Citrin found that flow void occurred when much of CSF passing through the cerebral aqueduct on T2W spin-echo images[7]. By using quantitative MRI to select the NPH patient with shunt responsiveness, the phase contrast MRI was reported useful for evaluating dynamic flow parameters. High CSF velocity at cerebral aqueduct was shown to predict shunt responsiveness[8-10]. Witthiwej et al found that mean velocity more than 26 mm/s correlated with overall improvement and the peak velocity more than 70 mm/s correlated with gait improvement[11]. However, some studies found that parameters of CSF flow failed to predict outcome after shunting[12-14].

The purpose of the present study was to evaluate findings on conventional MRI and CSF flow study as the predictors for shunt responsiveness in NPH patients.

Material and Method

The retrospective study was performed in patients clinically suspected NPH at the neurosurgery division of our hospital during January 2006 and June 2012. All patients were treated by shunt surgery. Patients who could not be evaluated their symptoms after shunt operation and unavailable MRI CSF flow study were excluded from the study. The age, sex, history of diabetes mellitus, hypertension, dyslipidemia, benign prostatic hypertrophy (BPH), cervical spondylosis, and Alzheimer's disease were collected as the demographic data.

CSF flow study was performed by 2D phase contrast technique (Achieva, 3 Tesla, Phillips, Best, the Netherlands) with parameters of TR 12 ms, TE 8.3 ms, Flip angle 15°, slice thickness 4 mm, and double NEX. Velocity encoding gradient (VENC) was initially set as 10 cm/s and adjusted increasingly according to each patient if aliasing artifact was presented. Flow parameters were measured on non-aliasing images at middle level of cerebral aqueduct on the axial plane perpendicular with the long axis of the duct.

Two experienced neuroradiologists blind to clinical data reviewed the conventional MRI separately and made consensus for any discrepancy. Example pictures of each finding were available for comparison as the operational definition. The findings on conventional MRI were recorded as Evans' index, callosal angle (measured on coronal view image at position of posterior commissure), presence of narrowed parasagittal high convexity, widening of sylvian fissure, narrowing posterior part of cingulate sulcus, bowing of corpus callosum, focal dilatation of sulci, periventricular hyperintensity, and degree of white matter change (according to Fazekas' scale)[15]. The disproportionately enlarged subarachnoid-space hydrocephalus (DESH) was defined as combination of ventricular dilatation, dilated sylvian fissure with tight high-convexity and medial surface of subarachnoid space[16]. Presence of infarction or other additional findings were also recorded. An in-training neuroradiologist processed CSF flow data by using commercial software (ViewForum, Philips, Best, the Netherlands) and collected the peak, maximum, mean, minimum velocity, flux, and stroke volume.

The clinical evaluation was done by an experienced neurosurgeon. Clinical rating score was evaluated in each part of the triad symptoms before and after operation according to the Japanese idiopathic normal pressure hydrocephalus grading scale (iNPHGS)[17]. At least 1 point score increased postoperatively was classified as improvement of that symptom. The overall significant improvement was

defined as at least 3 point scores of the sum of all symptoms. For the non-improved patients, follow-up at least up 1 year was done before determination of the clinical scale.

All data was analyzed by SPSS (version 18.0). The receiver operation curve (ROC) was analyzed to identify cut point of the CSF flow parameters related with clinical outcome. Imaging findings were analyzed with Fisher's test. The 95% confidence interval was calculated. Inter-observer agreement was analyzed with kappa statistics and calculated for percent agreement.

Results

There were 33 patients (22 males, 11 females) with mean age of 70.4 years old (range 44 to 89 years old). Only one iNPH patient was aged less than 60 years old (56 years old). Underlying diseases included diabetes mellitus in 16 cases, hypertension in 27 cases, dyslipidemia in 14 cases, benign prostatic hypertrophy (BPH) in 4 cases, cervical spondylosis in 3 cases, and Alzheimer's disease in 6 cases. Gait disturbance was noted in all 33 patients (100%). Cognitive impairment and urinary disturbance were noted in 30 patients each (90.9%). Classical triad symptoms (gait disturbance, urinary incontinence, and cognitive impairment) are noted in 27 patients (81.8%). Of the 33 patients, 19 were primary NPH and 14 were secondary NPH due to posttraumatic brain injury and post operation for tumors such as acoustic neuroma, meningioma, and suprasellar germinoma. The duration of symptoms before treatment and outcomes were not statistically correlated in our study (2 to 108 months with mean 19.6 months in overall improved group, and 1 to 72 month with mean 14.7 months in non-improved group).

Spinal tap test (STT) is the standard of invasive investigation of NPH consists of the removal of at least 30 ml of cerebrospinal fluid (CSF) from the patient. Positive STT defined as any significant improvement of one of clinical triad symptoms. STT were done in 23 patients with positive tap test in 21 and negative in 2. The diagnostic performance of the tap test for predicting shunt responsive in overall outcome was 93.3% sensitivity, 12.5% specificity, and 65.2% accuracy. After VP shunting, all showed improvement at least 1 score of the iNPHGS. Improvement of 2 scores of iNPHGS was noted in 26 patients and 21 patients showed overall improvement. Cognitive improvement was found in 19 patients. Gait improvement was found in 27 patients, and urinary improvement was found in 20 patients. Five of 6 patients with clinical diagnosis of Alzheimer's disease improved in cognitive function after shunt placement and 3 of 4 patients with clinical diagnosis of BPH also had improvement in their urination.

Of 33 patients, MRI findings revealed narrowing parasagittal high convexity in 29, widening sylvian fissure in 26, bowing corpus callosum in 29, narrowing posterior part of cingulate sulcus in 19, focal dilated sulcus in 7, mild white matter change in 12, moderate to severe white matter change in 21, Evans index more than 0.3 in 28, and callosal angle less than 90 degree in 15 patients (Table 1).

The only statistically significant predictors of MRI finding for shunt responsiveness were Fazekas score, mean velocity, peak velocity, and flux. The other conventional MRI findings showed no relationship with shunt responsiveness. Three CSF flow parameters (flux, mean velocity, peak velocity) showed statistic correlation with overall shunt responsiveness with area under curve of 0.735, 0.724, and 0.641 for mean velocity, peak velocity, and CSF flux, respectively. The value of peak velocity more than 62 mm^3/s, mean velocity more than 27 mm/s, and CSF flux more than 0.22 mm^3/s were used to predict overall improvement after shunting with sensitivity of 76.2%, 70.0%, and 66.7% and specificity of 75%, 80.0%, and 60.0% respectively (Table 2). The patients with higher Fazekas score (moderate to severe change of deep white matter) had worse shunt outcome than the lesser score in urination.

Nineteen idiopathic NPH were analyzed for MRI findings of DESH. There was no statistically significant difference of DESH finding and shunt responsiveness with the sensitivity and specificity of 61% and 33%, respectively. Comparing DESH and CSF flow parameters for predicting shunt outcome was shown on Table 3.

Inter-observer agreement of the conventional MRI findings showed high level of percent agreement ranged from 81.2% to 100%.

Discussion

The definite pathogenesis of NPH was still unknown. Some hypotheses suggested that poor cerebral compliance cause ventricular dilatation and poor perfusion of subcortical cerebral hemispheres[18,19]. Gait impairment was results from compromised corticospinal tract that closest to the lateral ventricle. The urinary symptom may due to involvement of sacral fiber of the corticospinal tract[20,21]. Moreover, dementia symptoms in NPH are subcortical type and may be due

Table 1. Correlation between clinical outcome and conventional MRI findings

Findings	Presence	Overall improve after VP shunt	Gait improve after VP shunt	Urinary improve after VP shunt	Cognitive improve after VP shunt
Narrowing parasagittal high convexity	29/33 (87.9%)	19/29 (65.5%)	24/29 (82.8%)	18/27 (66.7%)	17/26 (65.4%)
Bowing corpus callosum	29/33 (87.9%)	17/29 (58.6%)	23/29 (79.3%)	16/26 (61.5%)	17/26(65.4%)
Evan's index >0.3	28/33 (84.8%)	16/28 (57.1%)	22/28 (78.6%)	16/25 (64.0%)	15/25(60.0%)
Widening sylvian fissure	26/33 (78.8%)	17/26 (65.4%)	22/26 (84.6%)	15/23 (65.2%)	15/25(60.0%)
Periventricular effusion	26/33 (78.8%)	15/26 (57.7%)	21/26 (80.8%)	13/23 (56.5%)	15/24(62.5%)
Moderate to severe white matter change (Fazeka grade 2, 3)	21/33 (63.6%)	13/21 (61.9%)	17/21 (81.0%)	10/19 (52.6%)	11/20(55.0%)
Mild level of white matter change (Fazeka grade 0,1)	12/33 (36.4%)	8/12 (66.7%)	10/12 (83.3%)	10/11 (90.9%)	8/10(80.0%)
Narrowing at posterior part of cingulate sulcus	19/33 (57.6%)	11/19 (57.9%)	16/19 (84.2%)	11/19 (57.9%)	12/18 (66.7%)
Callosal angle <90°	15/33 (45.4%)	9/15 (60.0%)	13/15 (86.7%)	7/14 (50.0%)	9/13 (69.2%)
Focal dilated sulci	7/33 (21.2%)	5/7 (71.4%)	7/7 (100.0%)	3/5 (60.0%)	4/6 (66.7%)

Table 2. Diagnostic performance of CSF flow parameters in predicting overall improvement after shunting

Parameter	threshold	sensitivity	specificity	PPV	NPV	accuracy	LR+
Flux	≥0.22	66.7%	60.0%	77.8%	53.3%	66.7%	1.67
Mean velocity	≥27	70.0%	80.0%	87.5%	57.1%	73.3%	3.50
	≥29	61.9%	83.3%	86.7%	55.6%	69.7%	3.70
Peak velocity	≥62	76.2%	75.0%	84.2%	64.3%	75.8%	3.00

Table 3. Sensitivity and specificity of DESH and CSF flow parameters in predicting overall improvement after shunting in iNPH cases (n = 19)

Predictors	Sensitivity	Specificity	*p*-value
DESH	61.5%	33.3%	1.000
Flux (18 mm3/s)	90%	80%	0.126
Mean velocity (20 mm/s)	82%	80%	0.150
Peak velocity (62 mm/s)	63.6%	80%	0.069

to decreased CBF at subcortical region[19].

Clinical outcome and co-morbidity

In our study, the mean age was 70.4 years old (range 44 to 89). The mean age of the patients corresponds with previously reported literatures[5,12,22]. The duration of symptoms before treatment and outcomes were not statistically correlated in our study (2 to 108 months with mean 19.6 months in overall improved group, and 1 to 72 month with mean 14.7 months in non-improved group). However, these results from previous study were still controversial[23,24].

We found that no correlation between underlying DM and HT, dyslipidemia and shunt responsivesness. Bech-Azeddine studied about comorbidity that correlates with NPH and found the tendency to increased prevalence of Alzheimer's disease (AD) and cardiovascular disease (CVD) in non-responders after shunting[25]. Even though no correlation of underlying AD and shunt responsiveness

in our study, five of six patients (83.3%) with underlying AD showed improvement of memory impairment and gait disturbance. This may support the multi-etiology of cognitive impairment. Bech-Azeddine R et al studied in 28 NPH patients diagnosed by clinical, radiological, and CSF dynamic study and underwent biopsy at frontal cerebrum during shunt operation. They found tendency of increased prevalence of CVD or AD in the subgroup of nonresponsive or deteriorated cases after shunting[25]. Pathological specimens reflected clinical diagnosis of comorbidity and AD was found in 7 from 28 biopsy specimens in their study. However, no significant correlation between co-morbidity finding and shunt outcome was noted.

Three of four cases with pre-operative diagnosis of BPH presented with urinary incontinence. Interestingly, all of these three patients showed improvement in magnitude of their urinary problems after shunting. One case also showed good response from pre-operative urinary iNPHGS score of 3 to 1 after 2 months follow-up. This may imply that some patients diagnosed BPH had suffered from NPH symptoms.

Conventional MRI findings in NPH

Many characteristics on imaging were used for diagnosis of hydrocephalus such as ventricular index more than 0.3. Waldemar et al found the ventricular ratio of 0.35 as a predictor of clinical outcome after shunting given sensitivity of 50% and specificity of 100%[19]. Enlarged sylvian fissure and focal dilated sulci were found to support the diagnosis of shunt responsiveness in iNPH according to the study of Kitagaki et al[26]. Adachi et al found that narrowing of posterior cingulate sulcus was seen only in the patient with NPH and was not seen in the control group or in the patient with dementia from other causes with both sensitivity and specificity of 100%[27]. Ishii K et al found that mean callosal angle in the patients with NPH group was about 66° (66°$\pm$14°) that significantly differed from the patients with AD (104°$\pm$15°) and the control group (112°$\pm$11°), and the callosal angle of 90° could be used to diagnose NPH with sensitivity of 97%, specificity of 88%, and accuracy of 93%[28]. However, none of these findings showed statistical significant in predicting shunt responsiveness in our study.

One interesting finding in our study was the severity of white matter change. Severe white matter change (Fazekas scale 2 to 3) was negatively correlated with improvement of urinary incontinence after shunting (p = 0.049). This finding was agreed with some previous studies[29-31]. This may support that subcortical or deep white matter hyperintensity on T2W was due to poor cerebral blood flow and resulted in white matter ischemia. However, Tullberg et al found that some patterns of white matter change decreased in size and clinical improvement correlated with reduction of white matter change. However, vascular white matter changes on MR images could not exclude NPH patients from shunt surgery[24].

The disproportionately enlarged subarachnoid-space hydrocephalus or DESH pattern was reported by Japanese group as high accuracy for diagnosis and predicting shunt responsive cases in iNPH[16,26,32]. In this study, nineteen idiopathic NPH were analyzed for MRI findings of DESH. We found lower diagnostic performance for DESH in the subgroup analysis in predicting outcome. There was no statistically significant difference of DESH findings and shunt responsiveness with the sensitivity and specificity of 61% and 33% respectively. Study with more cases may be needed to evaluate the findings.

MRI CSF flow studied in NPH

In our study, three parameters correlated with overall shunt responsiveness were mean velocity, peak velocity, and CSF flux. These agreed with many previous studies presenting useful of CSF parameters for predicting the shunt outcome. Difference of peak velocity through cerebral aqueduct between normal control group and NPH patients were reported[20,33,34]. In our previous study with 1.5T MR machine, the mean velocity of the CSF flow through the aqueduct of Sylvius was significantly different between shunt-responsive and non-responsive groups (p<0.05). The peak velocity was a significant difference between gait responsive and non-responsive groups (p<0.05). Using a mean velocity threshold 26 mm/sec to identify the significant responsive group, the sensitivity is 50%, specificity 83.3%, positive predictive value 87.5%, and accuracy 70%. In order to identify the gait responsive group by using a threshold of peak velocity 70 mm/sec, the sensitivity was 60%, specificity 83.3%, positive predictive value 81.5%, and accuracy 60%[11].

There was controversy in using CSF flow study to predict shunt responsiveness[8,10,12-14]. The different results might be explained by different time point of the flow measurement in the clinical course of the disease and MRI technique of measurement. Scollato et al studied the clinical and radiologic diagnosis of 9 NPH patients who refused to CSF shunt. They followed clinical symptoms and phase contrast cine MRI every 6 months up to 2 years and

found increased stroke volume (SV) in the first 18 to 20 months from onset, followed by plateau of the SV and slightly declined finally to a more precipitous drop in the next 12 months. During this followed time, the patients' symptoms were progressively worsening[35]. Moreover, other factors related to the physiology of breathing might affect the result of the measurement[36].

Spinal tap test in NPH patients

STT is generally used for preoperative predicting shunt outcome. The diagnostic performance of the STT was studied as a standard diagnostic method of NPH diagnosis[4]. In our study, most predictive value of STT was related to improvement gait instability. One of two patients with no improvement after STT showed overall improvement after shunt placement. Comparison between diagnostic performance of STT and CSF flow parameters, the specificity of MRI was much better than that of STT. A study of Sharma et al in 37 clinically suspected NPH patients who were tested by CSF flow velocity at cerebral aqueduct by phase contrast cine MRI before and within 30 minutes after lumbar CSF drainage revealed that 93% of shunt responsive patients had decreased peak velocity more than 2 cm/s after lumbar CSF drainage and all patients with peak velocity decreased less than 2 cm/s showed no improvement[20]. By comparison, CSF flow parameters before and after CSF drainage test may be a supplementary way to improve prediction of shunt outcome with tap test.

Limitations

The limitation of this study was relative small number of the patients that might cause weakly statistical significance. As compared with our previous study in 1.5T MRI, we found that the reproducibility of CSF flow parameters by different MRI scanner gave the different values. So the values for hyperdynamic flow parameters in our study might not be represent the parameters in other institutes.

Conclusion

This study showed that severity of white matter change and CSF flow analysis could predict shunt-responsive cases. Co-morbidity of other diseases with the similar clinical signs and symptoms should be considered in such patients. The hyperdynamic CSF flow as the specific value (peak velocity $\geq$62 mm^3/s, mean velocity $\geq$27 mm/s) in our institution can confidently diagnose NPH and predict the noticeably improvement after VP shunting.

What is already known on this topic?

Controversy of MRI findings in selecting shunt responsive cases of NPH patients was reported.

What this study adds?

Most of imaging features on MRI were not predictive of such cases. Severity of white matter change and MRI CSF flow analysis could predict shunt-responsive cases.

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Potential conflicts of interest

None.

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การศึกษาลักษณะภาพเอ็มอาร์ไอและการวัดค่าการไหลของน้ำไขสันหลังในการทำนายผู้ป่วย normal pressure hydrocephalus ที่ตอบสนองต่อการใส่ท่อระบาย

ธีรพล วิทธิเวช, วิวิธวรรณ สุขียามานนท์, ทิตพงษ์ ส่งแสง, พนิดา ชาญเชาว์วานิช, ปฤณัต อิทธิเมธินทร์, วัฒนชัย โชตินัยวัตรกุล, อรสา ชวาลภาฤทธิ์

ภูมิหลัง: ยังเป็นที่ถกเถียงกันเกี่ยวกับการเลือกผู้ป่วย normal pressure hydrocephalus (NPH) ที่น่าจะตอบสนองต่อการใส่ท่อระบายน้ำโดยใช้ลักษณะสมองในภาพเอ็มอาร์ไอ

วัตถุประสงค์: เพื่อศึกษาการใช้ลักษณะสมองในภาพเอ็มอาร์ไอและการไหลของน้ำไขสันหลังในการคัดกรองผู้ป่วย normal pressure hydrocephalus (NPH) ที่อาจตอบสนองต่อการใส่ท่อระบายน้ำไขสันหลัง

วัสดุและวิธีการ: เป็นการศึกษาย้อนหลังในผู้ป่วยที่มารับการรักษาภาวะ NPH โดยการผ่าตัดใส่ท่อระบายน้ำไขสันหลังและได้รับการตรวจเอ็มอาร์ไอก่อนผ่าตัด ลักษณะที่พบในภาพเอ็มอาร์ไอและค่าวัดการไหลของน้ำไขสันหลังผ่าน aqueduct of sylvius ถูกเก็บบันทึกเพื่อเปรียบเทียบระหว่างกลุ่มที่ใส่ท่อระบายแล้วอาการดีขึ้นและไม่ดีขึ้น การให้คะแนนอาการผู้ป่วยก่อนและหลังใส่ท่อระบายใช้สเกล Idiopathic Normal Pressure Hydrocephalus Grading Scale ของประเทศญี่ปุ่นโดยกำหนดให้คะแนนรวมหลังผ่าตัดดีขึ้นอย่างน้อยสามคะแนน ระยะเวลาในการตัดสินว่าอาการดีขึ้นหรือไม่คือระยะเวลาอย่างน้อยหนึ่งปีหลังผ่าตัด

ผลการศึกษา: ผู้ป่วย 33 รายที่มีอาการเดินผิดปกติทุกรายได้รับการใส่ท่อระบาย ภาวะสมองเสื่อมและปัสสาวะผิดปกติพบ 30 ราย ผู้ป่วยอาการดีขึ้นหลังผ่าตัด 21 ราย มีเพียงความรุนแรงของรอยโรคในสมองเนื้อขาว ในภาพเอ็มอาร์ไอและการวัดค่าการไหลของน้ำไขสันหลังที่สามารถทำนายการตอบสนองต่อการผ่าตัดของผู้ป่วย ลักษณะรอยโรคในสมองเนื้อขาวรุนแรง (Fazekas grade 2 ถึง 3) จะไม่ตอบสนองต่อการผ่าตัด ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติของลักษณะร่องสมองแคบแต่ร่องซิลเวียนกว้างระหว่างผู้ป่วยทั้งสองกลุ่ม ค่าวัดการไหลที่ทำนายการตอบสนองต่อการผ่าตัดคือค่าเฉลี่ยของการไหลที่เท่ากับหรือมากกว่า 27 มิลลิเมตรต่อวินาที ค่าความเร็วสูงสุดของการไหลที่เท่ากับหรือมากกว่า 62 มิลลิเมตรต่อวินาที และค่า flux ของการไหลที่เท่ากับ หรือมากกว่า 0.22 ลูกบาศก์มิลลิเมตรต่อวินาที โดยมีความไวร้อยละ 70, 76.2, 66.7 และความจำเพาะร้อยละ 80, 75, 60 ในการทำนายตามลำดับ

สรุป: การตรวจและวัดการไหลของน้ำไขสันหลังด้วยเอ็มอาร์ไอสามารถใช้ร่วมกับลักษณะรอยโรคในสมองเนื้อขาวในการทำนายการตอบสนองต่อการผ่าตัดในผู้ป่วย NPH