ORIGINAL COMMUNICATION

Brain MRI as a predictor of CSF tap test response in patients with idiopathic normal pressure hydrocephalus

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Abstract In this study, our objective was to identify the characteristic morphological features of brain MRI associated with a positive cerebrospinal fluid (CSF) tap test in patients with idiopathic normal pressure hydrocephalus (iNPH). Patients diagnosed with clinical suspected iNPH were evaluated. All patients underwent a mini-mental state examination, a brain MRI, and a CSF tap test. The severities of clinical symptoms were rated before and after the CSF tap test. Characteristic brain MRI findings including frontal convexity narrowing, parietal convexity narrowing, upward bowing of the corpus callosum, empty sella, narrowing of the CSF space at the high convexity, marked dilatation of the Sylvian fissure, and disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure ("mismatch" sign) on T1-weighted or FLAIR image were analyzed. Forty-three patients (33 males/ten females, mean age 76.9 ± 6.9 years) with possible iNPH participated in this study. The presence versus absence of empty sella (52.4 vs. 14.3%, OR 6.6, 95% CI 1.5–29.4, $p = 0.02$) and "mismatch" sign (45.5 vs. 9.5%, OR 7.9, 95% CI 1.5–42.5, $p = 0.02$) were associated with positive CSF tap test responses. The sensitivity, specificity, positive predictive value, and negative predictive value of the presence of either of these two MRI features in the prediction of CSF tap response were 72.7, 81, 80, and 73.9%, respectively. Specific brain MRI features can be used as markers for the identification of potential CSF tap test responders in iNPH patients. These features may serve as supplemental evidence in the diagnosis of iNPH patients.

Keywords CSF tap test · Magnetic resonance imaging · Normal pressure hydrocephalus

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Introduction

Normal pressure hydrocephalus (NPH) is a clinical syndrome that was first described in 1965 as presenting a triad of symptoms including dementia, gait disturbance, and urinary incontinence [1]. The causes of NPH can be idiopathic or can be secondary to traumatic brain injury, meningitis, subarachnoid hemorrhage (SAH) or intracranial surgery [2]. The exact pathologic process of idiopathic normal pressure hydrocephalus (iNPH) remains unclear. The underlying pathophysiological mechanism appears to include impaired cerebrospinal fluid (CSF) flow within the ventricles and/or subarachnoid space, defective CSF absorption through the arachnoid granulation, or impaired intracranial vascular compliance [3, 4].

Relkin et al. [5] proposed diagnostic criteria for the classification of patients into probable, possible, and unlikely iNPH, based solely on clinical symptoms in combination with interpretation of brain-imaging studies but not the response to shunt replacement. Nevertheless, they applied the term "shunt-responsive iNPH" to any diagnostic category, probable, possible, or unlikely, that responds favorably to surgical intervention [5–7]. In contrast, the Japanese guidelines for management of iNPH [8] suggested that definitive diagnosis of iNPH was based on a patient's response to shunt surgery. The shunt-associated complications should be the first concern when treating iNPH patients. Recent literature of shunt-associated complications in iNPH was controversial [6, 9]. One review [9] suggested that there are no long-term detrimental effects, but the other meta-analysis [6] showed that the procedure was associated with a 38% complication rate, resulting in permanent neurological deficits, intracerebral hemorrhage, subdural hemorrhage, meningeal infection, and death.

Many supplemental diagnostic tools have been used to improve the diagnostic procedure in iNPH, including magnetic resonance imaging (MRI) of the brain [10–13], radionuclide cisternogram [14, 15], cine phase-contrast MRI for aqueductal CSF stroke volume [16–18], CSF tap test [19–21], external lumbar CSF drainage [22, 23], and lumbar infusion test [24–26].

The CSF tap test is a simple method that has been proven to have a high positive predictive value of successful shunt surgery [19, 23]. However, it should not be used as a test for exclusion from shunt surgery because of the relatively low sensitivity (26–62%) predicting a favorable surgical outcome [27]. While external lumbar CSF drainage has a higher sensitivity than the CSF tap test, its disadvantages include a prolonged hospital stay and a relatively higher complication rate [28].

Some specific morphological patterns of brain MRI, including enlarged basal cisterns and Sylvian fissures, narrowing of the CSF space at high convexity and high midline areas, and focally dilated sulci, have been useful in the diagnosis of iNPH [10, 11]. A recent review [29] summarized the structural imaging features in NPH with the conclusion that there was not enough evidence to support the diagnosis of NPH by specific MRI morphological patterns alone. In addition, previous studies on MRI findings in patients with iNPH have either had a small subject size or did not provide prospective data [10, 11].

The aim of the present study was to examine the correlation between the specific morphological patterns of brain MRI and CSF tap test responses in patients with possible iNPH. The results may be used as a supplemental aid in clinical diagnosis for patients with iNPH.

Methods

Patients

Patients ($n = 48$) with physical and cognitive symptoms and brain image findings (Brain CT or MRI) suggestive of iNPH were evaluated at Taipei Veterans General Hospital. Diagnosis of iNPH was based on the criteria proposed by Relkin et al. [5]. Patients must be older than 40 years of age with insidious progression of symptoms (gait disturbance plus at least one other area of impairment in cognition, urinary symptoms, or both) for at least 3–6 months and have normal CSF opening pressure. Brain scans (MRI or CT) of all participants showed widening of the ventricles (Evans ratio >0.3) and no macroscopic obstruction to CSF flow. The evidence for diagnostic value of other imaging results (e.g., cine phase-contrast MRI and radionuclide cisternogram) is weak [5, 17, 18, 27] and therefore, these supportive measures were not included as criteria.

Procedures

History taking and clinical severity rating

Age, gender, body mass index (BMI), past histories, personal histories, and initial and full-blown symptoms for all patients were recorded. Patients also underwent the mini-mental state examination (MMSE) [30] and a serum total cholesterol level check. A four-point subscale modified from Krauss et al. [31] was used to rate the severity of each fundamental symptom of iNPH (gait disturbance, cognitive impairment, and urinary incontinence) (Table 1) after an unstructured interview with patients and caregivers. All subjects underwent CSF tap test and brain MRI.
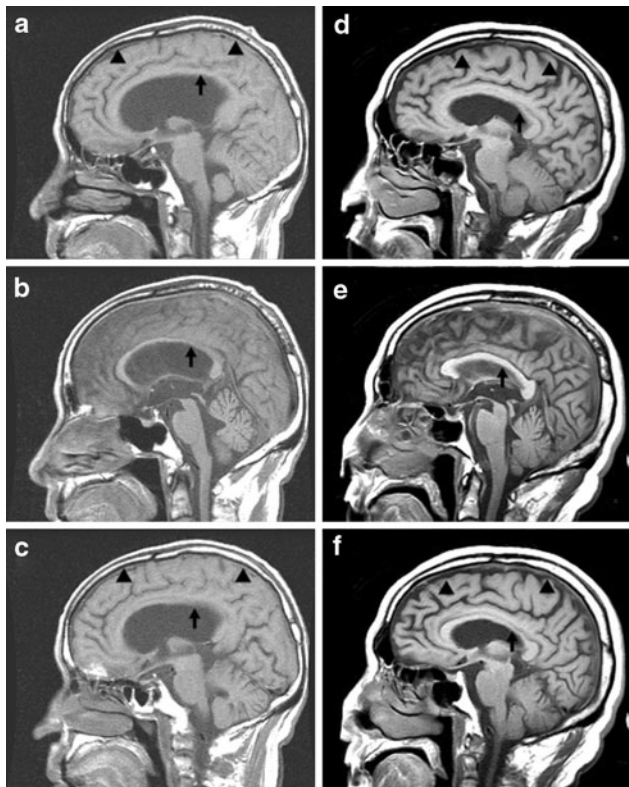
CSF tap test

The CSF tap test was performed by lumbar puncture (LP) followed by measurement of CSF opening pressure and finally CSF collection. We collected 40 cc of CSF or as much as possible until the patients could no longer tolerate the procedure. One day after the procedure we re-evaluated the severity of patients' symptoms using the four-point scale and MMSE as mentioned above. The following criteria were used to identify responders: improvement on any one of the three fundamental symptoms using the four-point scale or a three-point or greater improvement on the follow-up MMSE results [22].

Brain MRI

Axial and sagittal spin-echo T1-weighted images were obtained by using a 1.5-T MRI unit (Signa Excite, General

Table 1 The four-point rating scale for the three domains of the clinical triad in patients with idiopathic normal pressure hydrocephalus

Score	Gait	Mental status	Urinary control
0	Normal	Normal	Normal
1	Discrete imbalance when turning, with short steps	Minimal attention or memory deficits	Precipitate micturition
2	Aid needed for ambulation and frequent falls	Apparent attention or memory deficits but oriented to situation	Incontinence or more times per day
3	Impossible gait	Stuporous or delusive patients	Absolute incontinence

Fig. 1 **a–c** A paramedian-sagittal T1-weighted brain MRI obtained from a CSF tap test responder showing frontal convexity tightness, parietal convexity tightness (*arrowheads*), and upward bowing of the corpus callosum (*arrows*). **d–f** A paramedian-sagittal T1-weighted brain MRI obtained from a CSF tap test non-responder without frontal convexity tightness, parietal convexity tightness (*arrowheads*), and upward bowing of the corpus callosum (*arrows*)

Electric, Milwaukee, WI, USA). We also obtained axial fast spin-echo T2-weighted and fluid-attenuated inversion recovery (FLAIR) images in order to exclude other illnesses. The following items were recorded according to visual analysis of brain MRIs: (1) frontal convexity narrowing on sagittal T1-weighted images, (2) parietal convexity narrowing on sagittal T1-weighted images, (3) upward bowing of the corpus callosum on sagittal T1-weighted images (Fig. 1), (4) empty sella on sagittal T1-weighted images (Fig. 2), (5) narrowing of the CSF space at the high convexity (according to the upper two axial sections) on axial T1-weighted or FLAIR images [10, 11], (6) marked dilatation of the Sylvian fissure on axial T1-weighted or FLAIR images, and (7) disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure ("mismatch" sign) on axial T1-weighted or FLAIR image (Fig. 3). Visual analyses were conducted independently by two neuroradiologists who were experienced in MRI correlates of NPH patients and who were blind to both diagnosis and CSF tap test results of subjects. The inter-rater reliability was high (Kappa values range from 0.732 to 0.836). All borderline findings during the visual analyses were considered negative.

Statistics

All statistical analyses were performed on the statistical software package SPSS for Windows (version 13.0.; SPSS Inc., Chicago, IL, USA). The patients were divided into two groups: CSF tap test responders and non-responders. The clinical profile and MRI characteristic features were compared between these two groups. Chi-square and t test were used when appropriate. The predictors of MRI features were presented as odds ratios (ORs) with 95% confidence intervals (CIs). The sensitivity and specificity along with the positive and negative predictive value of MRI characteristic features were assessed. The statistical significance level was set at $p < 0.05$.

Results

Of the 48 patients with NPH evaluated for this study, three were excluded because of known secondary causes (SAH, $n = 2$ and meningitis, $n = 1$), one because of pacemaker interference with MRI examination, and one due to the absence of a reliable caregiver to provide history. The remaining 43 patients (33 males and ten females, mean age 76.9 ± 6.9 years, range 52–89) constituted the final sample for analysis. All patients had gait disturbance, 97.7% (42/43) had cognitive impairments, and 55.8% (24/43) had urinary incontinence. The mean initial MMSE score was
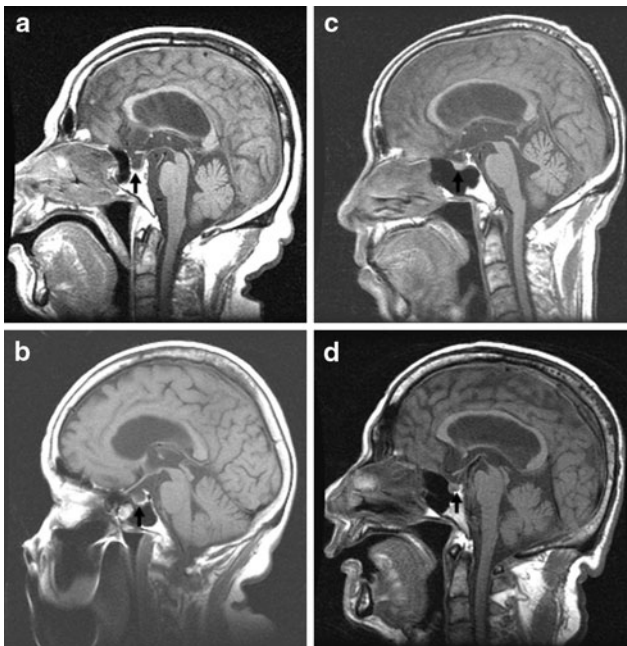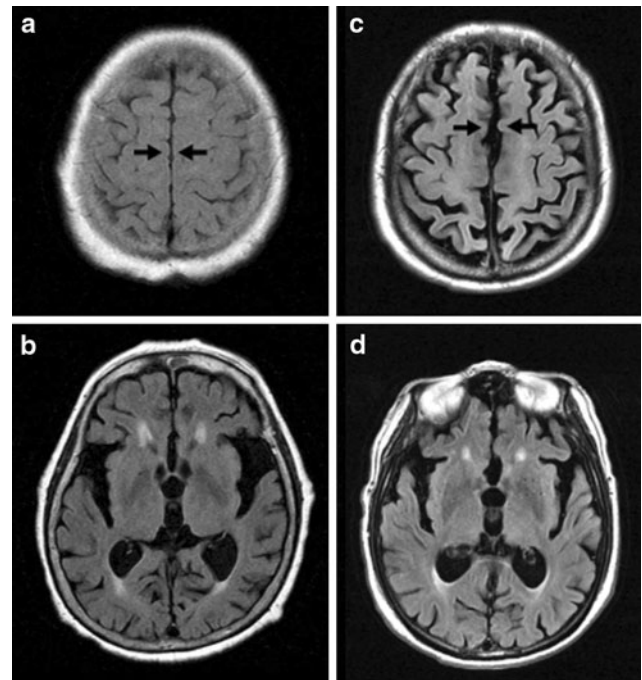
Fig. 2 a, b A paramedian-sagittal T1-weighted brain MRI obtained from a CSF tap test responder showing an enlarged and empty sella (*arrows*). c, d A paramedian-sagittal T1-weighted brain MRI obtained from a CSF tap test non-responder showing no abnormality of sella turcica (*arrows*)

Fig. 3 a, b An axial T1-weighted brain MRI obtained from a CSF tap test responder, showing disproportion between narrowing of the CSF spaces at the high convexity and dilatation of the Sylvian fissures (narrowing of the high convexity CSF spaces (*arrows*) with relative dilated Sylvian fissures). c, d An axial T1-weighted brain MRI obtained from a CSF tap test non-responder showing no narrowing of the high convexity CSF spaces (*arrows*) and non-dilated Sylvian fissures

18.3 ± 6.7. The mean duration of symptoms was 26.6 ± 25.1 months (range 3–96). The mean score on the four-point scale was 1.4 ± 0.6 for gait, 1.4 ± 0.7 for cognition, and 1.0 ± 1.0 for urinary control. The mean total score was 3.7 ± 1.9.

According to the results of the CSF tap test, 22 of the 43 patients (51.2%) were classified as responders while the rest ($n = 21$, 48.8%) were non-responders. The mean drainage volume of CSF during the tap test was 25.5 ml in the tap test responder group and 22.4 ml in the tap test non-responder group. Among the 22 CSF tap test responders, 19 patients showed gait improvement (86.4%), seven patients showed cognitive improvement (31.8%), two patients showed improvement of urinary incontinence (9.1%), five patients showed both gait and mental improvement (22.7%), and no patients showed improvement of all three clinical symptoms. The personal histories, past histories, initial symptoms, full-blown symptoms, duration of the symptoms, the four-point subscale scores, initial MMSE scores, and the volumes of CSF drainage did not differ between the responders and non-responders (Table 2).

The results of visual analysis of brain MRI are summarized in Table 3. One sagittal brain MRI exam was excluded due to marked motion artifacts. The CSF tap test responders were associated with the presence of empty sella (52.4 vs. 14.3%, responders vs. non-responders,

respectively; OR = 6.6, 95% CI = 1.48–29.36, $p = 0.02$) and the "mismatch" sign (45.5 vs. 9.5%, responders vs. non-responders, respectively; OR = 7.9, 95% CI = 1.47–42.54, $p = 0.02$). The sensitivity, specificity, positive predictive value, and negative predictive value of empty sella were 52.4, 85.7, 78.6, and 64.3%, respectively, and for "mismatch" sign were 45.4, 90.5, 83.3, and 61.3%, respectively. The presence of either empty sella or "mismatch" sign was the best predictor for the CSF tap test response (72.7 vs. 19.0%, responders vs. non-responders, respectively; OR = 11.3, 95% CI = 2.69–47.72, $p = 0.001$). The sensitivity, specificity, positive predictive value, and negative predictive value for showing one of these features were 72.7, 81, 80, and 73.9%, respectively.

Discussion

Using the routinely performed axial and sagittal spin-echo MRI to evaluate patients with iNPH, we found that empty sella and disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure ("mismatch" sign) were correlated with CSF tap

Table 2 The demographics, clinical data, and results of cerebrospinal fluid (CSF) tap test between the CSF tap responder and non-responder groups

Characteristics[a]	Tap test responder (n = 22)	Tap test non-responder (n = 21)
Male patient	15 (68.2%)	18 (85.7%)
Age, mean (SD), year	76.2 (7.54)	77.7 (6.25)
BMI, mean (SD)	23.1 (3.60)	23.8 (4.06)
Alcohol consumption history	4 (18.2%)	0 (0%)
Current smoker	4 (18.2%)	1 (4.8%)
Hypertension	12 (54.5%)	11 (52.4%)
Diabetes mellitus	7 (31.8%)	8 (38.1%)
Coronary artery disease	3 (13.6%)	9 (42.9%)
Heart failure	0 (0%)	1 (4.8%)
Ischemic stroke	4 (18.2%)	3 (14.3%)
Total cholesterol, mean (SD), mg/dl	198.6 (48.74)	188.3 (31.74)
Duration of symptoms, mean (SD), month	21.0 (17.54)	32.4 (30.56)
Initial symptoms		
Gait disturbance	14 (63.6%)	16 (76.2%)
Mental problem	13 (59.1%)	11 (52.4%)
Urinary incontinence	3 (13.6%)	2 (9.5%)
Full-blown symptoms		
Gait disturbance	22 (100%)	21 (100%)
Mental problem	22 (100%)	20 (95.2%)
Urinary incontinence	14 (63.6%)	10 (47.6%)
Clinical triad	14 (63.6%)	9 (42.9%)
Evan's ratio, mean (SD)	0.34 (0.025)	0.34 (0.025)
Gait score, mean (SD)	1.3 (0.48)	1.5 (0.75)
Mental score, mean (SD)	1.2 (0.43)	1.6 (0.87)
Urinary score, mean (SD)	1.1 (0.97)	0.9 (1.06)
4 point scale, mean (SD)	3.6 (1.44)	3.8 (2.38)
CSF drainage volume, mean (SD)	25.5 (6.71)	22.4 (9.02)
MMSE before CSF drainage, mean (SD)	17.6 (6.20)	18.9 (7.34)

BMI body mass index, *MMSE* mini-mental state examination

[a] There were no significant differences on any measure between the two groups (by Chi-square and *t* test when appropriate, *p* < 0.05)

Table 3 Percentages of magnetic resonance imaging (MRI) features in CSF tap test responders and non responders and the odds ratios

MRI features	CSF-TT responder (%)	CSF-TT non-responder (%)	OR (95% CI)	*p* value[a]
Frontal convexity narrowing	38.1	38.1	1 (0.3–3.5)	1
Parietal convexity narrowing	57.1	47.6	1.5 (0.4–5.0)	0.76
Upward bowing of the corpus callosum	66.7	52.4	1.8 (0.5–6.3)	0.53
Narrowing of the CSF space at the high convexity	50.0	23.8	3.2 (0.9–11.8)	0.14
Marked dilatation of the Sylvian fissure	45.5	33.3	1.7 (0.5–5.7)	0.62
Empty sella	52.4	14.3	6.6 (1.5–29.4)	0.02
Disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure ("mismatch" sign)	45.5	9.5	7.9 (1.5–42.5)	0.02
Empty sella or "mismatch" sign	72.7	19.0	11.3 (2.7–47.7)	0.001

CSF-TT CSF tap test, *OR* odds ratio, *CI* confidence interval

[a] Chi-square test

test response or non-response. The specificity and positive predictive value of each MRI feature were high while the sensitivity was relatively low.

The disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure was highly correlated with the CSF tap test response.

In line with previous studies [10, 11], these features may be useful in making the diagnosis of iNPH. However, isolated narrowing of the high convexity CSF space or marked dilation of the Sylvian fissure alone did not correlate with the CSF tap test response. One hypothesis suggested that patients with iNPH presenting defective CSF absorption due to "supraSylvian subarachnoid block" [11] have high CSF pressure in the ventricles/Sylvian fissures and low pressure in the supraSylvian subarachnoid space resulting in both of these MRI findings [10]. This hypothesis was supported by the diminished size of the Sylvian fissure and ventricular system together after shunt surgery [11]. When only one sign develops, it may signify that dilation of the Sylvian fissure is secondary to brain atrophy or no pressure gradient between the ventricles/Sylvian fissures and supraSylvian subarachnoid spaces. When the pressure gradient is present, the high CSF pressure in the ventricles/Sylvian fissures compresses brain tissue and influences vascular compliance [3]. A positive response to the CSF tap test can be predicted when the pressure gradient is present because the CSF tap test releases the pressure. However, our results showed that not all CSF responders demonstrated "mismatch" signs. The absence of "mismatch" signs in responders may be explained by different sites of CSF stagnation in addition to the supraSylvian region, or may be due to defective CSF absorption at the arachnoid villi without CSF circulation block.

The association between empty sella and idiopathic intracranial hypertension is well known, and the validity of the detection of empty sella based on the sagittal T1 images has also been demonstrated [32]. The relationship between empty sella and iNPH was rarely mentioned [33, 34]. According to Bradley's hypothesis [35], increased compression of brain tissue may result in the pathogenesis of iNPH. Other reports [4, 36, 37] described periods of increased intraventricular pressure in the pathological course of iNPH. The extension of the subarachnoid space of the sella turcica may result from mildly or intermittently increased intraventricular pressure. The sensitivity of determining CSF tap test responders was increased with either the presence of an empty sella or "mismatch" sign. These results may indicate other causes of iNPH besides supraSylvian subarachnoid blockage [10, 11].

The current management of iNPH patients is based on clinical symptoms and the results of supplemental prognostic tests, including brain imaging studies or CSF drainage tests [27]. According to the Japanese guidelines for the management of iNPH [8], symptomatic improvement after the CSF tap test or external lumbar drainage is essential to the decision of whether shunt surgery should be performed. A prior study [27] recommended one or more of the following three tests as supplemental prognostic tools in the treatment of iNPH: CSF tap test, outflow resistance determination, and/or external lumbar drainage. However, the selection of supplemental tests may be based on personal experience, favorable prognostic value, and equipment/personnel availability. The results of our study suggest that if brain MRI of a suspected iNPH patient shows "mismatch" sign or an empty sella, we can predict a high probability of positive response of the CSF tap test. Our brain MRI findings, therefore, may provide supplemental information in the diagnosis of iNPH patients.

Other MRI findings in our patients with possible iNPH did not show significant associations with response to the CSF tap test. A previous study found a high correlation between a narrowing of the posterior aspect of the cingulate sulcus (similar to our MRI features including frontal convexity narrowing, parietal convexity narrowing, and upward bowing of the corpus callosum) and iNPH in a small-size population [38]. However, our study did not replicate this finding.

We reduced the potential bias of clinical evaluation before and after CSF tap tests by using an objective grading scale and MMSE in place of subjective statements by patients or caregivers. Although there is no consensus about the extent of improvement in MMSE score after CSF tap test to represent clinical improvement of NPH symptoms, most of our CSF tap test responders showed gait improvement. Therefore, the possibility of misclassification (responder vs. nonresponder) resulting from improvement in MMSE score alone was low [19]. Further, the mean drainage volume of CSF during the tap test in our study was 25.5 ml in the tap test responder group and 22.4 ml in the tap test non-responder group. The volume in both groups was less than optimal (30–50 ml) [8, 39]. We therefore, cannot exclude the possibility that some patients in the non-responder group might have become responders if more CSF was drained.

In conclusion, an empty sella and disproportion between narrowing of the CSF space at the high convexity and dilatation of the Sylvian fissure ("mismatch" sign) on brain MRI are important imaging findings for iNPH. These findings could help to identify the potential CSF tap test responder and may serve as additional support in diagnosis in iNPH. Further studies on the predictive value of these MRI findings on response to shunt surgery are warranted in the future.

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