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Original Article

Baseline radiological parameters associated with good neurological outcome following ventriculoperitoneal shunt in normal pressure hydrocephalus: A single-center study on 82 patients

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ABSTRACT

Background: Idiopathic normal pressure hydrocephalus (iNPH) is a benign neurologic condition with treatment response rates ranging only between 30 and 50%. Several studies have attempted to identify clinical or radiological predictive factors of a favorable and sustained response to shunting, with conflicting and inconclusive results. With this report, we aimed to define the role of the Evans index (EI), enlargement of temporal horns, lateral ventricular bulges, and isolated elements of disproportionally enlarged subarachnoid spaces (high-convexity tightness and sulcal focal dilation) in predicting outcomes following ventriculoperitoneal shunt (VPS) placement.

Methods: All patients referred to Ospedali Riuniti of Ancona, Italy, from 2010 to 2021 were retrospectively examined for evaluation of iNPH. Clinical notes and neuroimaging were reviewed. After screening, 82 patients undergoing VPS procedures for iNPH were included in this series. Most (82.9%) patients were aged >65, with a male-to-female ratio of 1.92:1.

Results: Small baseline EI was associated with a significant improvement in gait apraxia scores (0.36 ± 0.04 vs. 0.40 ± 0.05, $P = 0.04$) and urinary incontinence episodes (0.38 ± 0.03 vs. 0.40 ± 0.05, $P = 0.04$). An EI > 0.40 was associated with a reduced likelihood of gait improvement (30.2%) in contrast to symptom stability or worsening (53%, $P = 0.03$). Similarly, an EI > 0.40 was associated with a reduced likelihood of continence improvement compared to stability or worsening of episode frequency (21.8% vs. 54%, $P = 0.004$). The presence of moderately compressed or obliterated cortical sulci was associated with a significant improvement of modified Rankin scale (mRS) functional status following surgery compared to patients with no convexity tightness (78% vs. 49.1%, $P = 0.02$ and 39.1% vs. 16.9%, $P = 0.03$, respectively). A large preoperative EI was predictive of poor response in the domains of gait apraxia (odds ratio [OR] = 0.001, 95% confidence interval [CI]: 0.001–0.4, $P = 0.004$) and urinary continence (OR = 0.001, 95% CI: 0.001–0.3, $P = 0.003$). The strongest predictors of improved mRS performance status were moderately (OR= 3.72, 95% CI: 1.22–11.35, $P = 0.02$) or severely compressed cortical sulci (OR= 3.15, 95% CI: 1.07–9.26, $P = 0.03$).

Conclusion: The EI is a significant parameter predictive of enhanced gait function and urinary continence postsurgery. Furthermore, noteworthy evidence supports the association of high-convexity tightness with improved overall functional scores following surgical intervention.

Keywords: Disproportionally enlarged subarachnoid spaces, Evans index, Normal pressure hydrocephalus, Radiological parameters, Ventriculoperitoneal shunt

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INTRODUCTION

Normal pressure hydrocephalus (NPH) was first described as a condition characterized by a clinical triad comprising urinary incontinence, gait disorder, and memory impairment associated with normal cerebrospinal fluid (CSF) pressure, enlarged cerebral ventricles, and improvement after ventricular shunt surgery.[1] The complete triad is, however, only present in <60% of patients. Its components are not specific: gait disturbances due to many other etiologies occur in 20% of people over 75 years of age, while urinary dysfunctions may build up to 18% of men and 38% of women in elderly life, and the prevalence of mild cognitive deficits is attested at about 35% in people aged >70 years. Moreover, the ventricular size is known to increase with age and in patients with neurodegenerative disorders.[6]

The NPH syndrome Hakim and Adams described has been further classified into idiopathic NPH (iNPH) and secondary NPH, with the latter typically arising from conditions such as meningitis or subarachnoid hemorrhage. Evidence regarding iNPH suggests that ventricular dilation is ascribed to impaired CSF resorption and/or slurred CSF conductance in the subarachnoid space. The symptoms associated with iNPH have been attributed to the stretching of the periventricular white matter, increased intracranial pressure, fibrosing meningitis, or ischemia.[11] Others suggest that the ventricular dilation may be unrelated to CSF dynamics and instead is secondary to periventricular microvascular disease that results in encephalomalacia and dilation of the ventricles,[3] a hypothesis supported by the observation of an association between hypertension, diabetes, coronary diseases, and iNPH.[4,5]

iNPH is known to be one of the most treatable forms of acquired dementia, but the treatment response rate is, variable.[8] In addition, the shunt benefit in patients with iNPH is not always maintained, with the success rate at late follow-up reaching as high as 50%.[7,9,17] Several works with conflicting results have tried to identify clinical or radiological factors that predict a favorable and sustained response to shunt placement in patients with iNPH.[16] Because iNPH is a disease of the older population, correct identification of iNPH is critical to successful treatment; however, the criteria for selecting patients for shunt surgery remain unclear. No clinical picture or diagnostic test available in standard practice can distinguish iNPH adequately from other dementias in older people.

We report a single Institutional experience in diagnosing and treating iNPH, with the aim of characterizing independent clinical and radiological predictors of outcomes after CSF.

MATERIALS AND METHODS

Patient selection

All patients referred to Ospedali Riuniti of Ancona, Italy, from 2010 to 2021 for the evaluation of iNPH were examined clinically and received neuroimaging to assess ventriculomegaly or additional intracranial pathological features in cases at least two clinical features of NPH were present.[15]

Overall, 147 patients were screened. Presumptive iNPH diagnosis and indication for CSF shunting were defined based on the following criteria: ventriculomegaly confirmed on computed tomography (CT) or magnetic resonance imaging (MRI) scan, presence of two or more clinical features of NPH, no risk factor for secondary NPH (history of subarachnoid hemorrhage, meningitis, encephalitis, concussion, traumatic brain injury, cerebral infarction, venous thrombosis, Paget's disease of cranium, or achondroplasia), and clinical improvement in symptoms after the CSF tapping test (spinal drainage of 30 cc).

After review, this series included 82 patients undergoing a ventriculoperitoneal shunt (VPS) for iNPH. The clinical presentation and preoperative neuroimaging features of ventricles and brain parenchyma were recorded to assess their role as predictive factors of symptom relief and functional status following surgery.

Data collection and endpoints

All included patients were admitted to the Neurosurgery Department and received standard of care for iNHP. Cognitive decline and gait apraxia were assessed at the presentation using the Mini-Mental State Examination (MMSE) and the Tinetti Gait and Balance test (TT). A cutoff of <24 points for both tests was used to define cognitive and gait function deterioration. The functional status was evaluated using the modified Rankin score (mRS) and dichotomized into good (mRS 1–2) or poor function (mRS 3–5). Patients were followed for 6 months following surgery. Demographic and clinical variables, including patient name, age, sex, radiological parameters, and time to surgery, were recorded.

The primary outcome of this study was the functional status following CSF diversion. We analyzed a composite outcome of 3 and 6-month improvements in gait, cognitive, urinary, and mRS scores. The scores were calculated separately for each outcome (i.e., motor, cognitive, urinary, and performance status). They were categorized as reached if the 3- and 6-month assessments were recorded as improved compared to the baseline. Symptoms' improvement was defined as a 2- or more-point increase in MMSE and TT, while mRS improvement was defined as a 1-point decrease. Urinary incontinence was assessed using a self-recorded diary provided to the patient. Improvement in continence function was defined as a 50% decrease in mean daily events during the past 30 days preceding the outcome assessment.

Neuroimaging and radiologic features definitions

Neuroimaging analyses were conducted on axial sagittal, and coronal reconstructed 3D volumetric MRI. 3D T1-weighted (T1w) and T2-weighted (T2w) images were obtained with a Philips 1.5T MRI unit before shunt surgery. Two independent expert neurosurgeons retrospectively analyzed images to calculate the following neuroradiological parameters [Figure 1]:

- Evans index (EI) is defined as the ratio between the diameter of the frontal horns and the inner skull diameter in the imaging slice above the foramen of Monro using axial T1w images.[20]
- Third-ventricle diameter was measured using axial and coronal T1w images to measure the widest diameter of the ventricle between the anterior and posterior commissures. It was defined as severely enlarged when the lateral width was >15 mm.
- High-convexity subarachnoid space tightness using axial T1w and T2w images and graded as occluded (obliterated) if no sulci were seen on the 10 most cranial slices covering the vertex. Moderate sulci compression was defined as having a width of 1–2 mm in more than 50% of the sulci.
- The presence of focally enlarged sulci was analyzed on axial and coronal T1w and T2w scans. The sulci were determined as focally widened if there were no signs of cortical atrophy, the widening was asymmetric, and the affected sulci lacked connection with the Sylvian fissure, as described in a previous publication[2]
- Dilation of the temporal horns was defined as a single temporal horn maximal width >6 mm on axial T1w and T2w images.
- The presence of bulging in the lateral ventricular roof was assessed in the sagittal plane (T1w and T2w), as described in a previous work.[18]

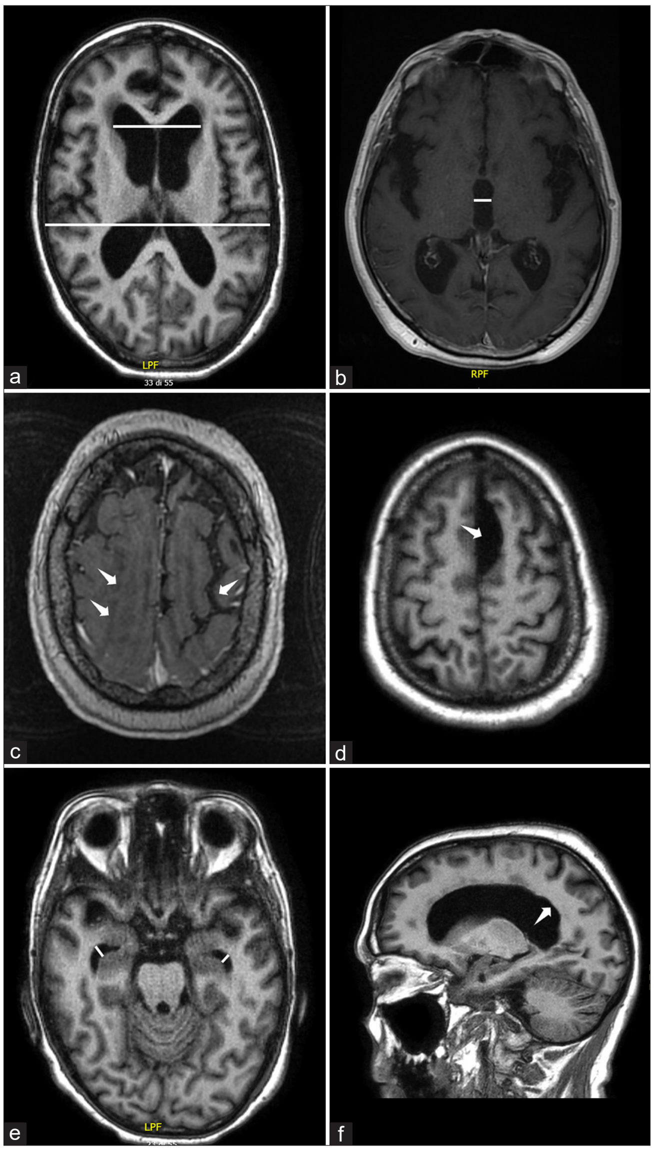

Figure 1: Neuroradiological assessment of included patients. (a) Evans index. (b) Measurement of the third ventricular diameter. (c) Vertex sulci. Right hemisphere (two arrows) obliterated sulci. Left hemisphere (1 arrow) focally dilated sulcus. (d) Axial view, enlarged subarachnoid space (arrow). (e) Temporal horn measurement. (f) Focal lateral ventricle roof bulding (arrow).

Statistical analysis

The statistical analyses were performed using R core team software (2022). Categorical variables were reported as numbers and percentages, whereas continuous variables were reported as mean ± standard deviation, median, and interquartile range (IQR). The Kolmogorov–Smirnov and Skewness tests were used to assess the normality of the distribution of continuous variables. Baseline characteristics and presurgical findings were evaluated in unadjusted univariate analyses performed using the *t*-test or Mann–Whitney (U-test) in accordance with normality and the Chi-square or Fisher's exact test, where appropriate.

Univariate analysis (UVA) was used to examine the relationship between preoperative neurological status and imaging findings, with the primary outcomes. The variables were then entered into a univariate logistic regression model to assess their predictive value for the functional outcome.

The results of all tests are presented as *P*-values, and statistical significance was set as a probability value of 0.05 (95% confidence interval [CI]).

RESULTS

Baseline demographics and neuroimaging characteristics

The demographic characteristics and baseline radiological findings of the 82 patients undergoing VPS for iNPH are shown in Table 1.

Table 1: Baseline characteristics of patients included.

Overall population		Patients (*n*=82)
Demographics	Male	54 (65.8)
	Female	28 (34.1)
Time to surgery	Mean time	21.6±23
	<12 months	47 (57.3)
	>12 months	35 (42.6)
Baseline symptoms	Gait impairment	47 (57.3)
	Cognitive decline	70 (85.2)
	Urinary incontinence	70 (85.2)
Admission neurological status	mRS 1–2	25 (30.4)
	mRS 3–5	57 (69.5)
Radiological parameters	Mean Evans index	0.39±0.5
	Evans >0.30	82 (100)
	Evans >0.40	34 (41.4)
	Ventricular bulging	41 (50)
	Compressed cortical sulci: Moderate	28 (34.1)
	Compressed cortical sulci: Severe	19 (23.7)
	3rd ventricle diameter >15 mm	21 (25.6)
	Dilated temporal horn	66 (80.4)
	Focal cortical sulci dilation	42 (51.2)
Improved outcome	Gait	43 (52.4)
	Cognitive	32 (39)
	Urinary	20 (24.4)
	mRS	23 (28)

Continuous variables are expressed as mean±standard deviation or median (range), whereas dichotomic variables are expressed as frequency (%). mRS: Modified Rankin score. Evans: Evans index

Most patients (82.9%) were over 65 years old, with a male-to-female ratio of 1.92:1. The baseline neurological status was assessed at the time of diagnosis, before surgery, and tap testing. Patients showed significant cognitive decline and gait apraxia in 85.2% and 57.3% of cases, respectively, while urinary incontinence was recorded in 85.2% of patients. The baseline mRS score was good in only 30.4% of patients.

The mean EI was 0.39 ± 0.50. In 41.4% of patients, the index was higher than 0.4. In comparison, the most striking neuroimaging features included dilated temporal horns (80.4%), focal cortical sulci distention (51.2%), lateral ventricles bulging (50%), moderate compression of cortical sulci (34.1%), sulci obliteration (23.7%), and dilated third ventricle (25.6%). Most patients (57.3%) underwent CSF diversion within 1 year after the onset of symptoms. The CSF shunt procedure was a VPS in all included cases. The mean time from symptom onset to VPS was 21.6 ± 23 months, with a median time of 12 months (IQR 12–24) in the whole series.

Functional outcomes and response predictors

Following CSF diversion, 52.4% of patients (n = 43) experienced sustained improvement in gait apraxia. Similarly, 39% (n = 32) reported amelioration of urinary incontinence and 24.4% (n = 20) reported experienced better cognitive scores. The mRS score improved in 28% of cases (n = 23).

The baseline preoperative EI was associated with a significant change in gait apraxia scores. Patients experiencing a significant improvement in gait had a lower pre-operative EI compared to patients whose gait ability was either stable or worsened after surgery (0.36 ± 0.04 vs. 0.40 ± 0.05 vs. P = 0.04). A baseline EI > 0.40 was associated with a reduced likelihood of gait improvement (30.2%) in contrast to symptom stability or worsening (53%, P = 0.03).

Similarly, patients who experienced a significant reduction in urinary incontinence episodes had a mean lower EI (0.38 ± 0.03 vs. 0.40 ± 0.05, P = 0.04) compared to those with stable or worsened incontinence. Increased EI (>0.40) was associated with a reduced likelihood of continence improvement compared to stability or worsening (21.8% vs. 54%, P = 0.004).

No radiological parameters were found to be associated with changes in cognitive scores.

The preoperative evidence of high-convexity tightness, demonstrated by moderately compressed or obliterated cortical sulci, was associated with a significant improvement of mRS functional status following surgery compared to patients with no tightness (78% vs. 49.1%, P = 0.02; and 39.1% vs. 16.9%, P = 0.03, respectively).

See Figure 2 for example of pre- and post-shunting measurment of included radiological parameters.

The demographic characteristics and admission clinical status did not affect late outcomes. Table 2 shows the UVA of sustained cognitive, gait, urinary incontinence, and mRS status.

Regression analysis

We performed a univariate logistic regression analysis to identify predictors of improvement in functional outcomes. Results are shown in Table 3.

An increased preoperative EI was predictive of poor response in the domains of gait apraxia (odds ratio [OR] = 0.001, 95% CI: 0.001–0.4, P = 0.004) and urinary continence (OR= 0.001, 95% CI: 0.001–0.3, P = 0.003).

The strongest predictors of improved mRS performance status were moderately (OR= 3.72, 95% CI: 1.22–11.35, P = 0.02) or severely compressed cortical sulci (OR= 3.15, 95% CI: 1.07–9.26, P = 0.03).

Table 2 (a): Neurological outcome 3 months after CSF shunt.

2. (a)			
Gait apraxia	**Stable/worse (n=39)**	**Improved (n=43)**	***P*-value**
Demographics			
Age >65 yo	23 (58.9)	31 (72.0)	0.21
Time to surgery			
Mean time	21.3±15.3	21.9±29.4	0.46
Admission neurological status			
mRS 3–5	28 (71.7)	29 (67.4)	0.66
Radiological parameters			
Mean Evans index	0.40±0.05	0.36±0.04	**0.04**
Evans index >0.40	21 (53.8)	13 (30.2)	**0.03**
Periventricular T2w changes	23 (58.9)	19 (44.1)	0.18
Ventricular bulging	22 (56.4)	19 (44.1)	0.26
Compressed cortical sulci moderate	20 (51.2)	27 (62.7)	0.29
Compressed cortical sulci severe	9 (23.0)	10 (23.2)	0.98
Third ventricle diameter>15 mm	12 (30.7)	9 (20.9)	0.30
Dilated temporal horn	30 (76.9)	36 (83.7)	0.43
Focal cortical sulci dilation	24 (61.5)	18 (41.8)	0.07

Bold numbers represent significant *P*-values, mRS: Modified ranking score. yo: years old. Composite neurological outcome (3+6 months) after CSF shunt.

Table 2b: Neurological outcome 3 months after CSF shunt

Cognitive decline	**Stable/worse (*n*=62)**	**Improved (*n*=20)**	***P*-value**
Demographics			
Age >65 yo	41 (66.1)	13 (65)	0.92
Time to surgery			
Mean time	20.8±14.6	24.1±41.1	0.10
Admission neurological status			
mRS 3–5	43 (69.3)	14 (70)	0.95
Radiological parameters			
Mean Evans index	0.39±0.04	0.40±0.06	0.19
Evans index >0.40	26 (41.9)	8 (40)	0.87
Periventricular T2w changes	33 (53.2)	9 (45)	0.61
Ventricular bulging	34 (54.8)	7 (35.0)	0.12
Compressed cortical sulci moderate	33 (53.2)	14 (70)	0.18
Compressed cortical sulci severe	13 (20.9)	6 (30)	0.40
Third ventricle diameter >15 mm	16 (25.8)	5 (25)	1.00
Dilated temporal horn	50 (80.6)	16 (80)	1.00

(Contd...)

Bold numbers represent significant *P*-values, mRS: Modified ranking score. yo: years old. Composite neurological outcome (3+6 months) after CSF shunt.

Table 2(c): Neurological outcome 3 months after CSF shunt

Urinary incontinence	**Stable/worse (*n*=50)**	**Improved (*n*=32)**	***P*-value**
Demographics			
Age >65 yo	29 (58)	25 (78.1)	0.06
Time to surgery			
Mean time	21.4±15.5	22.0±32.8	0.34
Admission neurological status			
mRS 3–5	35 (70)	22 (68.7)	0.90
Radiological parameters			
Mean Evans index	0.40±0.05	0.38±0.03	**0.02**
Evans index >0.40	27 (54)	7 (21.8)	**0.004**
Periventricular T2w changes	25 (50)	16 (50)	1.00
Ventricular bulging	25 (50)	16 (50)	1.00
Compressed cortical sulci moderate	25 (50)	22 (68.7)	0.09
Compressed cortical sulci severe	13 (26)	6 (18.7)	0.44
Third ventricle diameter >15 mm	16 (32)	5 (15.6)	0.12
Dilated temporal horn	41 (82)	25 (78.1)	0.66
Focal cortical sulci dilation	23 (46)	19 (59.3)	0.23

Bold numbers represent significant *P*-values, mRS: Modified ranking score. yo: years old. Composite neurological outcome (3+6 months) after CSF shunt.

Table 2(d): Neurological outcome 3 months after CSF shunt

mRS	**Stable/worse (*n*=59)**	**Improved (*n*=23)**	***P*-value**
Demographics			
Age >65 yo	37 (62.7)	17 (73.9)	0.33
Time to surgery			
Mean time	21.6±15.2	21.7±38.0	0.97
Admission neurological status			
mRS 3–5	43 (72.8)	14 (60.8)	0.28
Radiological parameters			
Mean Evans index	0.39±0.05	0.39±0.04	0.84
Evans index >0.40	27 (45.7)	7 (30.4)	0.20
Periventricular T2w changes	33 (55.9)	9 (39.1)	0.17
Ventricular bulging	31 (52.5)	10 (43.4)	0.46
Compressed cortical sulci moderate	29 (49.1)	18 (78.2)	**0.02**
Compressed cortical sulci severe	10 (16.9)	9 (39.1)	**0.03**

(Contd...)

Third ventricle diameter >15 mm	15 (25.4)	6 (26.0)	0.95
2. (d) *(Continued)*			
mRS	**Stable/worse (*n*=59)**	**Improved (*n*=23)**	***P*-value**
Dilated temporal horn	49 (83.0)	17 (73.9)	0.34
Focal cortical sulci dilation	31 (52.5)	11 (47.8)	0.70

Composite neurological outcome (3+6 months) after CSF shunt.
mRS: Modified ranking score. yo: years old.

DISCUSSION

In this study, we examined the outcome following VPS surgery for iNPH, comparing the baseline clinical and neuroradiological parameters between shunt-responsive and nonresponsive patients with stratification of the different components of the clinical syndrome. Most iNPH patients who underwent surgery showed functional improvement, particularly in gait scores.

Several studies have addressed the role of different clinical and radiological variables in predicting shunt response for iNHP. A recent meta-analysis[16] highlighted that only the callosal angle and periventricular white matter change significantly differentiated iNPH shunt responders from shunt nonresponders. The authors, however, concluded that both markers were weak predictors on their own and that other radiological predictors did not significantly differentiate shunt responders from nonresponders. The EI and the disproportionally enlarged subarachnoid space (DESH) parameters are critical, given that they are included in the current Japanese diagnostic guidelines[12] and the American–European iNPH guidelines.[15] For this reason, we aimed further investigate the role of EI, enlargement of temporal horns, lateral ventricular bulges, and isolated elements of DESH, including high-convexity tightness and sulcal focal dilation.

EI

Several studies[2,10,13,18,19] explored the role of EI in predicting shunt response in iNHP. Agerskov *et al.*[2] reported that all iNHP patients included in their series had an EI > 0.3; however, this was not predictive of shunt response. Similar results were reported by Hong *et al.*[10] and Virhammar *et al.*,[18] showing no significant difference in EI between shunt responders and nonresponders. Narita *et al.*[13] also found no association between EI and postshunt improvement; however, Wu *et al.*[19] exploiting machine learning models, found that while EI alone correlated moderately with the MMSE and Tinetti scores, combining it with other features significantly improved predictive accuracy, highlighting its utility in conjunction with additional factors. Interestingly, our results indicate that increased EI is associated with a diminished likelihood of improved gait function and urinary continence, a trend that persisted even after dichotomizing EI at a threshold of 0.40. This finding provides further insight into the potential prognostic value of EI and deserves additional investigations to corroborate its utility.

Focal dilated cortical sulci

Several authors classified the presence of focally enlarged cortical sulci differently. While Virhammar *et al.*[18] and Narita *et al.*[13] categorized focally enlarged cortical sulci as present or absent, Poca *et al.*[14] classified sulci as usual, obliterated, or enlarged, and Agerskov *et al.*[2] reported on the effect of both focally enlarged sulci and obliteration of high convexity sulci. Poca *et al.*[14] observed that individuals with enlarged sulci were less likely to improve in cognitive tests, reporting a significant difference between groups. Conversely, the other authors[2,13,18] found no association between dilated sulci and outcome assessment scores. Consistent with these reports, we observed no significant predictive role of cortical sulci dilation on relevant functional outcomes following VPS.

Temporal horn dimensions

Poca *et al.*[14] categorized temporal horns as either normal or enlarged on CT scans, while Agerskov *et al.*[2] and Virhammar *et al.*[18] measured the maximum diameter in MRI. Two studies[2,14] addressing temporal horns on CT scans found no association between temporal horn size and shunt outcome, with minimal differences in size between responders and nonresponders, as reported by Agerskov *et al.*[2] Conversely, Virhammar *et al.*[18] observed a significant difference between responders and nonresponders, calculating an OR of 1.84. In our series, however, although measuring ventricular size in MRI scans, we could not observe any predictive value of temporal horn dimensions on responsiveness. These findings underscore the variability in results across studies and suggest that the impact of temporal horn size on shunt response in iNPH patients warrants further investigation.

Lateral ventricles bulging

Narita *et al.*[13] quantified protrusions above the thalamus, while Virhammar *et al.*[18] assessed the lateral ventricle roof in the sagittal plane. However, none of these studies could find a significant association between this parameter and shunt response. Consistent with previous reports, we employed the same measuring strategy described by Virhammar *et al.*[18] and did not observe any predictive role of lateral ventricle bulging on shunt responsiveness.

Table 3: Predictive factors of good neurological outcome in iNPH following CSF diversion.

Variable	Reference	Gait			Cognitive			Urinary			mRS		
		OR	95% CI	*P*-value	OR	95% CI	*P*-value	OR	95% CI	*P*-value	OR	95% CI	*P*-value
Age >65 yo	<65	3.36	0.95–11.7	0.058	4.73	0.98–22.8	0.052	0.76	0.21–2.78	0.69	0.96	0.27–3.46	0.96
Time to surgery	.	1.00	0.98–1.01	0.89	1.00	0.98–1.01	0.90	1.00	0.98–1.02	0.59	1.00	0.98–1.02	0.97
Mean Evans index	.	0.001	0.001–0.4	**0.04**	0.001	0.001–0.3	**0.03**	4.51	0.03–12.3	0.19	2.58	0.00–398	0.84
Evans index >0.40	<0.40	0.37	0.15–0.91	**0.03**	0.23	0.08–0.65	**0.005**	0.92	0.33–2.57	0.87	0.51	0.18–1.44	0.20
Focal cortical sulci dilation	No	0.45	0.18–1.09	0.07	1.71	0.69–4.21	0.23	0.93	0.34–2.56	0.90	0.82	0.31–2.17	0.70
Ventricular bulging	No	0.61	0.25–1.46	0.27	1.00	0.41–2.42	1.00	0.44	0.15–1.86	0.19	0.69	0.26–1.83	0.46
Moderate cortical sulci compress	No	1.60	0.66–3.86	0.29	2.2	0.86–5.57	0.09	2.05	0.69–6.02	0.19	3.72	1.22–11.35	**0.02**
Severe cortical sulci compress	No	1.01	0.36–2.82	0.98	0.65	0.22–1.95	0.45	1.61	0.51–5.02	0.40	3.15	1.07–9.26	**0.03**
Third ventricle diameter >15 mm	No	0.59	0.21–1.62	0.31	0.39	0.12–1.21	0.10	0.95	0.30–3.06	0.94	1.03	0.34–3.10	0.35
Dilated temporal horn	No	1.54	0.51–4.63	0.44	0.78	0.25–2.36	0.66	0.96	0.27–3.39	0.95	0.57	0.18–1.83	0.32

CI: Confidence interval, CSF: Cerebrospinal fluid, iNPH: Idiopathic normal pressure hydrocephalus, mRS: Modified ranking score, OR: Odds ratio, Bold numbers represent significant *P*-values

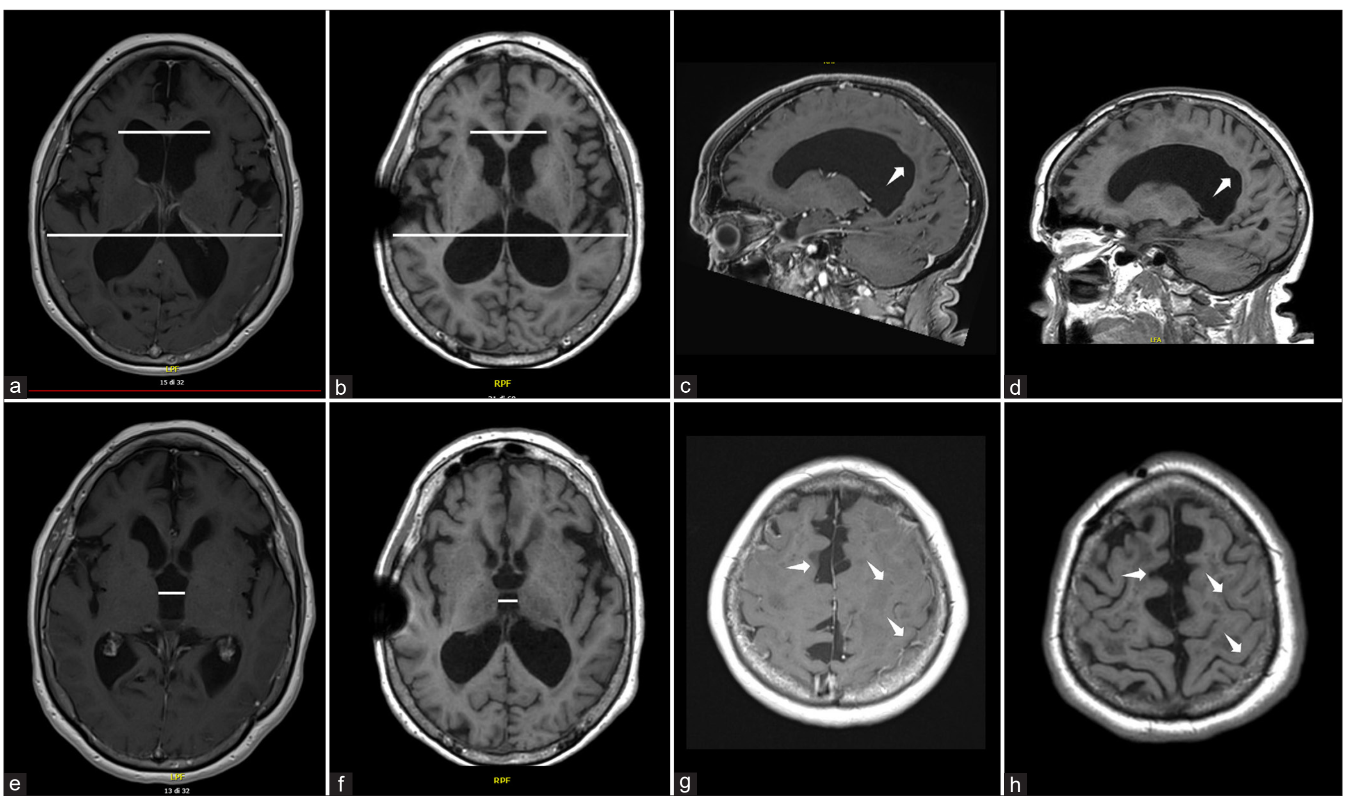

Figure 2: Pre- and post-shunting magnetic resonance imaging. (a) and (b) Evans index. (c) and (d) Focal lateral ventricle roof bulging (arrow). (e) and (f) Measurement of third ventricle diameter. (g) and (h) Left hemisphere obliterated sulci (2 arrows), right hemisphere enlarged subarachnoid space (1 arrow).

High-convexity subarachnoid space tightness

These last two studies[13,18] evaluated high convexity tightness as a potential marker for identifying responders. Narita *et al*.[13] reported a significant correlation between tightness and changes in functional total and gait scores. In addition, they found tightness significantly correlated with MMSE changes in simple regression analysis. Our study revealed that baseline measures of increased high-convexity tightness might be predictive markers for favorable outcomes, manifesting as improved functional status, as assessed by mRS scores. Conversely, Virhammar *et al*.[18] did not observe a significant difference in tightness between responders and nonresponders.

CONCLUSION

Although numerous studies have examined neuroimaging markers that predict shunt responsiveness in iNPH, recent meta-analyses have yielded inconclusive results. Despite this, the EI remains a key indicator, strongly associated with improvements in gait function and urinary continence following surgery. In addition, evidence linking high-convexity tightness to better overall mRS scores following surgical intervention is particularly noteworthy. These findings underscore the need for further focused research to achieve more definitive conclusions. These efforts are essential for developing comprehensive guidelines to optimize the management and treatment strategies for iNPH patients.

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