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ORIGINAL RESEARCH

MR Imaging Findings in Patients with Secondary Intracranial Hypertension

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BACKGROUND AND PURPOSE: IH can alter the configuration of anatomic structures of the central nervous system. We determined the sensitivity and specificity of MR imaging to detect these changes in patients with secondary IH.

MATERIALS AND METHODS: Patients (n = 36) with IH were prospectively investigated with MR imaging and were matched to 36 controls. MR images were evaluated for elongation and edema of the optic nerves, protrusion of the optic disc, flattening of the posterior sclera, height of the pituitary gland, and width of the optic nerve sheath. On MRV, we recorded venous sinus abnormalities and measured the luminal width of the superior ophthalmic veins. A grading score was introduced to define cranial venous outflow obstruction.

RESULTS: Cranial venous outflow obstruction and ONS hydrops were the most valid signs indicating IH with a sensitivity of 94% and 92% and a specificity of 100% and 89%, respectively. Sensitivities and specificities were 56% and 97% for reduced pituitary height, 64% and 78% for flattening of the posterior sclera, 31% and 97% for widening of the superior ophthalmic veins, 33% and 100% for optic disc protrusion, 14% and 100% for optic nerve edema, and 6% and 100% for elongation of the optic nerve. At least 2 MR imaging findings could be demonstrated in each patient but in none of the controls. The number of positive MR imaging findings correlated with CSF pressure (r = 0.62, P = .01).

CONCLUSIONS: The combination of cranial and orbital MR imaging and MRV can be highly sensitive and specific in the diagnosis of patients with IH.

ABBREVIATIONS: CI = confidence interval; CVOO = cranial venous outflow obstruction; FLAIR = fluid-attenuated inversion recovery; ICC = intraclass correlation coefficient; IH = intracranial hypertension; IIH = idiopathic intracranial hypertension; IJV = internal jugular vein; LP = lumbar puncture; LTS = left transverse sinus, MIP = maximum intensity projection, MRI = MR imaging; MRV = MR venography; ONS = optic nerve sheath; OR = odds ratio; PRES = posterior reversible encephalopathy syndrome; RTS = right transverse sinus; SIH = secondary intracranial hypertension; SOV = superior ophthalmic vein; SSS = superior sagittal sinus; STIR = short tau inversion recovery; T1WI = T1-weighted imaging; T2WI = T2-weighted imaging; TS = transverse/sigmoid sinus; TSE = turbo spin-echo; VI = visual impairment

IH can be caused by numerous conditions (SIH) but can also be observed without any evidence of an underlying condition (pseudotumor cerebri, IIH[1-4]). The direct measurement of intracranial or lumbar CSF pressure is regarded as the criterion standard in the diagnostic work-up of IH, but due to its invasive nature, the dependence on patient compliance, and the susceptibility for false-positive or false-negative results, it has potential limitations.[4] Furthermore, clinical signs and neurologic symptoms are variably expressed and might not be specific for IH.[2,5-7] Therefore, a complementary noninvasive diagnosis of IH is preferable in clinical routine. Recently, venous sinus stenoses, which might serve as diagnostic markers, have been reported in patients with IIH but are not well-documented as occurring in patients with SIH.[8-12] Other MR imaging signs of IH have been partly investigated but not in a larger series of patients with SIH and lacking an integrative imaging protocol.[13-22] Reported findings are the following: elongation of the optic nerve, protrusion of the optic nerve head, widening of the ONS, deformation of the pituitary gland, and dilation of the SOV.

The aim of our study was to determine the sensitivity and specificity of quantitative and qualitative MR imaging findings for IH in patients with SIH, by using a standardized MR imaging protocol, which combines orbital, cranial, and venous imaging.

Materials and Methods

Patients

Thirty-six patients with SIH due to various causes were prospectively included in the study, among them 7 children. Clinical characteristics are given in Table 1. IH was proved by lumbar CSF pressure measurements in 22 patients, and in 3 patients, elevated pressure was reported intraoperatively with CSF gushing out at high pressure on opening the dura mater. In the remaining 11 patients without CSF pressure measurement, IH was diagnosed by positive funduscopy findings showing bilateral papilledema, clinical symptoms, and follow-up imaging showing a reduction of MR imaging signs of increased intracranial pressure going along with clinical improvement. Patients with

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Table 1: Clinical characteristics in 36 patients with IH and 36 control subjects

Patient Group[a]	Opening CSF Pressure on LP in cm H_2O (mean) (range)	Demographics: Group Size, Sex	Demographics: Patient Age (mean) (range)	Diagnosis, Clinical Signs, and Symptoms: Diagnosis	Papilledema	Mild VI	Severe VI	Headache	Nausea/ Vomiting	Other Symptoms
All patients with IH	39.8 (24–70)	$n = 36$ F ($n = 23$) M ($n = 13$)	40.9 yr 2–76 yr	Meningeal disease ($n = 10$), thrombosis or occlusion of venous sinus or the dominant IJV ($n = 10$), intracranial tumor ($n = 8$), hydrocephalus (other than caused by tumor, $n = 5$), other ($n = 5$), see below, multiple ($n = 3$)	23/35 66%	20/36 56%	12/36 33%	30/36 83%	9/36 25%	See below
Patient Subgroup I	29.5 (22–38)	$n = 12$ F ($n = 7$) M ($n = 5$)	41.6 yr 32–66 yr	Occlusion of a venous sinus or IJV by meningioma or postoperatively ($n = 3$), viral meningitis ($n = 3$), bacterial meningitis ($n = 1$), venous sinus thrombosis ($n = 1$), excessive arterial hypertension ($n = 1$), head trauma with hygromas ($n = 1$), hydrocephalus ($n = 1$), minocycline medication ($n = 1$)	7/12 58%	7/12 58%	3/12 25%	12/12 100%	4/12 33%	Fever, meningism ($n = 4$), transient aphasia ($n = 3$), vertigo ($n = 2$), transient apraxia ($n = 1$), cough ($n = 1$), hypacusis ($n = 1$), tinnitus ($n = 1$), reduced consciousness ($n = 1$), paraesthesia ($n = 1$)
Patient Subgroup II	52 40–70	$n = 10$ F ($n = 6$) M ($n = 4$)	34.5 yr 2–62 yr	Thrombosis of venous sinus or IJV ($n = 4$), hydrocephalus ($n = 3$), meningiosis ($n = 2$), neurosarcoid meningitis ($n = 1$)	7/9 78%	4/10 40%	5/10 50%	8/10 80%	3/10 30%	Vertigo, dysaesthesia ($n = 1$), tinnitus ($n = 1$), double vision ($n = 1$), head enlargement ($n = 1$), unspecific feeling of illness ($n = 1$)
Patient Subgroup III	Not tested[b]	$n = 14$ F ($n = 10$) M ($n = 4$)	44.8 yr 9–76 yr	Meningioma alone or combined with stenosis or occlusion of a venous sinus ($n = 4$), venous sinus thrombosis alone or combined with brain abscess or dural metastasis ($n = 3$), brain tumor with occlusive hydrocephalus ($n = 2$), meningeosis ($n = 2$), arterial hypertension, PRES ($n = 1$), hydrocephalus ($n = 1$)	9/14 64%	9/14 64%	4/14 29%	10/14 71%	2/14 14%	Double vision ($n = 4$), paresis ($n = 4$), reduced consciousness ($n = 3$), nystagmus ($n = 1$). vertigo ($n = 1$), fever ($n = 1$)
Controls	Not tested.	$n = 36$ F ($n = 23$) M ($n = 13$)	39 yr 2–80 yr	Mostly psychiatric	Not tested	0/36 0%	0/36 0%	0/36 0%	0/36 0%	

[a] Patients with IH ($n = 36$) were subgrouped into those with CSF pressure <40 cm H_2O ($n = 12$, group I), those with >40 cm H_2O ($n = 10$, group II), and those without direct pressure measurements ($n = 14$, group III).
[b] In subgroup III, 3 patients were reported to have elevated CSF pressure intraoperatively.

visual disturbances (32/36) were grouped into 2 categories: 1) patients with little or transient visual disturbances and visual acuity of >70% ($n = 20$), and 2) patients with severe visual loss ($n = 12$). Four patients had undergone surgery before inclusion in the study, including 3 children (7–14 years of age) with ventriculoperitoneal shunt operations and 1 adult (51 years of age) with occlusion of the dominant IJV due to neck surgery. Patients with IIH were not included in this study.

Control Group

Thirty-six individuals matched for age and sex with the SIH patient group served as controls. These individuals had cranial MR imaging performed for various reasons, mostly psychiatric disease, and did not have any clinical evidence of IH, such as headache or visual disturbances. Written informed consent was obtained from both patients with SIH and controls, and institutional review board approval was

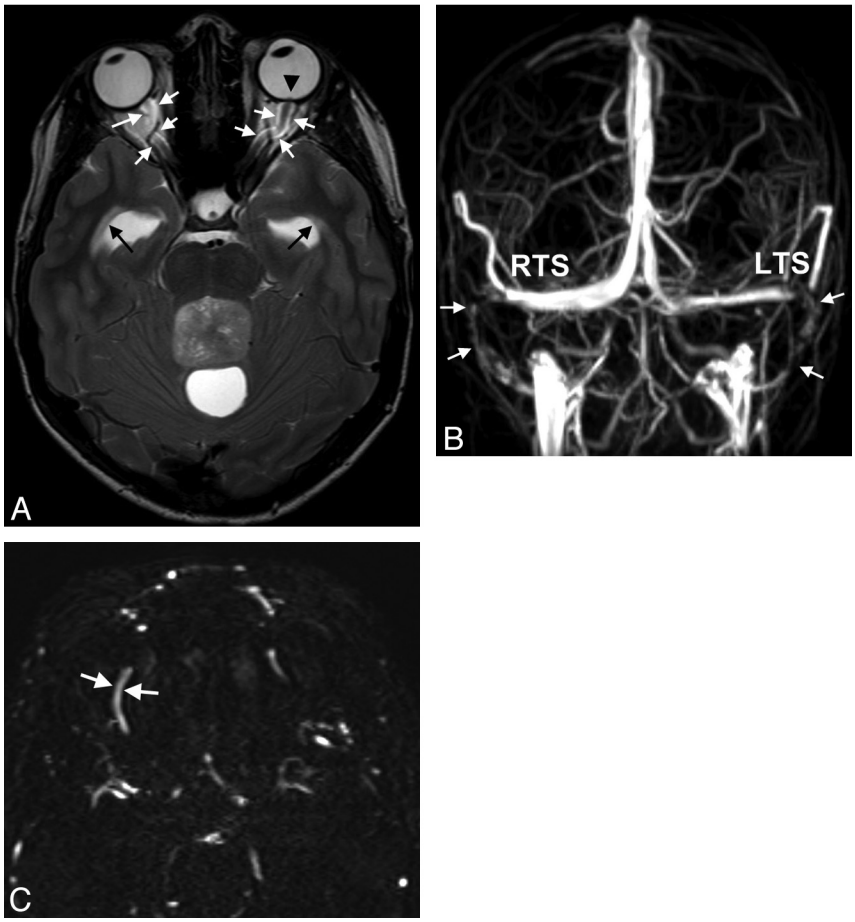

Fig 1. A 15-year-old boy with double vision and reduced acuity has bilateral papilledema. *A,* On axial T2WI, ventriculomegaly with periventricular CSF flow (*black arrows*) due to an obstructing tumor within the fourth ventricle is found. Optic nerve sheath hydrops, elongation of the optic nerve (*white arrows* in *A*), and optic papilla protrusion are seen (*black arrowhead*). *B,* Anteroposterior view of MIP of MRV depicts bilateral narrowings of the lateral RTS and LTS and the sigmoid sinus (*arrows*). *C,* On primary axial sections of MRV, the SOVs are enlarged (*arrows,* right SOV, 2.8-mm width). Medulloblastoma was found at surgery.

obtained. No individual fulfilled the usual exclusion criteria for MR imaging.

MR Imaging

MR imaging was performed in all patients by using a standardized protocol with a 3T unit and a head-sense-coil, including the following sequences: 1) T2 TSE axial: TR/TE, 4021/100 ms; section thickness, 3 mm; 2) STIR coronal: TR/TE/TI, 3838/90/180 ms; section thickness, 3 mm, covering the orbit and pituitary gland; and 3) 3D phase-contrast MRV: TR/TE, 17/7.9 ms; velocity encoding, 15 cm/s. Additional contrast-enhanced T1 sequences ($n = 29$), contrast-enhanced time-of-flight angiography ($n = 3$), time-resolved contrast-enhanced MR angiography ($n = 1$), digital subtraction angiography ($n = 4$), and/or CT venography ($n = 1$) were used to rule out venous sinus thrombosis in uncertain cases. Follow-up MR imaging was performed in 27 patients.

Analysis of MR Imaging Findings

Apart from the presence of space-occupying lesions with or without mass effect or obstruction of adjacent venous sinuses, special attention was paid to the following MR imaging findings: 1) nonquantitative cross-sectional findings: ventriculomegaly, periventricular edema caused by transependymal CSF flow (Fig 1*A*), flattening of the posterior sclera (Fig 2*A*), optic papilla protrusion (Fig 1*A*), optic nerve edema (Fig 2*B*), and elongation of the optic nerve (Fig 1*A*); and 2) quantitative cross-sectional criteria: pituitary height (Fig 3*C*, -*F*) and ONS width as measured at 4 different locations (3, 6, 10, and 20 mm behind the globe; Figs 2 and 4) by using coronal STIR sequences. With the source images of MRV, the maximum diameters of the SOV were measured (Fig 1*C*). Intracranial venous anatomy and pathology were judged by using MIPs, source images of MRV, and cross-sectional MR images. Gross venous anatomic variants, signal-intensity changes reflecting thrombosis within the venous sinuses (Fig 3*A*, -*D*), and venous sinus pathologies regarded as stenoses (but not typical for thrombosis) were further analyzed by using the primary MRV sections.

A simple classification system was used for grading venous sinus pathologies. A reduction of the diameter of a dural sinus of <50% was regarded as being within the normal range of variation (grade 0 lesion), whereas a more severe narrowing or a complete signal-intensity loss was categorized as a significant stenosis or occlusion (grade 1 lesion, Figs 1*B*, 2*C*, 3*B*, and 4*D*). CVOO was assumed in cases in which a grade 1 lesion affected the following: both TSs or at least the dominant TS if the opposite TS was severely hypoplastic or absent (type I), the mid or dorsal part of the SSS (type II), or a combination of the previous 2 types (type III). MR images were blinded for the presence of IH and were evaluated by 3 readers (A.C.R., an experienced board-certified radiologist/neuroradiologist; C.R., a board-certified radiologist and Specialist Registrar in neuroradiology; and M.-C.F., a senior medical student who was trained to evaluate cranial

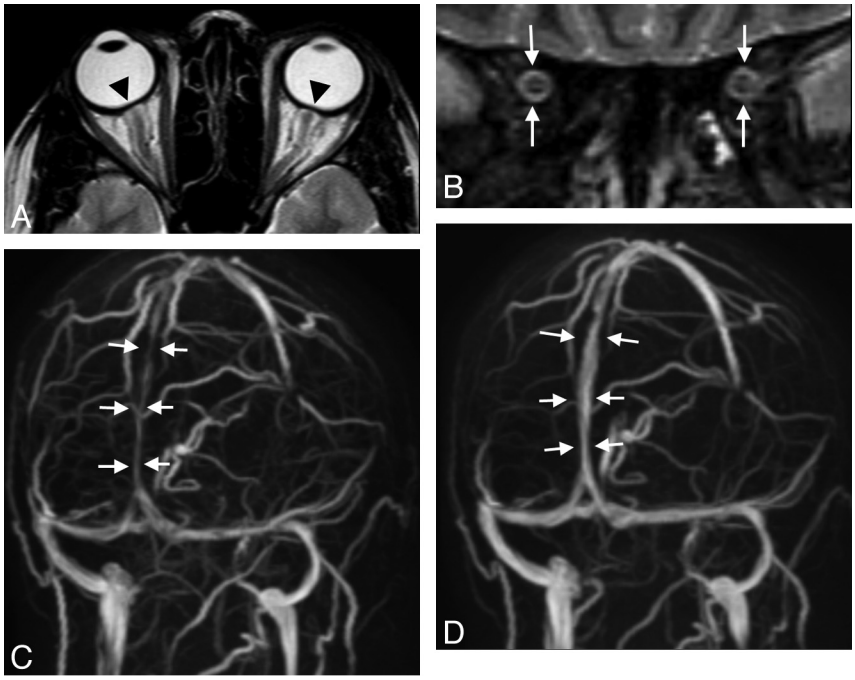

Fig 2. A 30-year-old woman with arterial hypertension and visual disturbances has bilateral papilledema. *A,* MR imaging of the orbit displays a flattened posterior sclera (*arrowheads*). *B,* ONS hydrops is present, and there is edema of the optic nerve as seen on the coronal STIR sequence measured 20 mm behind the globe (*white arrows,* ONS width of 5.4 mm). *C,* Slightly oblique MIP of MRV shows lengthy narrowings of the intracranial venous sinuses, especially of the superior sagittal sinus (*arrows*). Vision returns to normal with successful treatment of hypertension. On follow-up MR imaging 3 months later, ONS width is reduced to 4.8 mm, and the posterior sclera appears normal (not shown). *D,* The intracranial venous sinuses regain normal caliber, as shown by MRV.

MR images with respect to features of IH). The results of the first reader were used for the primary analysis. The results of all 3 readers were used to calculate interobserver reliabilities.

Statistical Analysis

On the basis of cross-tabulations, the sensitivity, specificity, and OR of different MR imaging findings were calculated (95% CI). A Pearson correlation coefficient test was used to find correlations between CSF pressure and quantitative MR imaging signs of IH. A Spearman correlation coefficient test was chosen to find correlations between CSF pressure values and the number of positive MR imaging signs of IH. A Mann-Whitney *U* test was used to prove differences between mean values of measurements in patient subgroups and between patients and controls. For analysis of interobserver reliabilities, κ values and percentages of interobserver agreements (qualitative signs) and ICCs (quantitative signs) were calculated. For each test, the level of statistical significance was defined as $P < .05$. Statistical analysis was performed with the Statistical Package for the Social Sciences software, Version 13 (SPSS, Chicago, Illinois) except for computation of κ and ICC values, which was done with R by using the irr package (R Development Core Team, 2010; R: A language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria).

Results

MR Imaging Findings in SIH

The main findings were CVOO, ONS hydrops, reduced pituitary height, and flattened posterior sclera (Tables 2 and 3). All the investigated findings differed significantly between patients and controls ($P < .05$).

CVOO

All except 2 patients ($n = 34$, sensitivity 94%) had CVOO. Venous sinus stenoses were apparent in sinuses distant from thrombosed sinuses in 6/8 patients (75%, Fig 3) and distant from sinuses compressed by a tumor in 7/8 patients (88%), or occurred in patients without any primary pathology of a venous sinus (18/20 patients, 90%; Figs 1, 2, and 4). Most patients (31/36, 86%) had stenoses that could not be directly attributed to a primary underlying pathology (ie, compression by a tumor or acute thrombosis). Type I CVOO (Fig 1*B*) was found in 41%; type II (Fig 2*C*), in 12%; and type III (Fig 4D), in 47%. In the control group, CVOO was not detected, but flow irregularities were seen in 44%.

ONS Hydrops

Mean diameters of the ONS were greater in patients compared with controls in all 4 positions ($P < .01$, Table 2). Using upper normal limits of the width of the ONS of 6.4, 5.8, 5.1, and 4.8 mm in positions 1–4 as proposed,[23] we observed ONS hydrops with sensitivities of 78%, 75%, 75%, and 75% and specificities of 89%, 100%, 97%, and 100%. In 33/36 patients, ONS hydrops occurred in at least 1 of the 4 positions of the optic nerve (sensitivity 92%), which could be detected in only 4/36 controls (specificity, 89%; Table 3). ONS hydrops was always bilateral (Figs 2 and 4).

Reduced Pituitary Height

Mean pituitary height was lower in patients than in controls (Table 2). A pituitary height <2.6 mm was observed in 20/36 patients and in 1/36 controls (56% sensitivity, 97% specificity; Table 3 and Fig 3*C*). When we took into account age- and

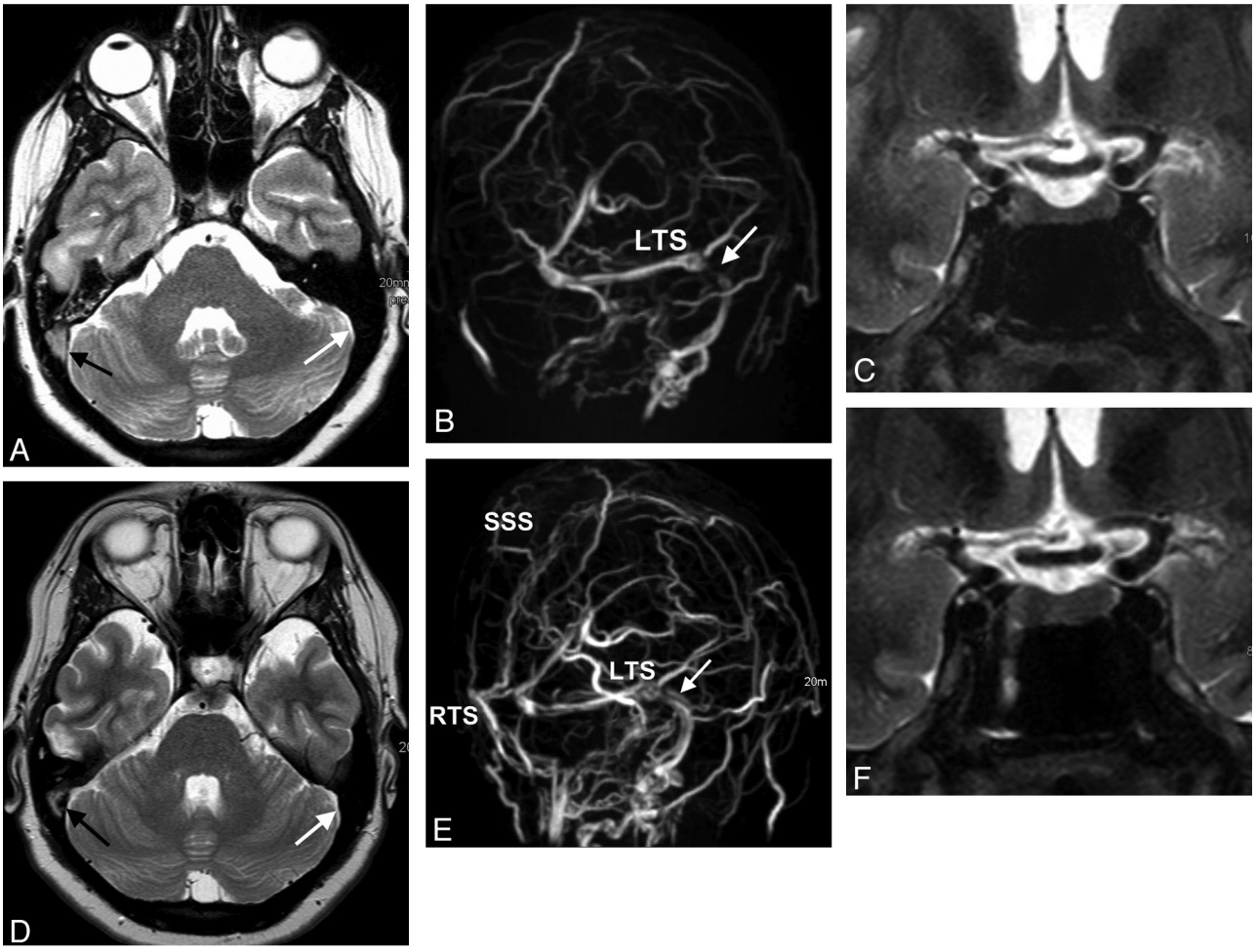

Fig 3. A 28-year-old woman with venous sinus thrombosis secondary to in vitro fertilization. *A,* Signal intensity typical for thrombosed blood is seen in the SSS and the RTS on axial T2w (*black arrow*) but not in the LTS (*white arrow*). *B,* There is corresponding signal-intensity loss on MIP of MRV in the RTS and SSS (left oblique view). There is a stenosis in the LTS (*white arrow*) without evidence of a thrombus. *C,* ONS hydrops is present (not shown), and the height of the pituitary gland is reduced to 2.5 mm (coronal STIR). *D* and *E,* CSF pressure is 40 cm H_2O. Six months later, partial recanalization of the RTS and SSS occurs following therapy with low-molecular heparin seen on T2WI (*black arrow* in *D*) and on MIPs of MRV (*E*). The stenosis in the LTS is believed to be the result of IH vanishing (*white arrow* in *E*). *F,* The pituitary height-weight returns to normal (4.5 mm).

sex-adapted lower normal limits of the pituitary height of 3 mm for children, 2.7 mm for men of all ages, 3.3 mm for women 18–62 years of age, and 1.8 mm for women older than 62 years of age,[23] 22 patient and 2 control measurements were abnormal, resulting in a sensitivity and specificity of 61% and 94%, respectively.

Flattened Posterior Sclera, Optic Papilla Protrusion, Elongation, and Edema of the Optic Nerve

The posterior sclera was flattened in 23 patients and in 8 controls. Protrusion of the optic disc, optic nerve edema, and optic nerve elongation were observed in 33%, 14%, and 6% of patients but in none of the controls (specificity of 100% each). Funduscopy was performed in 11 of 12 patients with protrusion of the disc, and bilateral papilledema was found in all of them. Optic disc protrusion was found in only 12/23 patients with proved papilledema (sensitivity of 52%).

Dilation of the SOV

The mean diameter of the SOV was greater in patients with SIH than in controls (Table 2). In 11 patients and in 1 control, the maximum diameter of the SOV exceeded 2.6 mm (Table 3).

Ventriculomegaly

Ventriculomegaly was noted in 7 patients. In 2 patients with obstructive hydrocephalus and 1 patient with hydrocephalus of unknown origin, periventricular edema was present. In all of these 7 patients, CVOO was present; in 7/8 patients, cross-sectional MR imaging signs of IH were seen.

Correlating CSF Pressure with MR Imaging Findings and Vision Loss

CSF pressure was significantly higher in patients with optic disc protrusion (48.3 $\pm$ 13.4 cm H_2O) and optic nerve edema (54.7 $\pm$ 8.1 cm H_2O) than in patients without these findings (mean, 36.1 $\pm$ 10.9 cm H_2O and 38.3 $\pm$ 12.3 cm H_2O, respectively; $P < .05$ each). In patients with CVOO, CSF pressure was higher in those having CVOO type III (54.4 $\pm$ 12.7 cm H_2O) than in those having either CVOO type I or II (36.7 $\pm$ 11.2 cm H_2O, $P < .05$). ONS diameter, height of the pituitary gland, and diameter of the SOV did not significantly correlate with

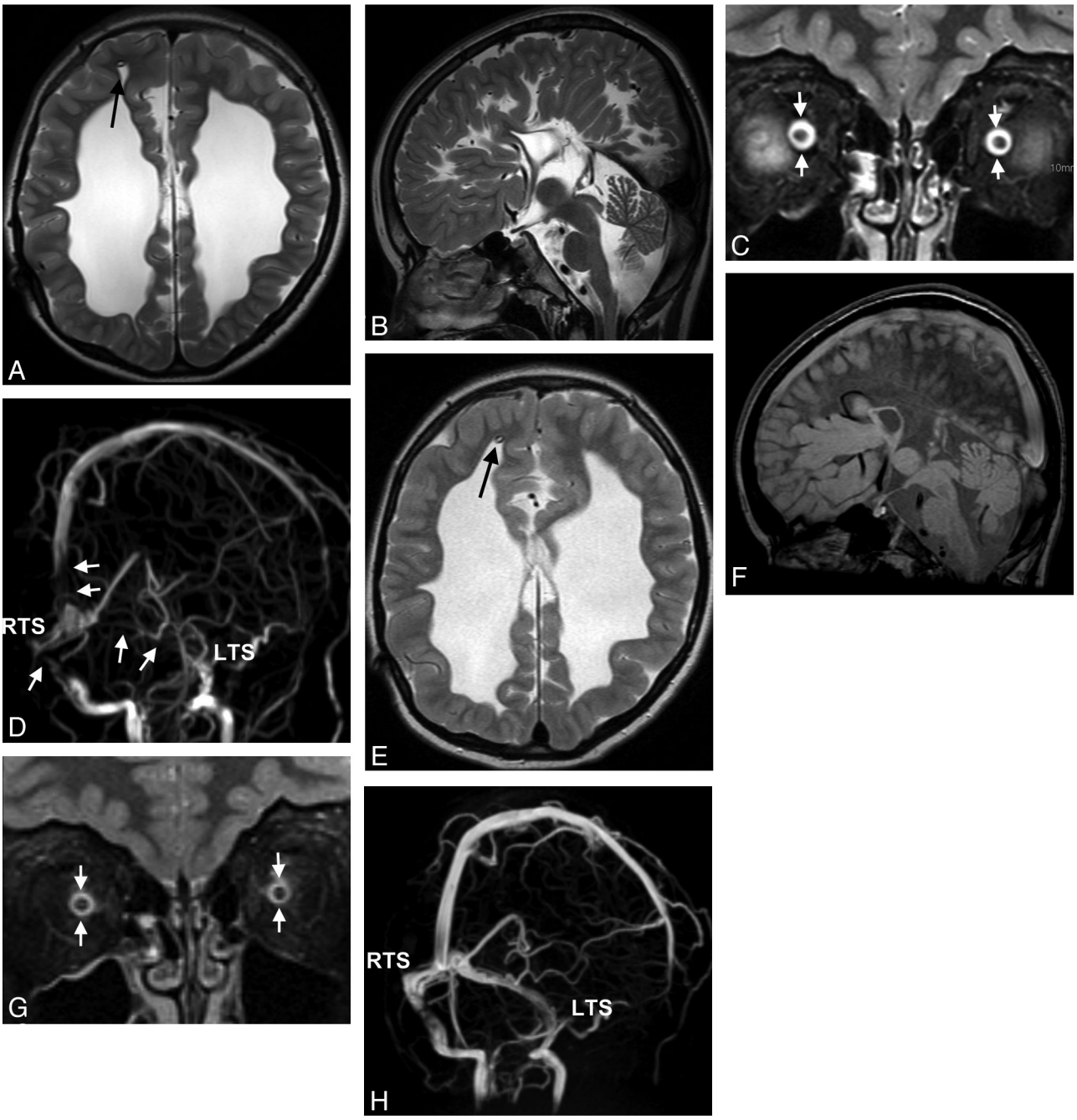

Fig 4. Cranial MR imaging of a 7-year-old boy with congenital posthemorrhagic hydrocephalus before (*A–D*) and 7 days later after (*E–H*) correction of the distal part of an insufficient ventriculoperitoneal shunt (*arrows* in *A* and *E*). Standard imaging (axial T2WI in *A* and *E*; sagittal T2WI and FLAIR in *B* and *F*) does not reflect IH, and does not change after therapy. ONS hydrops (*arrows* in *C*, width of 6.8 mm measured in a plane 3 mm dorsal to the optic globe; upper normal limit is 6.3 mm) normalizes after therapy (*arrows* in *G*, width of 5.9 mm). Oblique views of MIP of MRV (*D* and *H*) display signal-intensity losses in the LTS and RTS and the SSS (*arrows* in *D*), also normalizing on follow-up (*H*). Bilateral papilledema resolves.

the degree of CSF pressure increase. There was a positive correlation of CSF pressure and the number of positive MR imaging findings of IH (Spearman correlation coefficient, $r = 0.62$; $P = .01$). At least 2 MR imaging findings could be demonstrated in each patient. Concerning visual impairment, no significant differences in CSF pressure values were found between patients in groups 1 (little or transient impairment) and 2 (severe impairment) (mean, 37.4 ± 10.7 cm H_2O versus 43.3 ± 14.0 cm H_2O), but patients in group 2 had significantly more frequent MR imaging features of optic disc protrusion (58%) and optic nerve edema (33%) than patients in group 1 (25% and 5%, $P < .05$ each). There were no noted differences between patients with and without direct pressure measurements (Tables 2 and 3).

Interobserver Reliability

Concerning quantitative signs, the interobserver reliability was best for measurements of the pituitary height, was good for measurements of the ONS diameters, and was worst for measurements of the SOVs (Table 2). Concerning qualitive signs, the interobserver reliability was excellent for CVOO, ventriculomegaly, and periventricular CSF flow; was mediocre

Table 2: Differences in MRI measurements between 36 patients with IH and 36 controls[a]

		Diameter of the ONS (mm)[b]				Pituitary Height (mm)	SOV Diameter (mm)
		Position 1	Position 2	Position 3	Position 4		
Patients with IH (all, $n = 36$)	Mean	7.0	6.1	5.4	5.1	3.1	2.3
	SD	0.9	0.9	1.0	0.7	1.6	0.7
	95% CI	6.7–7.3	5.8–6.4	5.1–5.7	4.9–5.3	2.6–3.6	2.0–2.5
	ICC	0.832	0.84	0.866	0.84	0.863	0.389
Patient subgroup I ($n = 12$)	Mean	7.2	6.2	5.3	5.1	3.2	2.2
CSF pressure 22–38 cm H_2O	SD	0.6	0.7	1.1	0.5	1.0	0.8
Patient subgroup II ($n = 10$)	Mean	6.7	5.9	5.2	5.1	2.8	2.4
CSF pressure 40–70 cm H_2O	SD	0.6	0.7	0.8	0.7	1.3	0.5
Patient subgroup III ($n = 14$)	Mean	7.0	6.2	5.7	5.0	3.2	2.2
No CSF pressure measurements	SD	1.2	1.1	1.0	0.8	2.0	0.7
Controls ($n = 36$)	Mean	5.8	4.9	4.4	4.1	5.2	1.7
	SD	0.6	0.6	0.5	0.3	1.5	0.5
	95% CI	5.6–6.0	4.7–5.1	4.3–4.6	4.0–4.3	4.7–5.6	1.5–1.8
	ICC	0.76	0.728	0.78	0.732	0.893	0.634

[a] Results of all measurements differed significantly between all patients and controls ($P < .01$) and also between the different patient subgroups (I–III) and controls ($P < .05$). No significant differences existed among results of patient subgroups I, II, and III.
[b] ONS diameter was measured 3, 6, 10, and 20 mm behind the globe (positions 1–4).

Table 3: MR imaging signs in 36 patients with IH and 36 control subjects[a]

Patient Group	Opening CSF Pressure on LP in cm H_2O (mean) (range)		CVOO	ONS Hydrops[b]	Reduced Pituitary Height (<2.6 mm)	Flattened Posterior Sclera	Optic Disc Protrusion	Dilated SOV (<2.6 mm in diameter)	Ventriculomegaly	Periventricular CSF Flow	Optic Nerve Edema	Optic Nerve Elongation	No. of Positive MRI Signs (mean) (range)
All patients	39.8	Frequency,	34/36	33/36	20/36	23/36	12/36	11/36	7/36	5/36	5/36	2/36	4.3 (2–9)
	24–70	Sensitivity,	94%	92%	56%	64%	33%	31%	19%	14%	14%	6%	
		CI 95%,	81%–99%	76%–98%	38%–72%	46%–79%	19%–91%	16%–48%	8%–36%	5%–29%	5%–29%	1%–19%	
		Specificity,	100%	89%	97%	78%	100%	97%	100%	100%	100%	100%	
		95% CI,	90%–100%	73%–96%	85%–100%	61%–90%	90%–100%	85%–100%	90%–100%	90%–100%	90%–100%	90%–100%	
		OR	1007	88	44	6	37	15	18	13	13	5	
		95% CI,	47–21,741	18–424	5–355	2–17	2–658	2–127	1–338	1–240	1–240	.3–114	
		Agreement,[c]	100%	100%	91.7%	63.9%	77.8%	67%	91.7%	91.7%	69.4%	80.6%	
		κ[c]	1	1	0.888	0.484	0.675	0.338	0.852	0.79	0.47	0.533	
Patient subgroup I	29.5	Frequency	10/12	11/12	4/12	5/12	2/12	4/12	1/12	1/12	0/12	0/12	3.3 (2–6)
	22–38		83%	92%	33%	42%	17%	33%	8%	8%	0%	0%	
Patient subgroup II	52	Frequency	10/10	9/10	7/10	8/10	6/10	3/10	3/10	1/10	3/10	1/10	5.1 (3–7)
	40–70		100%	90%	70%	80%	60%	30%	30%	10%	30%	10%	
Patient subgroup III	N.T.	Frequency	14/14	13/14	9/14	10/14	4/14	4/14	3/14	3/14	2/14	1/14	4.5 (2–9)
			100%	93%	64%	71%	29%	29%	21%	21%	14%	7%	
Controls	N.T.	Frequency	0/36	4/36	35/36	8/36	0/36	1/36	0/36	0/36	0/36	0/36	0.4 (0–1)
			0%	11%	3%	22%	0%	3%	0%	0%	0%	0%	
		Agreement[c]	100%	78%	100%	69.4%	94.4%	94.4%	94.4%	97.2%	97.2%	94.4%	

[a] Frequency of all MRI signs differed between patients and controls ($P < .01$). Frequency of the MRI signs "optic disc protrusion" and "optic nerve edema" were more often found in patient group II compared with patient group I ($P < .05$). Frequencies of all MRI signs did not differ between patient subgroup III and the other patient groups.
[b] ONS hydrops was assumed if the diameter was above normal limits in ≥1 different position. Normal upper limits of ONS diameters were 6.4, 5.8, 5.1, and 4.8 mm in measurement positions 1, 2, 3, and 4 (3, 6, 10, and 20 mm behind the globe).
[c] Results of 3 readers used to determine the interobserver-reliability.

for optic disc protrusion, optic nerve elongation, and "optic nerve edema; and was worst for flattened posterior sclera (Table 3).

Follow-Up Investigations

Follow-up MR images were available in 27 patients. After CSF pressure was lowered, 20 patients improved clinically with associated decrease in MR imaging signs of IH (Fig 3). One patient remained stable clinically and on MR imaging. Six patients improved clinically, but MR imaging findings did not change. The rate of agreement (clinical versus neuroradiologic), therefore, was 21/27 (78%). Follow-up MR images after shunt revisions were available in 2 of 3 children with hydrocephalus and demonstrated normalization of MR imaging features except for the presence of hydrocephalus (Fig 4).

Discussion

Our study shows that the imaging parameters CVOO, ONS hydrops, and reduction in pituitary height discriminated best between patients with IH and controls. Most other signs studied did show a lesser sensitivity but a high specificity.

Intracranial Venous Morphology in IH

Thrombosis or occlusion of venous sinuses (primary CVOO) can result in IH,[23-26] probably by inducing venous hypertension and subsequent impairment of CSF absorption.[25] In patients with IIH, bilateral narrowing of the TS not associated with thrombosis has been found regularly.[27-31] Because stent angioplasty can help control IH in these patients, a causative role of these stenoses is favored by some.[29,30] On the other hand, lowering the intracranial pressure can result in normal-

ization of venous morphology, suggesting that these stenoses might be induced by IH itself (secondary CVOO).[25,26] We have shown that CVOO is not a specific feature of patients with IIH but is a universal phenomenon in most patients with IH irrespective of the underlying cause (Figs 2–4). Also, stenoses are not restricted to both lateral TSs as in IH but can occur in a variety of locations and present with different shapes. A widespread involvement of sinuses was associated with very high CSF pressure. Most interesting, in patients with primary CVOO, additional stenoses also occur in sinuses not affected by primary obstruction. We hypothesize that IH compresses the dural sleeve of the venous sinuses in all patients. This compression might lead to lengthy narrowing or—in the case of rather short bilateral TS stenoses—enlargement and invagination of arachnoid granulations into the sinus lumen or might induce a collapse of "vulnerable" sinus segments. The latter phenomenon might induce a vicious circle because the sinus stenoses themselves worsen IH via the mechanism of prestenotic venous hypertension. Because principally all segments of the venous sinuses can be affected, failures of venous sinus stent placement can occur.[11]

Analysis of MRVs can be challenging because flow signal-intensity irregularities occurred in a significant number of our controls (44%). Similar results have been published by Higgins et al.[32] Nevertheless, by using a simple new scoring system, stenoses were found to lead to CVOO in 94% of our patients with SIH but in none of the controls. Widening of the SOV in patients with IH has been demonstrated with T1WI[16] and could also be shown in our patients by using MRV. The reason for this is not clear but could be due to increased collateral venous outflow.

Cross-Sectional MR Imaging Signs of IH

Cross-sectional MR imaging and CT signs of IH have been studied in patients with IIH[13,14,17-22,33,34] with varying results. In a recent study, only 1 MR imaging sign (flattening of the posterior sclera) was found to be useful.[21] This could be due to the different nature of IIH compared with SIH but could also be due to technical limitations of that study: Although most MR imaging signs were derived from the orbital content, no detailed orbital studies were performed and authors did not describe at which location the width of the ONS was measured. However, this is an important aspect because this width varies significantly from anterior to posterior.[35,36] Changes of the pituitary shape were judged subjectively despite age- and sex-dependent variations of the pituitary size.[35,37]

With our approach of using quantitative markers and by using MR imaging sequences optimized for orbital imaging, we found several parameters to be useful for predicting IH, especially ONS hydrops and a decrease of the pituitary height. Flattening of the posterior sclera was a sign less sensitive and not specific for IH in our study, and interobserver reliability for this sign was low. In our opinion, judgment of this sign is delicate and prone to be influenced by partial volume effects. Protrusion of the optic disc indicates papilledema. This sign and optic nerve edema were associated with very high CSF pressure and with severe visual impairment. We favor a diagnostic approach that considers multiple indirect MR imaging signs of IH, because we found that the number of positive signs correlates with the degree of pressure increase and because pathologies of the orbit or sella might prevent using a single sign.

Making use of MR imaging signs of IH in patients with SIH has several possible implications: Because unlike in IIH, patients with SIH display a wider range of signs and symptoms due to their underlying disease, the clinical diagnosis of IH can be difficult and thus could be substantiated by MR imaging. In patients lacking obvious pathology on neuroimaging (Fig 2), MR imaging signs of IH might be the only indicators of IH and may lead to effective treatment (CSF diversion). Some patients with venous sinus thrombosis develop visual problems that can be attributed to IH. We found MR imaging to be helpful in diagnosing IH in these cases (Fig 3). In patients with hydrocephalus with shunt surgery procedures, ventriculomegaly can persist irrespective of the actual intracranial pressure (Fig 4). To our knowledge, this is the first report to show that the presence of venous sinus narrowing on MRV can easily demonstrate an increase in intracranial pressure in these patients. In the case of severe noncommunicating hydrocephalus, additional MR imaging features of IH probably do not influence patient treatment (Fig 1), but they may be of use on follow-up. In our study, these cases provide evidence that MR imaging signs of IH work in a variety of settings (communicating and noncommunicating hydrocephalus). Our preliminary data by using follow-up MR images indicate that MR imaging signs of IH are at least partially reversible on normalization of intracranial pressure.

Larger numbers of patients and controls are needed to substantiate our findings, especially with regard to children with shunt placements and patients acutely affected by IH.

Conclusions

With a standardized protocol, MR imaging is sensitive and specific in the diagnosis of patients with IH irrespective of the underlying cause. In our cohort, all patients but none of the controls displayed at least 2 MR imaging signs of increased intracranial pressure. This technique can be potentially helpful in increasing the diagnostic reliability and in detecting patients who need invasive procedures in IH. Venous sinus narrowings are not a specific feature of IIH. In patients with secondary IH, these narrowings occur in different locations and with different shapes than those reported for IIH. We speculate that they are caused by IH but might contribute to the increase in intracranial pressure. Venous sinus narrowing might be a sensitive sign for diagnosing ventriculoperitoneal shunt failure but larger numbers of patients are needed to confirm this possibility.

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