Feasibility of 3-Dimensional Sampling Perfection With Application Optimized Contrast Sequence in the Evaluation of Patients With Hydrocephalus

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Purpose: This study aimed to investigate the effectiveness and additive value of T2W 3-dimensional sampling perfection with application optimized contrast (3D-SPACE) with variant flip-angle mode in imaging of all types of hydrocephalus. Our secondary objective was to assess the reliability of 3D-SPACE sequence and correspondence of the results with phase-contrast magnetic resonance imaging (PC-MRI)–based data.

Materials and Methods: Forty-one patients with hydrocephalus have undergone 3-T MRI. T2W 3D-SPACE sequence has been obtained in addition to routine hydrocephalus protocol. Cerebrospinal fluid circulation, presence/type/etiology of hydrocephalus, obstruction level scores, and diagnostic levels of confidence were evaluated separately by 2 radiologists. In the first session, routine sequences with PC-MRI were evaluated, and in another session, only 3D-SPACE and 3-dimensional magnetization prepared rapid acquisition gradient echo sequences were evaluated. Results obtained in these sessions were compared with each other and those obtained in consensus session.

Results: Agreement values were very good for both 3D-SPACE and PC-MRI sequences ($P < 0.001$ for all). Also, the correlation of more experienced reader's 3D-SPACE–based scores and consensus-based scores was perfect ($\kappa = 1$, $P < 0.001$).The mean value of PC-MRI–based confidence scores were lower than those obtained in 3D-SPACE and consensus sessions.

Conclusions: T2W 3D-SPACE sequence provides morphologic cerebrospinal fluid flow data. It is a noninvasive technique providing extensive multiplanar reformatted images with a lower specific absorption rate. These advantages over PC-MRI make 3D-SPACE sequence a promising tool in management of patients with hydrocephalus.

Key Words: MRI, 3D-SPACE, variable flip angle, hydrocephalus, PC cine MR

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In patients with hydrocephalus, proper understanding of the basic pathology is essential to decide the best treatment option, improve postoperative outcome, and avoid unnecessary surgery.[1–5] Routine magnetic resonance imaging (MRI) sequences and techniques usually fail to determine the etiology and severity of the disease. Therefore, to diagnose and plan the management of hydrocephalus as well as to follow up surgically treated patients, such as those who undergo endoscopic third ventriculostomy (ETV), advanced techniques are used. Those techniques include phase-contrast cine MRI (PC-MRI), 3-dimensional heavily T2-weighted (W) sequences, cisternographic or ventriculographic studies, some of which are invasive.[6] Besides their invasive nature, these methods usually require additional examination, which decreases patient compliance, increases total cost, and causes patients to quit follow-up.

One of the most recent MRI techniques is 3-dimensional sampling perfection with application-optimized contrasts using different flip angle evolutions (3D-SPACE). It is a single slab turbo spin-echo (TSE) sequence with multiple different flip angles (FAs) developed by Mugler et al.[7,8] It provides 3-dimensional T1W, proton-density W, fluid-attenuated inversion recovery, conventional-heavily T2W, and inversion recovery images with isotropic data and high signal to noise ratio in a reasonable period.[3] The main advantage of this technique is that it eliminates the high specific absorption rate, which is a major drawback in use of 3-T MRI systems.[7,8]

In our previous studies, we have concluded that using T2W 3D-SPACE sequence with variant flip angle mode (VFAM) is beneficial in investigating presence of aqueductal stenosis and spontaneous third ventriculostomy.[3,9] In light of the data we have obtained in these previous studies, we have determined that using 3D-SPACE sequence with VFAM in evaluating patients with hydrocephalus is usually sufficient without the need of an additional sequence. Therefore, in our clinic, we have added this sequence in routine examination of the patients with hydrocephalus. Despite the increase in using 3D-SPACE sequence in routine workup, the inter observer and intraobserver variability in evaluation of this sequence is not yet determined.

In this current retrospective study, we aimed to investigate the role and additive value of T2W 3D-SPACE with VFAM in overall evaluation of all types of hydrocephalus. Our secondary objective was to assess the reliability of 3D-SPACE sequence and correspondence of the results with PC-MRI–based data.

MATERIALS AND METHODS

The study was approved by the institutional review board and written consent was obtained from each patient. Cases that had been referred to our radiology clinic in a 3-year period for evaluation of suspected or known hydrocephalus due to various etiologies were included in this retrospective study. Those cases with examinations obscured by significant motion artifacts (n = 3) and those whose PC-MRI examinations were not diagnostic due to technical insufficiency such as inappropriate velocity-encoding value or slice position (n = 2) were excluded. As a result, 41 patients (23 men, 18 women) were included in the study. Mean age of the patients included in the study was 30 years, varying with a range of 6 to 71 years. The median ages of men and women were 27 years (range, 7–62 years) and 36 years (range, 6–71 years), respectively.

MRI Protocol

All the examinations had been performed at a 3-T MRI system (Trio; Siemens, Erlangen, Germany) with a 12-channel head array birdcage coil. After acquisition of scout images, sagittal plane T2W TSE, T1W 3-dimensional magnetization prepared

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TABLE 1. 3-T MRI Protocol Used for Patients With Hydrocephalus

Sequences/Parameters	T2W-TSE	3D-MPRAGE	3D-SPACE (With VFAM)	PC-MRI (Qualitative)	Heavily T2W 3D-SPACE	PC-MRI (Quantitative)
TR/TE, ms	6000/93	2130/3.45	3000/579	34.9/9.8	3000/423	30/7.43
TI, ms	—	1100	—	—	—	—
Slice thickness, mm	3	0.8	0.6	4	0.8	4
FOV,* mm	220 × 220	230 × 230	240 × 240	240 × 240	210 × 210	240 × 240
Acquisition time, min	1.3	5.5	6	5	5	5
Velocity encoding, cm/s	—	—	—	6	—	20
NEX	1	1	2	2	1	1
No. slices	24	240	240	1	192	1
Flip angle, degrees	120	8	100	10	100	10
Imaging plane	Axial-sagittal	Sagittal	Sagittal	Axial-sagittal	Sagittal	Axial
Distance factor	30%	50%	—	—	—	—
PAT factor	2	2	2	None	2	None
PAT mode	GRAPPA	GRAPPA	GRAPPA	—	GRAPPA	—
Voxel size, mm	—	0.8 × 0.8 × 0.8	0.6 × 0.6 × 0.6	—	0.8 × 0.8 × 0.8	—
FA mode	—	—	T2 variant	—	T2 constant	—

3D-MPRAGE indicates 3D T1W magnetization prepared rapid acquisition gradient echo; 3D-SPACE, 3-dimensional sampling perfection with application-optimized contrasts using different flip angle evolutions; GRAPPA, generalized autocalibrating partially parallel acquisitions; NEX, number of excitations; PAT, parallel acquisition technique; PC-MRI, phase-contrast cine MRI (2D spoiled gradient-echo sequence with retrospective cardiac-gating); T2W-TSE indicates T2-weighted (W) turbo spin-echo; TI, time of inversion.

rapid acquisition gradient echo (3D-MPRAGE), T2W 3D-SPACE with VFAM, and PC-MRI images had been obtained. Twenty-four in-plane magnitude, phase and rephased images had been acquired from each PC-MRI sequence. The mean acquisition time of each PC-MRI sequence was approximately 5 minutes, which could have slightly varied depending on the patient's heart rate. Additionally, sagittal plane heavily T2W 3D-SPACE images had been obtained in 5 patients with suspicions of membranous obstruction, and additional axial plane PC-MRI images (through-plane quantitative acquisition with velocity encoding value: 20 cm/s) had been obtained in 6 with ETV history or suspected normal pressure hydrocephalus. The general data demonstrating the details of MRI protocol have been given in Table 1. However, field of view (FOV) size had varied for each case to achieve smallest voxel sizes by choosing the smallest possible FOV size to cover the entire cranium. Isotropic voxel size had been used while obtaining all 3-dimensional data.

Evaluation of the Data

Three-dimensional images obtained from 3D-MPRAGE and 3D-SPACE sequences were evaluated on dedicated workstation (Leonardo; Siemens, Erlangen, Germany) and thin-slice reformatted images were obtained in multiple planes (axial, coronal, and oblique planes). Also, curved reformat, multiplanar reconstruction, and maximum intensity projection images were obtained in this workstation.

Three sets of sessions were undertaken as follows:

Set 1 (named PC-MRI session) was composed of T2-TSE + PC-MRI + 3D-MPRAGE.

Set 2 (named 3D-SPACE session) was composed of only 3D-SPACE + 3D-MPRAGE.

Set 3 (named consensus session) was composed of all sequences together.

As a precaution to any interference between these 3 sessions, 3-week intervals were left in between the sessions and cases were evaluated without the same order. The following quotes constituted the main concerns in each session:

1) Presence of hydrocephalus
2) If hydrocephalus is present, type of hydrocephalus
3) If obstructive hydrocephalus is present, the localization and the etiology of obstruction
4) Presence of spontaneous third ventriculostomy
5) For those patients who have undergone cerebrospinal fluid (CSF) diversion surgery, current functional and morphologic status of the diversion
6) Additional pathological findings
7) Severity of obstruction level which has been scored for each dataset as follows:
    A) Obstruction scoring for PC-MRI session
        Score 0: No obstruction is detected. Systolic and diastolic prominent flows can be detected all through the pathway.
        Score 1: Lumen is narrowed anywhere through the pathway and the flow is hardly visible on all PC-MRI images.
        Score 2: No flow at systole or diastole.
    B) Obstruction scoring for 3D-SPACE session
        Score 0: No obstruction is detected and there is hypointense CSF flow all through the pathway.
        Score 1: Lumen is narrowed anywhere through the pathway and/or CSF flow is barely visible.
        Score 2: Lumen is totally obstructed anywhere through the pathway and no hypointense signal of CSF flow can be detected. At the level of obstruction, and particularly proximal to the obstruction, CSF is characterized with hyperintense signal.
    C) Obstruction scoring for consensus session
        Score 0: No obstruction
        Score 1: Partial obstruction
        Score 2: Complete obstruction

TABLE 2. Types and Causes of Hydrocephalus Described in the Study Patients

Type of Hydrocephalus	Cause of Hydrocephalus	No. Cases
Obstructive type	Intraventricular or periventricular cystic lesions	8
	Tumor of the foramen of Monro	1
	Aqueduct stenosis	20
	Chiari malformation	4
	Web in fourth ventricle outlet	1
Communicating type	Normal pressure hydrocephalus	6
Complex type	Posthemorrhagic, postmeningitis	2

In 1 patient, obstruction was detected in 2 different locations. Complex type of hydrocephalus: posthemorrhagic or postinfectious.

8) Level of confidence of the radiologists during evaluation (how confident the radiologist felt while elucidating the aforementioned quotes after evaluation of entire set of images in each data set, as determined for each radiologist separately) has been documented based on the following grading system:

Grade 0 (low confidence): Inadequate data for the final decision; additional sequence or technique is definitely required.

Grade 1 (moderate confidence): Final decision per hydrocephalus can be made with the present data; however, elucidation of other details such as underlying and/or other pathologies requires correlation with clinical findings, other sequences, and/or previous examinations.

Grade 2 (good confidence): Adequate for evaluation of the hydrocephalus and other pathologies overall; radiologist is almost completely confident.

Grade 3 (perfect confidence): The data obtained are sufficient to answer all quotes regarding hydrocephalus and other findings; the confidence level of the radiologist is excellent with regard to all structures in the FOV, without any need for further workup.

To determine "inter-observer" variability, obstruction scorings and confidence grading were done by 2 readers independently [first reader: M.G.K. (1 year experience with 3D-SPACE), and second reader: O.A. (4 years experience with 3D-SPACE)], based on the scheme described previously. To determine the "intra-observer" variability, obstruction scoring was done twice by the first reader, with a month interval.

In consensus session; the 2 radiologists reviewed all imaging data together with the clinical records for each patient, and final decision was made.

Statistical Analysis

Age was reported with median (minimum-maximum) values and compared between sexes by using Mann-Whitney *U* test. κ coefficient was used to determine the interobserver and intra-observer agreement. κ value normally lies between 0 and 1, with 0 indicating agreement purely by chance and 1 indicating perfect agreement.[10,11] κ values should be interpreted within the clinical context, values below less than 0.20 poor agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 good agreement, and 0.81 to 1.00 very good agreement.[10–12] The level of statistically significant difference was set at $P < 0.05$.

TABLE 3. Additional Pathological Findings Described in PC-MRI Sessions

Additional Findings	No. Patients
Syrinx	2
Cerebral atrophy	1
PVHI	4
Mucosal thickening in sinuses	10
The presence of a VPS	8
Mucosal polyp in paranasal sinuses	1
CC damage after VPS placement	2
Hamartomas in patients with NF1	2
Paranasal sinus mucocele	1
Retrocerebellar arachnoid cyst	2
Subdural effusion after VPS placement	2
Microglia	1
Tectal glioma	8
Partial empty sella	5
Patent stoma with ETV	3
Pineal gland cyst	1
Aqueductal web, adhesion, or forking	8
Colloid cyst	2
STV	1
Lymphadenomegaly	1

CC indicates corpus callosum; PVHI, periventricular white matter hyperintensities; STV, spontaneous third ventriculostomy.

Statistical analyses were performed with SPSS software version 13.0 (Chicago, IL).

RESULTS

No hydrocephalus was detected in 6 patients (Evans index, <0.3). In 2 of these 6 patients who had hydrocephalus previously, the ventricle sizes returned to normal after ventriculoperitoneal

TABLE 4. Additional Pathological Findings Described in 3D-SPACE Session

Additional Findings	No. Patients
Fractured VPS	1
STV	2
Effusion in mastoid air cells	4
Additional cysts	2
Cyst communication	2
Additional hamartomas in patients with NF1	2
Additional morphological characteristics of cysts	3
The foramina of Monro evaluation of patients with colloid cysts	2
Lacunar infarction	1
Lymphadenomegaly	2
Mucosal polyp in paranasal sinuses	3
Additional morphological characteristics of ETV	3
Optimum evaluation of space occupying lesions	2
Intact liliequist's membrane	28
Stenosis of foramen of Monro	1

NF1 indicates neurofibromatosis type 1; STV, spontaneous third ventriculostomy.

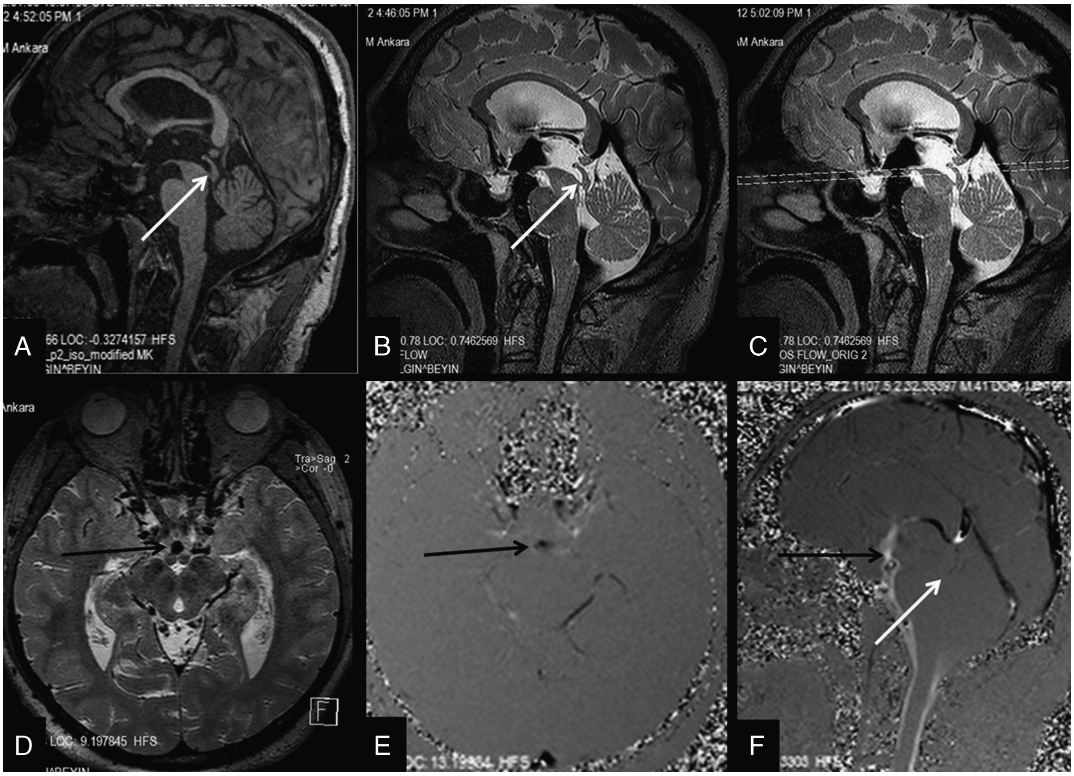

FIGURE 1. 3D-MPRAGE (A), 3D-SPACE with variant FA mode (B–D), and PC-MRI (E, F) images of a 41-year-old male patient with aqueductal stenosis. Sagittal 3D-MPRAGE image demonstrates an aqueductal web (arrow, A). In sagittal 3D-SPACE image, hyperintense signal is seen at the level of aqueduct consistent with occlusion (arrow, B). In the same image, CSF flow with hypointense signal is detected from inferior wall of the third ventricle to prepontine cistern showing patent ETV stoma. On axial reformatted 3D-SPACE image (D), passing through stoma as shown in Figure 2C, morphology of ETV is better visualized. These findings in 3D-SPACE images were consistent with findings on axial (E) and sagittal (F) PC-MRI images. In these PC-MRI images, black arrows indicate patent stoma and white arrow shows aqueductal stenosis.

shunt (VPS) procedure. In all the rest of the 35 patients, hydrocephalus was present. Etiology and type of hydrocephalus are summarized in Table 2.

Additional findings detected in patients in PC-MRI and 3D-SPACE sessions are given in Tables 3 and 4, respectively. In consensus session (in addition to the findings in Table 4), in 1 patient syrinx morphology, in 2 patients VPS catheter, and in 2 patients foramina of Monro were better evaluated (Fig. 1). In 1 patient, it was detected in 3D-SPACE sequence, that proximal end of VPS catheter was in brain parenchyma and the catheter position was revised (Fig. 2). Although in PC-MRI session, findings rose suspicion for STV; in consensus session, intact third ventricular walls were demonstrated and no STV was detected. On the other hand, in one other patient, although equivocal findings of STV were present in PC-MRI session, in consensus session, defects in inferior wall of the third ventricle and CSF outflow were clearly established and diagnosis of STV was made.

Intraobserver agreement values of obstruction scores were very good for both 3D-SPACE and PC-MRI sequences ($\kappa = 0.912$ and 0.925 for PC-MRI and SPACE, respectively; $P < 0.001$ for both) (Table 5). Interobserver agreement values of obstruction level scores were moderate to good for PC-MRI and 3D-SPACE images (Table 5). Also, the agreement between more experienced reader's (second reader) 3D-SPACE–based scores and consensus-based scores was excellent ($\kappa = 1$, $P < 0.001$) (Tables 5 and 6).

There was no significant difference between confidence scores of the 2 readers for both the PC-MRI and SPACE sessions ($P > 0.05$). No correlation was detected between consensus session–based confidence scores and PC-MRI/3D-SPACE–based scores ($P > 0.05$). Besides, median value of PC-MRI–based confidence scores was less than 3D-SPACE and consensus-based scores (Tables 7 and 8).

DISCUSSION

In this current study, we aimed to demonstrate the utility of 3D-SPACE sequence and our optimized 3D-protocol (3D-SPACE and 3D-MPRAGE) for patients with hydrocephalus. Overall, there was a good agreement between the 3D-SPACE and PC-MRI–based evaluations which support our previous studies.[3,9] Our results show that 3D-SPACE sequence can be used as a reliable tool in management of patients with hydrocephalus, with good to perfect intraobserver and interobserver agreement. Moreover, results for reliability analysis for 3D-SPACE sequence were generally better than those PC-MRI images. This may be attributed to the fact that 3D-SPACE sequence provides high-resolution isotropic data and extensive multiplanar reformatted images are obtained which enable both morphological and physiological analysis at the same time.[13]

Unlike PC-MRI, 3D-SPACE sequence allows scanning of the whole cranium in an acceptable acquisition time and without exceeding specific absorption rate limits by using less than 1 mm^3 voxels. On the other hand, PC-MRI sequence is made up of a single slice with a thickness of 2 to 5 mm and no data related to other slices are obtained. Therefore, the sequence should be repeated at the times when the slices do not pass through the appropriate area, or flow information in another plane is required. The acquisition time for PC-MRI in a single plane is approximately equal to the time needed to obtain 3D-SPACE sequence. However,

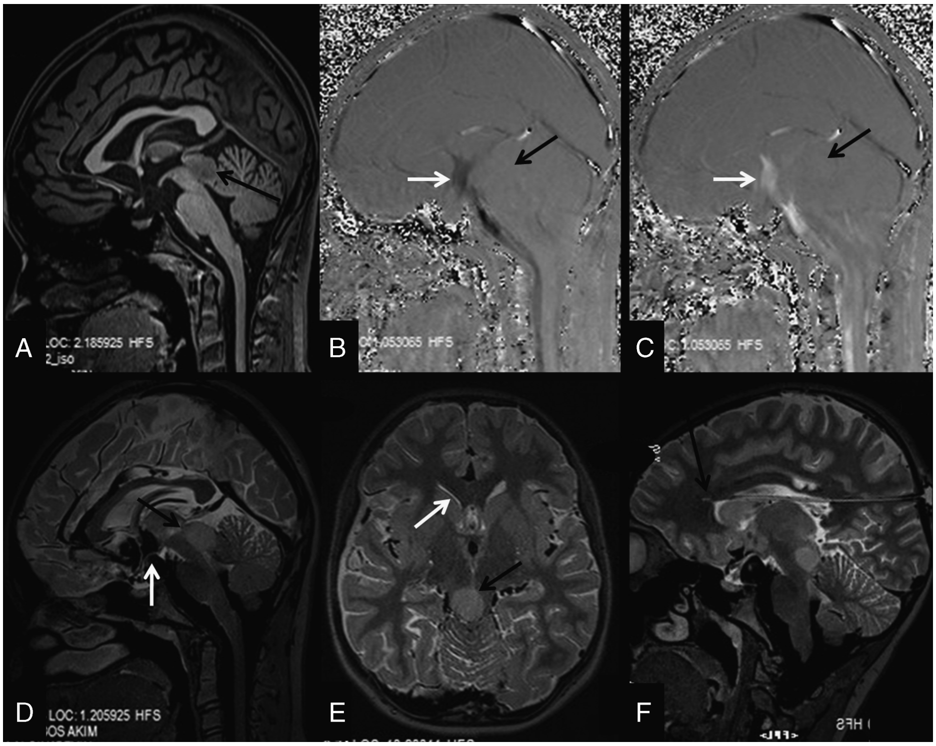

FIGURE 2. 3D-MPRAGE (A), PC-MRI (B, C), and 3D-SPACE with variant FA mode (D–F) images of an 11-year-old girl with aqueduct stenosis. In sagittal MPRAGE image (A), tectal glioma (arrow) is shown causing the aqueduct stenosis. In sagittal PC-MRI images (B, C), no flow is detected at the level of aqueduct (black arrows). Flow is present in systolic and diastolic phases at the level of inferior wall of the third ventricle (white arrows in B, C). In the sagittal 3D-MPRAGE image, inferior wall of the third ventricle is not clearly visualized (A). The sagittal 3D-SPACE image (D) clearly shows tectal glioma (black arrow), aqueductal stenosis, and intact inferior wall of the third ventricle (white arrow). Also, morphology of tectal glioma is well demarcated on axial reformatted 3D-SPACE image (black arrow, E). Also in this image, ventriculomegaly, known to be present previously, is shown to regress after placement of shunt catheter (white arrow, E). On the other hand, in the sagittal oblique reformatted image, distal end of the shunt catheter is shown to pass through corpus callosum (black arrow, F).

for a better evaluation, examination in more than one plane is often needed. Besides this, PC-MRI technique is more sensitive to technical factors such as cardiac arrhythmias. Thus, time required for a PC-MRI examination of a patient with hydrocephalus may lengthen up to 10 to 15 minutes. Although PC-MRI technique provides flow information, it lacks anatomic details and therefore does not allow morphological analysis. The advantages and disadvantages of 3D-SPACE over PC-MRI and 3-dimensional heavily T2W sequences are given in Table 9.

Another finding in this study is that 3D-SPACE–based scores were better correlated with consensus-based scores. Besides, absolute agreement was assessed between consensus-based scores and 3D-SPACE–based scores obtained by the second reader, who was more experienced with PC-MRI and 3D-SPACE techniques. This may suggest that radiologists who have experience with 3D-SPACE technique may accurately evaluate patients with hydrocephalus using this sequence without any need for PC-MRI. With our 3-dimensional protocol (3D-MPRAGE and 3D-SPACE sequences with isotropic voxels less than 1 mm^3), MRI acquisition time may be shortened to 10 to 15 minutes and MRI examinations can be standardized, which will not only avoid increase in cost due to unnecessary examinations but will also increase patient compliance. Another reason that this suggested protocol increases patient compliance is its noninvasive nature. Besides, during and after image acquisition with PC-MRI and other techniques such as cisternographic studies, a radiologist should be present in MRI suit to follow the procedure; whereas with this protocol, this is not obligatory.

In this study, there was no correlation between PC-MRI, 3D-SPACE, and consensus-based confidence scores. Besides, the mean value of PC-MRI–based confidence scores was less than those obtained with 3D-SPACE and consensus-based scorings.

TABLE 5. The Results for İntraobserver and İnterobserver Agreement Among Obstruction Scores Found in PC-MRI, 3D-SPACE, and Consensus-Based Sessions

Agreement	Sessions	κ (95% CI)
Intraobserver	PC-MRI-F1 vs PC-MRI-F2	0.912 (0.795–1.000)
	SPACE-F1 vs SPACE-F2	0.925 (0.823–1.000)
Interobserver	PC-MRI-F1 vs PC-MRI-S	0.582 (0.406–0.758)
	PC-MRI-F2 vs PC-MRI-S	0.620 (0.440–0.799)
	SPACE-F1 vs SPACE-S	0.666 (0.483–0.849)
	SPACE-F2 vs SPACE-S	0.668 (0.483–0.853)
Other agreements	PC-MRI-F1 vs consensus	0.614 (0.437–0.790)
	PC-MRI-F2 vs consensus	0.653 (0.474–0.831)
	SPACE-F1 vs consensus	0.666 (0.483–0.849)
	SPACE-F2 vs consensus	0.668 (0.483–0.853)
	PC-MRI-S vs consensus	0.963 (0.891–1.000)
	SPACE-S vs consensus	1.000 (1.000–1.000)

CI indicates confidence interval; F1, first scorings of the first reader; F2, second scorings of the first reader; S, scorings of second reader; κ indicates κ coefficient.

TABLE 6. Scores for Severity of Obstruction Done by the First (F) and the Second (S) Reader in PC-MRI, 3D-SPACE, and Consensus Sessions

Number	PCMRI-F1	PCMRI-F2	PCMRI-S	SPACE-F1	SPACE-F2	SPACE-S	Consensus
1	0	0	1	0	0	1	1
2	0	0	0	0	0	0	0
3	2	2	2	2	2	2	2
4	0	0	1	0	0	1	1
5	2	2	2	1	1	2	2
6	2	2	2	2	2	2	2
7	2	2	2	1	1	2	2
8	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	2	2	2	2	2	2	2
12	2	2	2	2	2	2	2
13	2	2	2	2	2	2	2
14	2	2	2	1	1	2	2
15	2	2	2	2	2	2	2
16	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0
18	0	0	1	0	0	1	1
19	0	0	0	0	0	0	0
20	0	0	1	0	0	1	1
21	0	0	0	0	0	0	0
22	1	1	2	1	1	2	2
23	2	2	2	2	2	2	2
24	0	0	0	0	0	0	0
25	0	1	1	1	1	1	1
26	2	2	1	1	1	1	1
27	2	2	2	2	2	2	2
28	0	0	0	0	1	0	0
29	0	0	0	0	0	0	0
30	2	2	1	1	1	1	1
31	2	2	2	2	2	2	2
32	0	0	0	0	0	0	0
33	2	2	2	2	2	2	2
34	2	2	2	2	2	2	2
35	0	0	0	0	0	0	0
36	0	2	1	1	1	1	1
37	1	1	1	1	1	1	1
38	2	2	2	2	2	2	2
39	0	0	1	0	1	1	1
40	2	2	2	2	2	2	2
41	0	0	0	0	0	0	0

F1 and F2 are the first and second reading scores of the first reader.

These results show that 3D-SPACE sequence has additive value in evaluation of patients with hydrocephalus and it generally increases the confidence scores (Tables 7 and 8). When 3D-SPACE sequence is added to conventional protocol, ventricular system morphology, position of VPS catheter, presence of ventriculostomy, and other associated findings are better evaluated.

In evaluation of patients with obstructive hydrocephalus, sometimes heavily T2W images are required to better evaluate anatomic details, luminal patency, and tissue-fluid distinction. In daily routine practice, gradient echo–based heavily 3-dimensional T2W sequences such as 3-dimensional constructive interference in the steady-state (3D-CISS) or 3-dimensional driven-equilibrium (3D-DRIVE) are used for this purpose. On the other hand, these sequences have a poor tissue distinction, limited slab thickness, and long acquisition time. Another disadvantage of these sequences could be banding, slab boundary, and other image artifacts from off-resonance and slab profile effects.[3,7,14] With 3D-SPACE technique, heavily T2W images through whole cranium can be obtained in an acceptable acquisition time as was done with 5 patients in this study.[15] Because 3D-SPACE is a TSE-based technique, all the limitations described previously can be overcome.

TABLE 7. Median (Minimum-Maximum) Values of Confidence Level Scores in Each Session

	n	Median (Min-Max)
PC-MRI-F	41	2 (1–3)
PC-MRI-S	41	2 (0–3)
SPACE-F	41	3 (1–3)
SPACE-S	41	3 (0–3)
Consensus	41	3 (2–3)

F indicates first reader; S, second reader.

TABLE 8. Confidence Level Scores of the First (F) and the Second (S) Reader in PC-MRI, 3D-SPACE, and Consensus Sessions

Number	PCMRI-F	PCMRI-S	SPACE-F	SPACE-S	Consensus
1	1	0	2	1	2
2	2	0	3	0	3
3	2	2	3	2	3
4	1	0	2	1	2
5	1	2	3	2	3
6	2	2	3	2	3
7	1	2	1	1	2
8	1	0	2	1	2
9	2	0	2	0	2
10	3	2	3	3	3
11	1	2	3	3	3
12	2	2	2	3	3
13	3	2	2	3	3
14	1	3	2	3	3
15	3	3	3	3	3
16	1	2	3	3	3
17	3	2	3	3	3
18	1	2	3	2	3
19	3	1	3	3	3
20	3	3	3	3	3
21	1	2	1	2	2
22	1	2	2	3	2
23	3	2	3	3	3
24	2	3	2	3	3
25	1	3	2	3	3
26	1	3	2	3	3
27	3	2	2	3	3
28	3	2	1	3	3
29	3	3	3	3	3
30	1	2	2	2	2
31	1	1	3	3	3
32	3	2	3	3	3
33	2	1	2	3	2
34	3	2	3	3	3
35	2	2	3	3	3
36	1	2	3	3	3
37	3	2	3	3	3
38	2	1	2	3	3
39	2	2	2	3	3
40	2	2	2	3	2
41	2	2	3	3	3

TABLE 9. Advantages and Disadvantages of the Sequences

Sequences	3D-SPACE	PC-MRI	3D-Heavily-T2W
Physiological data	+	+	−
Morphological data	+	−	+
Whole brain imaging	+	−	−
Experience requirement	+	++	−
Mean acquisition time, min	3–5	6–10	4–5
More complete imaging acquisition	++	+	++
Necessity of ECG or pulse triggering	−	+	−
Two- or 3-dimensional acquisition	3D	2D (single slice)	3D

In patients with normal pressure hydrocephalus, clinic, laboratory, and/or radiologic findings are often sufficient to achieve a certain diagnosis. Nevertheless, sometimes CSF quantitative analysis for velocity and stroke volume is required. It is not possible to obtain these parameters with 3D-SPACE technique. In these cases, it is obligatory to add through plane PC-MRI sequence in the protocol in addition to 3D-MPRAGE and 3D-SPACE for an accurate MRI examination. Even in these cases, the overall acquisition time is approximately 15 minutes.

The major difference between 3D-SPACE with variant VFA mode images and other T2W images are on 3D-SPACE images freely moving fluids (such as intravascular blood or unrestricted CSF) show low signal attenuation, whereas trapped or relatively slow flowing fluids show high signal attenuation. Hence; in patients with hydrocephalus, restricted CSF just proximal to the obstruction shows hyperintense signal and unrestricted fluid distal to the obstruction is seen hypointense on 3D-SPACE with variant VFA mode images. This is a feature which allows detection of accurate location of obstruction and provides information about CSF hydrodynamics in a noninvasive way without giving up morphologic detail.[9] Standard T2W TSE images may also show CSF flow voids as dark signal, but maybe not as sensitive as 3D-SPACE.[3] On the other hand, there are no exact data which determine a cutoff value to show with which velocity CSF shows high or low signal attenuation on 3D-SPACE with VFA mode images. It will be beneficial to determine this cutoff value and the parameters affecting this value to be able to obtain quantitative analysis. More comprehensive studies with larger series are needed to overcome the limitations regarding 3D-SPACE with variant VFA mode technique.

The major limitation in this preliminary study is that neither PC-MRI nor 3D-SPACE–based results were compared with gold standard techniques such as ventriculographic or cisternographic studies. However, PC-MRI and T2W images are widely accepted noninvasive methods, which were more appropriate to use than invasive techniques on ethical basis. The second limitation was that the readers were not blinded to sequence types. Another limitation is that the consensus "rather call it final diagnosis" was made by both observers together. Ideally, it should be done by a third independent experienced observer. Retrospective study concept is also a limitation of this study.

In conclusion, MRI has played a cardinal role in diagnosis of hydrocephalus as well as in therapy planning and follow-up period after surgery. Therefore, neuroradiologists require new and/or additional methods which can supply accurate morphologic and functional data in a practical way in routine use. The 3D-SPACE images with VFA mode alone may provide most of the information required for optimal management of the patients. Routine use of our simple, new, and optimized 3-dimensional hydrocephalus protocol, which consists of 3D-MPRAGE and 3D-SPACE sequences, decreases acquisition time and costs significantly and increases patient compliance by decreasing the need for invasive techniques or additional examinations. Although it lacks quantifying data, 3D-SPACE is one of the promising methods because it provides functional information without sacrificing morphologic details and therefore should be considered in routine use.

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