Dynamic magnetic resonance imaging of endoscopic third ventriculostomy patency with differently acquired fast imaging with steady-state precession sequences

Milos A. Lucic[1]*, Katarina Koprivsek[1], Dusko Kozic[1], Martina Spero[2], Milena Spirovski[1], Silvija Lucic[1]

[1]Diagnostic Imaging Center, Oncology Institute of Vojvodina, Sremska Kamenica, Novi Sad, University of Novi Sad, Faculty of Medicine, Novi Sad, Serbia. [2]Department of Radiology, University Hospital Dubrava, University of Zagreb, Zagreb, Croatia

Abstract

The aim of the study was to determine the possibilities of two differently acquired two-dimensional fast imaging with steady-state precession (FISP 2D) magnetic resonance sequences in estimation of the third ventricle floor fenestration patency after endoscopic third ventriculostomy (ETV) in the subjects with aqueductal stenosis/obstruction. Fifty eight subjects (37 males, 21 females, mean age 27 years) with previously successfully performed ETV underwent brain MRI on 1.5T MR imager 3-6 months after the procedure. Two different FISP 2D sequences (one included in the standard vendor provided software package, and the other, experimentally developed by our team) were performed respectively at two fixed slice positions: midsagittal and perpendicular to the ETV fenestration, and displayed in a closed-loop cinematographic format in order to estimate the patency. The ventricular volume reduction has been observed as well. Cerebrospinal fluid (CSF) flow through the ETV fenestration was observed in midsagittal plane with both FISP 2D sequences in 93.11% subjects, while in 6.89% subjects the dynamic CSF flow MRI was inconclusive. In the perpendicular plane CSF flow through the ETV fenestration was visible only by use of experimentally developed FISP 2D (TR30/FA70) sequence. Postoperative volume reduction of lateral and third ventricle was detected in 67.24% subjects. Though both FISP 2D sequences acquired in midsagittal plane may be used to estimate the effects of performed ETV, due to achieved higher CSF pulsatile flow sensitivity, only the use of FISP 2D (TR30/FA70) sequence enables the estimation of the treatment effect in perpendicular plane in the absence of phase-contrast sequences.

KEY WORDS: magnetic resonance imaging, dynamic magnetic resonance imaging, fast imaging with steady state precession, cerebrospinal fluid flow, endoscopic third ventriculostomy

INTRODUCTION

Endoscopic third ventriculostomy (ETV) has been largely accepted as the treatment of choice for the patients with non-communicating hydrocephalus caused by congenital or acquired aqueductal stenosis or obstruction [1,2], due to the low failure rate and less associated morbidity than other therapy modalities, e.g. ventriculoperitoneal shunting [3], even in the early childhood [4,5]. Since the indications for ETV are not only permanently increasing, but also constantly adjusting and getting re-tailored [1,2], they nowadays, apart from cerebral aqueduct stenosis, includes many clinical conditions with underlying disturbance of cerebrospinal fluid (CSF) hydrodynamics, such as in patients with posterior fossa tumors and cysts [6], communicating hydrocephalus [7], normal pressure hydrocephalus [8], and in patients with previous ventriculo-peritoneal shunts failure [9], but lately also in the hydrocephalic patients with achondroplasia [10].

In the patients with aqueductal stenosis or obstruction, intraaqueductal CSF flow is reduced or fully absent, so endoscopic fenestration of the third ventricle floor provides an alternative quasi-physiological CSF flow pathway to the subarachnoid spaces through the interpeduncular cistern and downwards, resulting in dispersed and minimized pressure gradient on midline brain structures, surrounding cerebral aqueduct [5].

Though the phenomenon of CSF flow through the third ventricle floor endoscopic fenestration is observable by several diagnostic methods, the use of different dynamic

*Corresponding author: Milos A. Lucic,
Diagnostic Imaging Center, Oncology Institute of Vojvodina, University of Novi Sad, Faculty of Medicine, Put doktora Goldmana 4, 21204 Sremska Kamenica, Novi Sad, Serbia.
Phone: +381 21 4805500
Fax: +381 21 4805602
E-mail: milos.a.lucic@gmail.com

magnetic resonance imaging (MRI) techniques, providing the valuable additional information on CSF hydrodynamics has been widely accepted [11,12].

Although the use of dynamic phase-contrast MR imaging of the pulsatile CSF flow in the assessment of ETV treatment efficacy by phase-contrast MRI techniques is certainly recognized [11,13], we tried to estimate the CSF pulsations through the third ventricle floor fenestration, induced by the strong arterial blood loading of endocranial arterial vessels during the systolic phase [14] by use of two differently acquired two-dimensional fast imaging with steady-state precession (FISP 2D) MRI sequences, first one being the part of the standard vendor software package [15], and the second one, experimentally developed by our investigation team [16], in an attempt to assess whether the ETV has been successfully performed, and to explore the diagnostic possibilities of both sequences, which we defined as the aim of the study.

MATERIALS AND METHODS

Patients and Inclusion Criteria

The study has been conducted in accordance with the ethical standards of the Declaration of Helsinki and approved by our institutional ethical committee, with the patients or parents informed consent provided.

Fifty eight patients (37 males and 21 females, mean age 27 years, age range from 8 to 47 years) were referred to our center for dynamic MRI examination after the ETV procedure from three different neurosurgery institutions, where they were hospitalized for the treatment of obstructive hydrocephalus due to the non-tumorous stenosis/obstruction of cerebral aqueduct. They have been included prospectively into the study, and dynamic MRI by use of two differently acquired FISP 2D sequences has been performed during a predefined postoperative period of minimally three, and maximally six months after the ETV procedure.

Only the patients with non-tumorous aqueduct stenosis/obstruction and good clinical outcome were included in the study, whereas under the good clinical outcome we considered the resolution of clinical symptoms and signs of increased intracranial pressure present prior to ETV. The patients with poor clinical outcome and/or the patients with other than non-tumorous stenosis/obstruction of cerebral aqueduct causes were excluded from the study, whereas under the poor clinical outcome we considered the continuous presence of the clinical symptoms after ETV.

Postoperative volume reduction of lateral and third ventricle as a potential marker of brain tissue re-adaptation to the new intracranial hydrodynamics conditions has also been observed and measured.

Dynamic MRI techniques

MRI examination in all patients has been performed on 1.5 Tesla MR imagers (Magnetom SP63-4000 and Magnetom Avanto TIM, Siemens, Erlangen, Germany) using a circularly polarized head coil and/or an eight-channel head coil, respectively. Before every dynamic MRI CSF flow study, a brain MRI has been performed by predefined protocol, including the standard set of following sequences with bellow given technical parameters:

- Three-dimensional Magnetization Prepared Rapid Gradient Echo T1W (3D MPRAGE) sequence in sagittal plane (TR 1900 ms, TE 2.26 ms, spatial resolution 0.9x0.9x0.9 mm, field of view(FOV) 250 mm, matrix 256x256);
- Turbo Spin Echo (TSE) T2W in axial plane (TR 4000 ms, TE 93ms, slice thickness 3 mm, FOV 250mm, matrix 256x312) without flow compensation gradient;
- TSE T2W in coronal plane (TR 4000 ms, TE 93 ms, slice thickness 3 mm, FOV 250mm, matrix 200x256) without flow compensation gradient, oriented parallel to the brain stem, for positioning of FISP 2D sequences in midsagittal plane;
- TSE T2W in sagittal plane without flow compensation gradient (TR 4000 ms, TE 93ms, slice thickness 3 mm, FOV 250 mm, matrix200x256) without flow compensation gradient, parallel to the third ventricle floor fenestration axis, for positioning of FISP 2D sequences in perpendicular plane (shown on Figure 1); and
- Three-dimensional Constructive Interference into Steady-State (3D CISS) sequence with flow compensation gradient in sagittal plane (TR 10.9 ms, TE 11 ms, spatial resolution 0.7x0.7x0.7 mm, FOV 250 mm, matrix 256x256), for detailed insight into distinct anatomical features.

Dynamic CSF flow MRI examination was performed by use of two different in-plane flow-sensitive velocity encoded
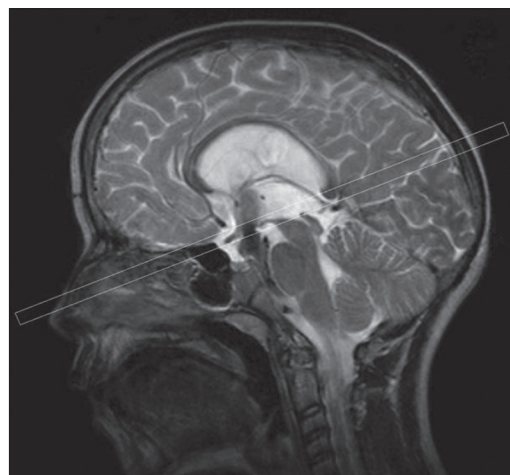

FIGURE 1. T2W sequence in sagittal plane demonstrates correct positioning of both FISP 2D sequences perpendicularly to the third ventricle floor fenestration

2D fast imaging with steady-state precession sequences (FISP 2D), respectively at two fixed slice positions, primarily in midsagittal plane, and then in perpendicularplane to the third ventricle floor fenestration, with following technical characteristics:

- Retrospectively ECG gated FISP 2D (further FISP 2D 40/17) sequence: TR 40 ms, TE 12 ms, flip angle (FA) 17º, slab thickness 4 mm, FOV 240mm, matrix 192x256, acquisition 1; and

- Retrospectively ECG gated FISP 2D (further FISP 2D 30/70) sequence: TR 30 ms, TE 12 ms, flip angle (FA) 70º, slab thickness 4 mm, FOV 200mm, matrix 192x256, acquisition 1.

Craniocaudal velocity encoding was applied in midsagittal, and anteroposterior velocity encoding in perpendicular plane to the third ventricle floor in both FISP 2D sequences.

The first sequence FISP 2D 40/17 is contained in the standard vendor-supplied software package, and the second one, FISP 2D 30/70 sequence has been experimentally developed by our investigation team with increased tissue contrast between CSF and brain structures without the prolongation of acquisition time.

The retrospective cardiac gating technique with conventional ECG electrodes for patient's heart action monitoring has been used. After the interpolation process, sixteen single MR images, synchronized with the different cardiac cycle phases, were obtained by use of both FISP 2D sequences, later displayed in a closed-loop cinematographic format.

Statistical Analysis

Comparison between the diagnostic information obtained by FISP 2D 40/17 and FISP 2D 30/70 sequences has been analyzed on the basis of the presence or absence of CSF flow information by use of SPSS Statistics v. 17.0 software. Bidirectional testing of the differences between FISP 2D 40/17 and FISP 2D 30/70 sequences in both acquired planes has been analyzed by Student's paired two-tailed t-test, and the Spearman's rank correlation test was used to test the statistical dependence between the presence or absence of CSF flow diagnostic information obtained. The statistical significance analyzed by Fisher exact test has been established at the level of p<0.001.

RESULTS

The absence of flow-void within cerebral aqueduct and the intensive flow-void through the third ventricle floor fenestration on the sagittal and coronal T2W sequences without flow compensation gradient, that has been taken as a starting presumption of the aqueductal stenosis/obstruction,

and fenestration patency has been identified in all included patients (Figure 2a,b).

The visualization of the CSF flow through the fenestration was possible by use of both sequences, FISP 2D 40/17, and FISP 2D 30/70 in midsagittal plane.

The CSF flow on FISP 2D 40/17 sequence demonstrated uniform signal intensity, regardless to the direction in different cardiac cycle phase, and respectively, both during systole and diastole, hence, being identical in both caudal and cranial flow direction (Figure 2c).

In contrast to FISP 2D 40/17 sequence, on FISP 2D 30/70 sequence in midsagittal plane, the signal of caudally directed CSF flow during systole presented with lowered intensity (Figure 2d), while the signal of cranial CSF flow directions during diastolic period presented with elevated intensity.

Achieved contrast between fluid and surrounding brain structures on individual images obtained by both of the FISP 2D sequences in midsagittal plane was though very good.

The mutual crossing of diagnostic information regarding the CSF flow through the third ventricle floor fenestration, obtained by FISP 2D 40/17 and FISP 2D 30/70 sequences in midsagittal plane is presented in the Table 1.

The contrast between CSF and brain structures in individual images achieved by use of FISP 2D 30/70 sequence in the perpendicular plane to the fenestration is excellent, while by use of FISP 2D 40/17 sequence the satisfactory contrast, providing the relevant diagnostic information could not be not obtained. In the perpendicular plane the signal alterations related to the flow direction in the function of the cardiac cycle are visible exclusively on FISP 2D 30/70 sequence (Figure 3a,b,c). The same phenomenon is not observable on FISP 2D 40/17 sequence acquired at the same level (Figure 3d).

The mutual crossing of diagnostic information on CSF flow through the third ventricle floor fenestration obtained by both FISP 2D 40/17 and FISP 2D 30/70 sequences in perpendicular plane is presented in the Table 2.

The bidirectional difference testing of the diagnostic information acquired by both FISP 2D 40/17, and FISP 2D 30/70 sequences in both acquired planes at the level of third ventricle floor fenestration is presented in the Table 3.

Postoperative volume reduction of lateral and third ventricle was detected in 39 of 58 patients (67.24%), while in 19 of 58 patients (32.76%) no significant changes to the preoperative ventricular volume was found, though none of the patients haven't had any clinical symptoms.

DISCUSSION

Detailed observation of the relationship and mutual complementarity between two differently acquired FISP 2D sequences appears to be of importance in assessing the intensity of CSF

TABLE 1. Mutual crossing of FISP 2D 40/17 and FISP 2D 30/70 sequences in midsagittal plane regarding the presence/absence of CSF flow diagnostic information obtained

Both sequences in midsagittal plane to the ETV fenestration		FISP 2D 30/70		Σ (patients Nr. and %)
		Provides the information (patients Nr. and %)	Does not provide the information (patients Nr. and %)	
FISP 2D 40/17	Provides the information (patients Nr. and %)	54 (93.11%)	–	54 (93.11%)
	Does not provide the information (patients Nr. and %)	3 (5.17%)	1 (1.72%)	4 (6.89%)
Σ (patients Nr. and %)		57 (98.28%)	1 (1.72%)	58 (100%)

TABLE 2. Mutual crossing of FISP 2D 40/17 and FISP 2D 30/70 sequences in perpendicular plane regarding the presence/absence of CSF flow diagnostic information obtained

Both sequences in perpendicular plane to the ETV fenestration		FISP 2D 30/70		Σ (patients Nr. and %)
		Provides the information (patients Nr. and %)	Does not provide the information (patients Nr. and %)	
FISP 2D 40/17	Provides the information (patients Nr. and %)	1 (1.75 vs. 100%)	-	1 (1.72%)
	Does not provide the information (patients Nr. and %)	56 (98.25 vs. 98.25%)	1 (100 vs. 1.75%)	57 (98.28%)
Σ (patients Nr. and %)		57 (98.28%)	1 (1.72%)	58 (100%)

TABLE 3. Bidirectional correlation of the CSF flow diagnostic information differences between FISP 2D 40/17 and FISP 2D 30/70 sequences in midsagittal and perpendicular plane by Student's paired two-tailed t-test with presented Spearman's correlation rank coefficient values and Fisher exact test p values

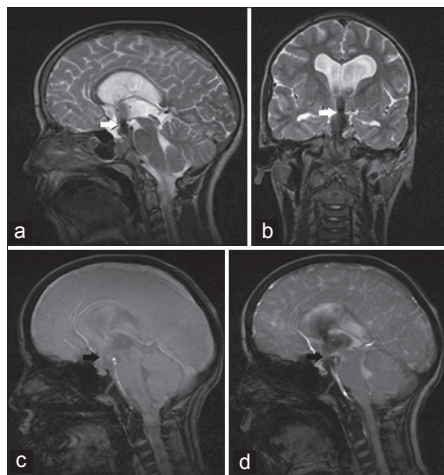| Correlated sequences	Planes to ETV fenestration	N (number of patients)	Correlation rank value	Significance (p)
FISP 2D 40/17 and FISP 2D 30/70	Midsagittal	58	1	$p<0.01$ ($p=0.002476$)
FISP 2D 40/17 and FISP 2D 30/70	Perpendicular	58	-1	$p<0.001$

FIGURE 2. T2W sagittal sequence (a) demonstrates the absence of flow void within the cerebral aqueduct and prominent flow void through the third ventricle floor fenestration (white arrows), clearly depicted on T2W sequence in coronal plane (b) as well. CSF flow through fenestration is visible on dynamic CSF flow MRI studies acquired both by FISP 2D 40/17 (C) and FISP 2D 30/70 (d) in midsagittal plane (black arrows), and the absence of physiological alterations synchronous to the cardiac action through the stenotic aqueduct is observable

flow through the third ventricle floor fenestration, having in mind that the statistically analyzed and determined contribution of the two compared sequences in regard to the valid diagnostic information provided, was not identical in both acquired planes.

The application of both FISP 2D 40/17 and FISP 2D 30/70 sequences in midsagittal plane demonstrates the diagnostic utility, showing a high concordance degree of obtained CSF flow information through the third ventricle floor fenestration, without the significant advantage of one sequence relative to another, as evidenced clearly by the results of bidirectional differences testing, and correlation rank values, as shown in Table 3.

The results of the acquisition of FISP 2D sequences in the perpendicular plane to the third ventricle floor fenestration are completely different, and demonstrate a significant advantage in the diagnostic information obtained by FISP 2D 30/70 sequence, compared to those obtained by use of FISP 2D 40/17 sequence.

FISP 2D 40/17 sequence in the perpendicular plane to third ventricle floor fenestration does not provide the accurate data on ETV efficacy, due to the lack of possibility to visualize the CSF flow, which correlates with the results of other studies performed by use of the sequences with similar technical characteristics [17-19].

The contrast between the CSF and brain parenchyma on FISP 2D 30/70 sequence is significantly improved, consequently to the increased flip angle, which results in an confident advantage of FISP 2D 30/70 to the FISP 2D 40/17 sequence with high statistical significance, demonstrating not only the presence of the flow, but also the flow direction, and allowing the evaluation of the third ventricle floor fenestration patency in almost all subjects.

Still, though the CSF flow became visible in both planes, the major disadvantage of FISP 2D 30/70 sequence application in the estimation of the third ventricle floor fenestration patency remains the absence of the possibility to quantify the CSF flow parameters, which is the crucial advantage of phase-contrast MR techniques, based on application of
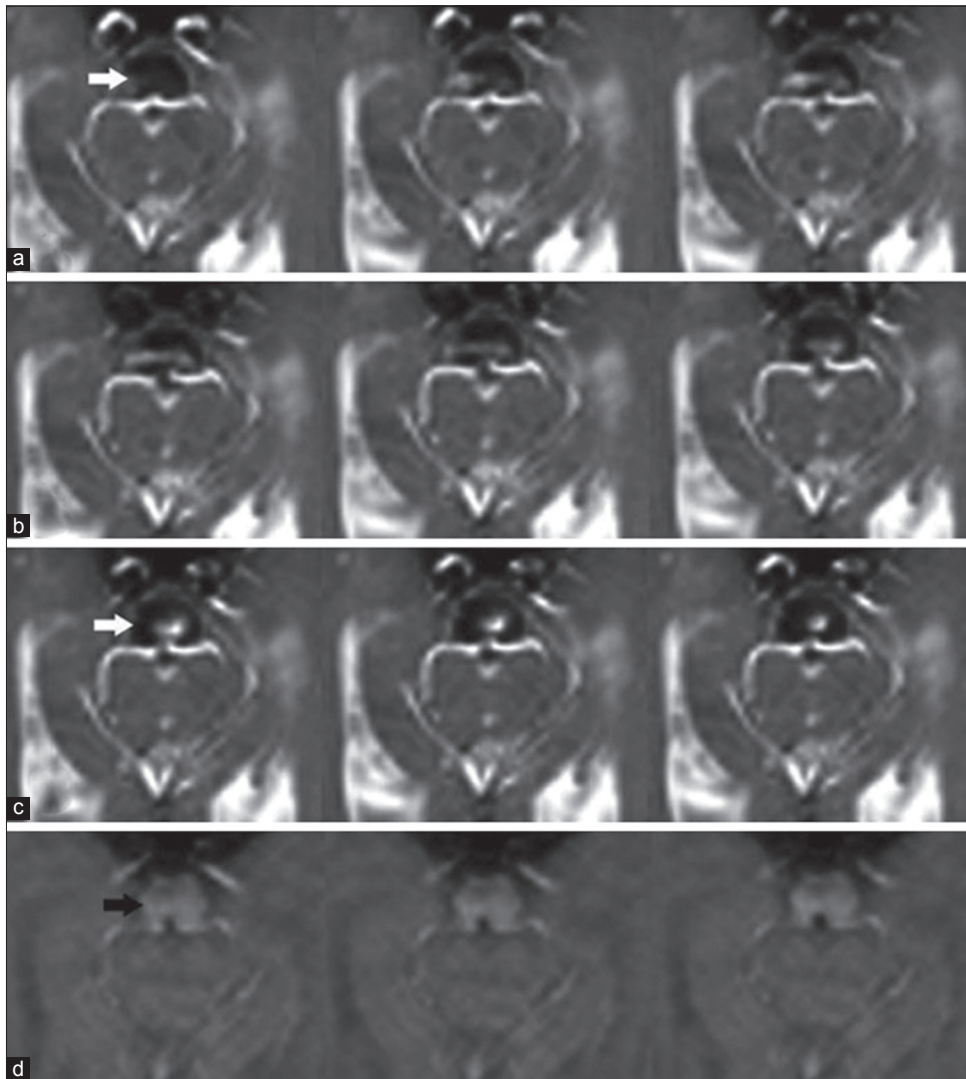
FIGURE 3. The alterations of CSF flow signal from black to white, synchronous to the cardiac cycle phase (white arrows) are clearly visible on dynamic CSF flow MRI studies acquired by FISP 2D 30/70 sequence in the perpendicular plane to the third ventricle floor fenestration (a, b, c rows), indicating successful ETV outcome. Though CSF flow is noticeable both on FISP 2D 30/70 CINE studies and T2W sequences without flow compensation gradient (in a form of flow-void), FISP 2D 40/17 sequence (d row) in perpendicular plane does not provide any valid diagnostic information on ETV fenestration patency

flow sensitive through-plane Fast Low-Angle Shot (FLASH) sequences [11-13,15-19].

Though there are numerous studies indicating the ventricle volume reduction as a sign of successful ETV [20-23], we found the absence of reduction in a ventricle volume in almost one third of the patients with both clinical and dynamic MRI signs of successful ETV three to six months after the surgery.

In our opinion, the solely morpho-anatomical measurement and estimation of ventricle volume reduction may not be sufficiently reliable early sign of successful ETV, due to the obvious and significant time delay in brain tissue re-adaptation to the new intracranial hydrodynamics conditions, and therefore should not be considered as a trustworthy immediate or early marker of ETV efficacy, but as a secondary consequence of successful retracing of CSF pathways by ETV.

CONCLUSION

Dynamic MRI of CSF flow by use of customized FISP 2D 30/70 sequence provides immediate and reliable information on the ETV efficacy, in addition to the flow-void presence at the level of the third ventricle floor fenestration in both midsaggital and perpendicular plane, even in the absence of phase-contrast techniques [15,16].

However, the inability of fast imaging with steady-state precession sequences to provide the reliable CSF flow quantification through the third ventricle floor fenestration, opens the space for the complementary use of phase-contrast MRI techniques, especially the incoherent gradient echo phase-contrast sequences (PC-GRE) or phase-contrast sequences with balanced steady-state free precession (PC-bSSFP) [24-26].

DECLARATION OF INTEREST

The authors declare no conflict of interest.

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