Three-Dimensional Constructive Interference in Steady State Sequences and Phase-Contrast Magnetic Resonance Imaging of Arrested Hydrocephalus

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■ OBJECTIVE: **To evaluate the role of three-dimensional constructive interference in steady state (3D-CISS) sequences and phase-contrast magnetic resonance imaging (PC-MRI) in patients with arrested hydrocephalus.**

■ METHODS: **A prospective study of 20 patients with arrested hydrocephalus was carried out. All patients underwent PC-MRI and 3D-CISS for assessment of the aqueduct. Axial (through-plane), sagittal (in-plane) PC-MRI, and sagittal 3D-CISS were applied to assess the cerebral aqueduct and the spontaneous third ventriculostomy if present. Aqueductal patency was graded using 3D-CISS and PC-MRI. Quantitative analysis of flow through the aqueduct was performed using PC-MRI.**

■ RESULTS: **The causes of obstruction were aqueductal obstruction in 75% ($n = 15$), third ventricular obstruction in 5% ($n = 1$), and fourth ventricular obstruction in 20% ($n = 4$). The cause of arrest of hydrocephalus was spontaneous third ventriculostomy in 65% ($n = 13$), endoscopic third ventriculostomy in 10% ($n = 2$), and ventriculoperitoneal shunt in 5% ($n = 1$), and no cause could be detected in 20% of patients ($n = 4$). There is a positive correlation ($r = 0.80$) and moderate agreement ($\kappa = 0.509$) of grading with PC-MRI and 3D-CISS sequences. The mean peak systolic velocity of cerebrospinal fluid was 1.86 $\pm$ 2.48 cm/second, the stroke volume was 6.43 $\pm$ 13.81 μL/cycle, and the mean flow was 0.21 $\pm$ 0.32 mL/minute.**

■ CONCLUSIONS: **We concluded that 3D-CISS and PC-MRI are noninvasive sequences for diagnosis of the level and cause of arrested hydrocephalus.**

INTRODUCTION

Hydrocephalus is a condition in which the impaired balance between the production and absorption of cerebrospinal fluid (CSF) results in a dilatation of the ventricular system.[1-3] Arrested hydrocephalus is a special form of chronic hydrocephalus that develops over a long period in which there is ventriculomegaly with no active periventricular transependymal CSF permeation. It occurs as a result of resumption of the proper balance between CSF production and absorption, which may be caused by a transependymal CSF resorption pathway through the periventricular blood vessels.[4] It also may occur as a result of spontaneous ventriculostomy, which is rupture of the walls of the ventricles, creating a direct communication between the ventricular system and subarachnoid space, resulting in internal drainage of CSF and arrest of hydrocephalus.[5,6]

Qualitative and quantitative CSF flow assessment could be obtained using three-dimensional constructive interference in steady state (3D-CISS) and phase-contrast magnetic resonance imaging (PC-MRI), respectively.[2] 3D-CISS is a gradient-echo imaging technique with high CSF-to-aqueduct contrast that provides anatomic details of the aqueduct, the cause of obstruction, and identification of the spontaneous and endoscopic third

Key words
- Arrested
- Hydrocephalus
- Phase-contrast MRI
- Third ventriculostomy

Abbreviations and Acronyms
3D-CISS: Three-dimensional constructive interference in steady state
BPC: Blake pouch cyst
CSF: Cerebrospinal fluid
ETV: Endoscopic third ventriculostomy
PC-MRI: Phase-contrast magnetic resonance imaging
PSV: Peak systolic velocity
STV: Spontaneous third ventriculostomy
SV: Stroke volume
TE: Echo time
TR: Repetition time
VPS: Ventriculoperitoneal shunt

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Citation: World Neurosurg. (2017) 98:296-302.
http://dx.doi.org/10.1016/j.wneu.2016.10.140

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

ventriculostomies.[7] However, these techniques lack physiologic information, so they are combined with cine sequences of PC-MRI, which allow adequate visualization of CSF movement across the aqueduct and the spontaneous third ventriculostomy (STV). It also provides significant information in preoperative evaluation of Chiari I malformation, normal pressure hydrocephalus, and patients with endoscopic third ventriculostomy (ETV) and ventriculoperitoneal shunt (VPS).[8-14] To our knowledge, no previous studies have measured flow in the aqueduct in patients with arrested hydrocephalus.

The aim of this work is to evaluate the role of 3D-CISS sequences and PC-MRI in patients with arrested hydrocephalus.

METHODS

Patients

We obtained institutional review board approval and informed consent from the patients. A prospective study was carried out of 21 patients with arrested hydrocephalus that was defined as ventriculomegaly (Evans index >0.3) with no periventricular CSF permeation on MRI. The inclusion criteria were patients with hydrocephalus with no active transependymal CSF permeation and we excluded 1 patient from the study because of minimal CSF permeation on MRI. Twenty patients were included in the study (age, 1–64 years; 14 adults and 7 children; 13 males and 7 females). The adult symptomatic patients had various clinical manifestations such as headache, motor disturbance, seizures, visual disturbance, macrocephaly, mental retardation, and incontinence. The children presented with macrocephaly, seizures, and delayed milestones. The most common symptom was headache, which was present in 11 patients (55%). There was no associated intraparenchymal hemorrhage or inflammatory or infective lesions. All patients underwent routine MRI, 3D-CISS, and PC-MRI.

MRI Techniques

The examinations were carried out on a 1.5-Tesla magnetic resonance system (Magnetom Avanto [Siemens Medical Solutions, Erlangen, Germany]). Axial and sagittal T1-weighted spin echo used the following parameters: repetition time (TR), 550 milliseconds; echo time (TE), 15 milliseconds; a flip angle, 90°; acquisition matrix, 256 × 256; field of view, 180 mm; slice thickness, 3 mm; gap, 0.3 mm. Axial, coronal T2-weighted turbo spin echo used the following parameters: TR, 4000 milliseconds, TE, 120 milliseconds; slice thickness, 3 mm; gap, 0.3 mm; acquisition matrix, 256 × 256; and field of view, 180 mm. Thin-cut midline sagittal 3D-CISS images used TR of 1200 milliseconds, TE of 260 milliseconds, flip angle of 40°, and a slice thickness of 0.6 mm. Two series of PC imaging techniques were applied: one in the axial plane, with through-plane velocity encoding in the craniocaudal direction for flow quantification, and one in the sagittal plane, with in-plane velocity encoding in the craniocaudal direction for qualitative assessment. Both sequences were performed with the following parameters: TR/TE, 50–15 milliseconds; flip angle, 10°–20°; slice thickness, 3 mm; velocity encoding, 3–6 cm/seconds. Measurements were made using retrospective peripherally gated PC cine MRI. Two signals were averaged; 16-phase to 32-phase images were obtained in a cardiac cycle.

Data Analysis

The image analysis was performed by 2 readers who were blinded to the clinical findings of the patients. The Evans index was

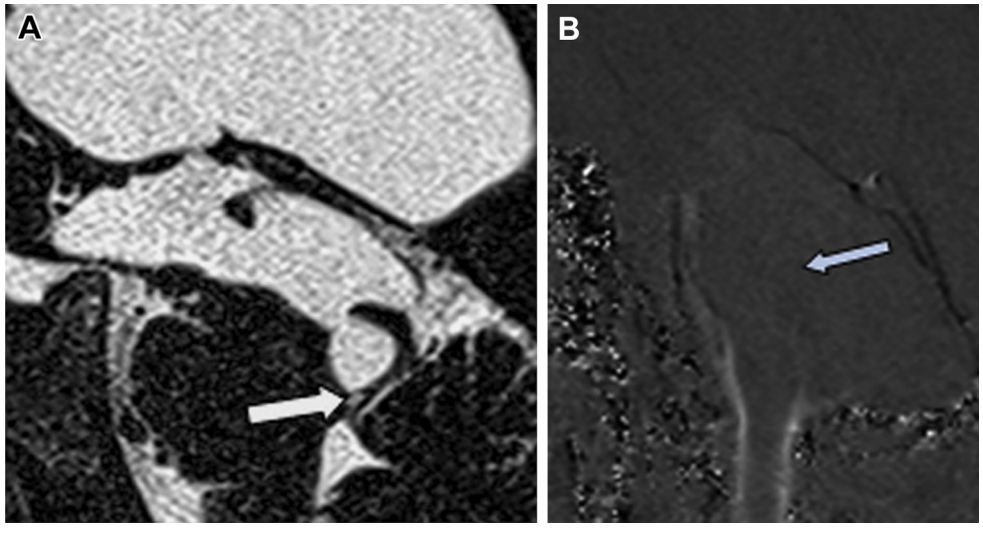

Figure 1. Aqueductal obstruction by aqueductal web. (**A**) Midline sagittal three-dimensional constructive interference in steady state image shows 2 distal aqueductal webs totally obstructing the aqueductal lumen with marked proximal funneling (grade 2) (*arrow*). (**B**) Diastolic in-plane phase-contrast magnetic resonance imaging shows complete obstruction of the aqueduct with no flow (*arrow*).