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Functional Magnetic Resonance Imaging Before and After Ventriculoperitoneal Shunting for Hydrocephalus

—Case Report—

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Abstract

A 70-year-old man with hydrocephalus was examined with functional magnetic resonance (fMR) imaging before and after ventriculoperitoneal shunting. Preoperatively, activation by right hand exercise revealed only a slight signal increase in the peri-rolandic area. However, 3 months after ventriculoperitoneal shunting, a significant signal increase was observed. fMR imaging may detect activity-related improvement of cerebral blood flow responses in patients with hydrocephalus after surgical treatment.

Key words: cerebral blood flow, functional magnetic resonance imaging, hydrocephalus, neural activation

Introduction

Functional magnetic resonance (fMR) imaging has rapidly become a useful technique in clinical practice.[21] fMR imaging was initially utilized to detect and localize normal brain function,[22,29,32] but has progressed with the introduction of high-speed MR imaging and the use of various stimulation tasks.[23] fMR imaging has been applied to determine the location of eloquent brain function as part of the preoperative evaluation for brain tumor resection[8] and epilepsy surgery.[4] Other recent fields of use include examination of the pathophysiology of such conditions as schizophrenia,[33] stroke,[3] and anosmia,[15] by comparing the images of patients with the disease to normal controls. This study used pre- and postoperative fMR imaging in a patient with hydrocephalus to document the apparent differences related to shunting.

Case Report

A 70-year-old male presented with progressive gait disturbance persisting for approximately 2 years. The patient's family thought his gait had become worse over the previous 6 months and also reported urinary incontinence and decreased short-term memory. He was referred to our institution for evaluation of suspected normal pressure hydrocephalus. His medical history included long-standing essential hypertension and diet-controlled diabetes mellitus, and an incident of subarachnoid hemorrhage 18 years before, which was treated conservatively because of unknown origin despite repeated cerebral angiography.

Neurological examination showed mild dementia and markedly ataxic gait. He also exhibited right hand tremor, exaggerated during intentional movement. MR imaging of the brain revealed enlarged ventricles and widening of the cortical sulci. A lumbar spinal tap for examination of cerebrospinal fluid (CSF) was performed. The opening pressure was 22.4 cmH_2O, and 30 cm^3 of clear CSF was withdrawn. CSF examination found no signs of infection or abnormal chemistry. Following CSF withdrawal, the patient's gait clearly improved, but only transiently for a few days, which indicated that he might benefit from CSF diversion. A component of degenerative disease could not be ruled out definitively.

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fMR imaging was performed on a SIEMENS 1.5 T VISION system (Siemens, Erlangen, Bayern, Germany). Twenty contiguous axial brain slices of 6 mm thickness were imaged with an interleaved multislice gradient-echo, echo-planar pulse sequence (repetition time/echo time/flip angle = 500 msec/30 msec/45 degrees). The field of view was 256 × 256 mm and the matrix size was 128 × 128, yielding a spatial resolution of 2.0 mm × 2.0 mm. Closing and opening the right hand (once/2 sec) was employed as the motor activity task. The patient was told to apply moderate grip force when closing the hand. The investigator checked the level of grip force by asking the patient to squeeze his hand. After allowing approximately 5 minutes training of the hand exercise, the experiment was begun. The hand exercise was performed in an ''OFF-ON-OFF-ON-OFF'' manner with ''OFF'' representing the baseline (rest) condition and ''ON'' the task condition. Each ''ON'' or ''OFF'' period lasted 18 seconds and the exercise started 2 seconds before the first ''ON'' period began. Six images were acquired for each slice during each ''ON'' or ''OFF'' period. This allowed image averaging to improve the signal-to-noise ratio. Post-image processing and analysis were performed with a MEDX software package (MEDX 2.1; Sensor Systems, Inc., Sterling, Va., U.S.A.), specifically designed for functional imaging analysis. The first image of each slice in each ''ON'' or ''OFF'' period was excluded during post-image processing to allow similar T_1 weighting of all the images. Images acquired during the ''ON'' periods were compared to the images obtained during the ''OFF'' periods on a pixel-by-pixel basis. The Student's t-test was used for comparisons. Pixels with a z score of 2.5 or higher at a 0.05 level of statistical significance were included in the functional map. However, significantly activated pixels with less than five contiguous neighbors were not included. The functional map was laid over a T_1-weighted anatomical image to determine the locations of activation. Minimal activation was observed in the left peri-rolandic cortex before the surgical treatment (Fig. 1).

Right occipital ventriculoperitoneal (VP) shunting, using a pressure-programmable valve (Johnson & Johnson, Lelocle, Switzerland) set at 120 mmH_2O, was performed under the diagnosis of communicating hydrocephalus. The patient's gait and urinary incontinence improved markedly following shunting, leaving only residual decreased short-term memory. Right hand tremor also decreased, but persisted with mild intentional component. These clinical findings were confirmed at 6-week follow up, although the ventricular size remained almost unchanged on computed tomography (Fig. 2). fMR imaging was repeated 3 months after the shunt procedure. Special attention was paid to maintain the same number of hand movements and similar grip force of each hand-closing contraction as used in the hand exercise performed during the first fMR imaging experiment. An obvious increase of activation in the peri-rolandic cortex was observed (Fig. 3). The patient was stable at 1-year follow up, and clinically unchanged since the first postoperative visit.

Discussion

Hydrocephalus is one of the most common diseases treated by neurosurgeons, but the exact pathophysiological changes underlying observed clinical improvement is not fully understood. Whether a CSF diversion procedure will improve symptoms is often difficult to predict, especially for patients with chronic hydrocephalus. In our institution, a 3-day continuous lumbar CSF drainage is performed to evaluate the indications for VP shunt. In the present patient, the slightly high CSF pressure and the clear clinical improvement seen after removal of 30-cm^3 CSF indicated VP shunting without further procedures. The clinical changes after shunting do not correlate well with ventricular size, especially in cases of chronic hydrocephalus. Frequently clinical improvement is seen without significant changes in ventricular size.[6,16]

The improvement of cerebral blood flow (CBF) after VP shunting has been frequently discussed as a potent mechanism of symptom improvement.[25,30] However, CBF improvement alone does not necessarily lead to the symptomatic resolution.[18,30] Cerebral metabolism studies with positron emission tomography of glucose utilization[10,13,27,31] and oxygen utilization[2] have also revealed that reduction of periventricular metabolism is a common finding in untreated hydrocephalus. However, postoperative increases in metabolism are not always seen despite clinical improvement.[2,10] Such changes in CBF or neuronal metabolism in the resting condition are inconsistent with the observed clinical improvements after treatment of hydrocephalus. Dysfunction of white matter including fiber stretching[5] or decreased connectivity[19] are also likely to be involved, so no single mechanism can explain the symptoms of hydrocephalus.

Dysfunction of vessel reactivity to stimulation (autoregulation) may be one of the mechanisms responsible for the symptoms of hydrocephalus. Loss of chemical autoregulation, the vessel response to blood CO_2 changes, may have been involved[20] and may be predictive of clinical outcome after VP shunt placement.[14,26] This mechanism was recently exam-

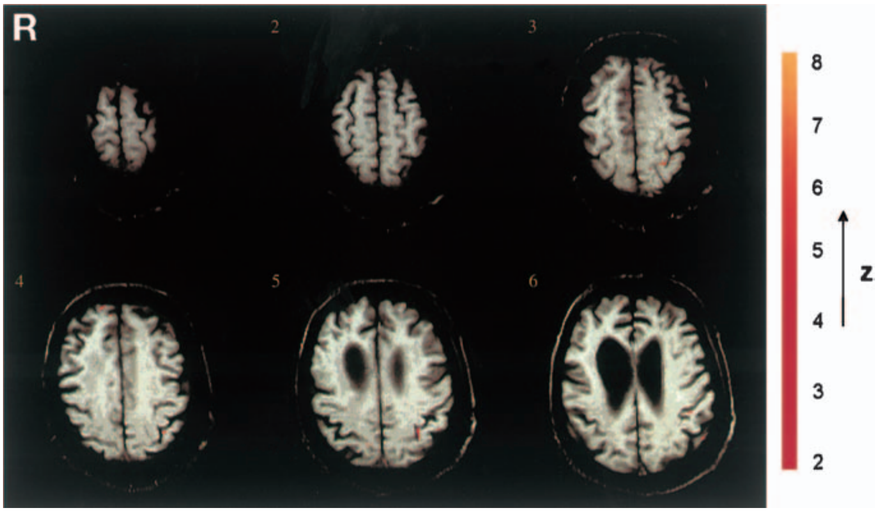

Fig. 1 Preoperative functional magnetic resonance images showing a subtle signal increase in the left peri-rolandic cortex with right hand exercise.

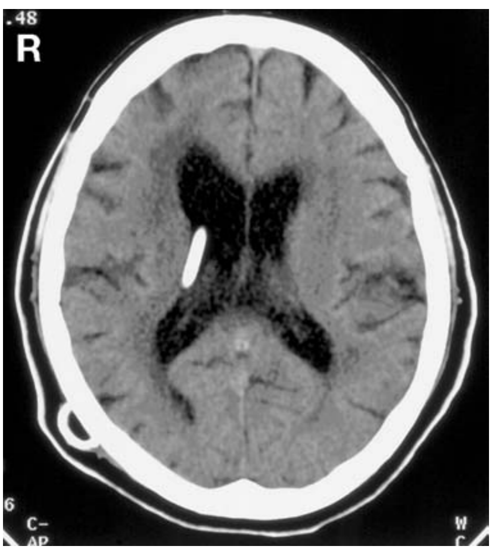

Fig. 2 Postoperative head computed tomography scan 6 weeks after a right occipital horn ventricular catheter was placed for ventriculoperitoneal shunting. The ventricular size has not changed in spite of clinical improvement.

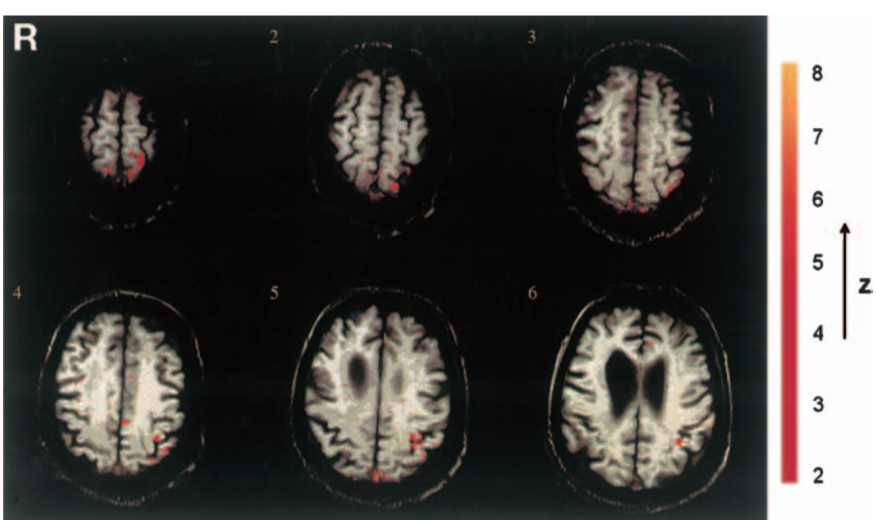

Fig. 3 Functional magnetic resonance images 3 months after ventriculoperitoneal shunting showing a significant signal increase in the left peri-rolandic cortex with right hand exercise.

ined in our chronic hydrocephalus model.[9] Activity-induced CBF increase can be considered as another type of autoregulation. fMR imaging performed during motor tasks reveals the responsiveness of the brain to the activation.[23] fMR imaging changes may correlate with clinical improvement more closely than imaging of the resting neuronal function. fMR imaging detects the uncoupling of CBF and oxidative metabolism during activation. The increase in CBF is proportionally greater than the increase in metabolism during task/stimulus activation.[7,24] The excess increase of CBF translates into a regional increase of oxyhemoglobin, despite the increased production of deoxyhemoglobin due to activated cells.[17] Therefore, fMR imaging reveals the activity-dependent CBF responses, and not the metabolism response. The mechanisms coupling neuronal activation to increased CBF are still unclear. However, nitric oxide,[1] astrocyte-derived epoxyeicosatrienoic acids,[12] or the chorinergic system[28] may be involved.

This study found significant changes in fMR imaging findings following VP shunting for hydrocephalus that correlated well with the clinical improvement. A comparable fMR imaging study noted no changes before and after cocaine infusion with visual stimulation.[11] Further fMR imaging studies of patients with hydrocephalus are required to better understand the extent of regional deficits in brain activation and recovery after treatment.

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