Commentary

MR Prediction of Shunt Response in NPH: CSF Morphology versus Physiology

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Radiology has benefited greatly from recent advances in computer technology and data processing. Digital imaging modalities such as MR store data in a form that is readily amenable to further processing, allowing us to construct secondary data maps which frequently shed additional insight into a clinical process. Examples include the processed images of functional MR that demonstrate brain activation, and the image maps of Echo Planar Perfusion Imaging that show mean transit time (MTT) or relative cerebral blood volume (rCBV). In these examples data processing has been used to glean additional information beyond the raw data, but it is the radiologist's duty to maintain clinical perspective, and to ask, "Does this analysis make sense?."

A new clinical sign based on processed data should also be considered in light of the quality of the input data; bad data subjected to sophisticated processing are still bad data. Anyone publishing a new sign in the radiology literature should do two things first: 1) ensure the sign has not been previously published and 2) start at the same point in the work up as those who might be using the new sign.

Results reported by Kitagaki et al in this issue of the *American Journal of Neuroradiology* (page 1277) should be evaluated along these lines. At first glance, the authors performed sophisticated computer processing on a sizable group of patients with shunt-responsive Normal Pressure Hydrocephalus (NPH), Alzheimer's Disease, and vascular dementia. They used MR to segment brain from CSF and then evaluated CSF volume in the ventricles, the basal cisterns, the Sylvian cisterns, and the suprasylvian subarachnoid spaces. They concluded that patients with NPH have larger ventricles and smaller suprasylvian subarachnoid spaces than patients with Alzheimer's Disease or vascular dementia. This finding is not surprising given that NPH is a form of communicating hydrocephalus. They also reported that the Sylvian cisterns can be particularly large in patients with NPH. Although this seems a counterintuitive way of distinguishing atrophy from communicating hydrocephalus, this finding was previously reported by George et al seven years ago (1). It appears the authors used a high tech tool, CSF morphometry, to describe previously reported patterns of communicating hydrocephalus and large Sylvian cisterns in patients with NPH. It should also be noted that their input images had a 5—mm slice thickness with a 2.5—mm interslice gap. With modern morphometric techniques, 3—D gradient echo techniques with 1–mm isotropic data would be much more appropriate for this kind of study.

An even greater problem with Kitagaki's study arises when it is viewed from a clinical perspective. A retrospective study, the authors selected only patients with suspected NPH who *had responded* to ventriculoperitoneal shunting. They compared this group to two groups who had two other forms of dementia; Alzheimer's Disease and vascular dementia. As any neurosurgeon involved in the treatment of hydrocephalus can attest, the problem is not in identifying patients with the clinical triad—it is finding a sign that will identify patients with the clinical triad who are likely to respond to the shunt versus those who will not. A more appropriate comparison in the present context would have been to perform CSF morphometrics in two groups of patients with clinical NPH to see if there were any difference between the patients who responded to ventriculoperitoneal shunting and those who did not.

As it happens, MR has been used to perform such a study, based on the sign of the aqueductal CSF flow void. This sign was first described in 1986 (2) and shortly thereafter was linked to patients with NPH. In a 1991 study that spanned seven years, we reported a group of 20 patients in whom shunts for clinical NPH were performed after MR imaging (3). The CSF flow void was quantified on the basis of its extent on proton density-weighted images which were not flow compensated. While a "normal" flow void shown on these images was confined to the aqueduct and upper fourth ventricle, an "increased" flow void was defined as low signal extending from the third ventricle or even the foramen of Monro through the fourth ventricle to the obex. When the magnitude of the CSF flow void was compared to the clinical response, there was a statistically significant ($P < .003$) relationship between hyperdynamic CSF flow and a favorable response to CSF shunting. When clinical follow up was obtained in 11 of the 20 patients in this series five years later, all were within one grade (on a 4 point scale) of the original clinical response.

Several years later, we performed a similar study using phase contrast flow quantification to measure the flow of CSF through the aqueduct (4). By using retrospective cardiac gating and a 512×512 matrix over a 16—cm field of view (.3—mm pixels), we were able to quantify the volume of CSF flowing in the craniocaudad direction during systole and in the caudocraniad direction during diastole. These numbers were essentially the same; within 5% (the precision of

the technique) in normal patients (5) and substantially less than 5% in hydrocephalic patients in whom much larger volumes of CSF moved to-and-fro over the cardiac cycle. This volume was defined as the "aqueductal CSF stroke volume," and was measured in 18 patients in whom shunting for clinical NPH was about to be performed. At one-month clinical follow up, 12 of the patients with hyperdynamic CSF flow (aqueductal stroke volume >42 μm) responded to shunting, while only half of those with normal or decreased flow responded. Again, the observation of increased CSF flow through the aqueduct was found to correlate—not just with the clinical triad of NPH but with response to ventriculoperitoneal shunting. Over the last decade, this sign has proven reliable and has been heavily relied upon by neurologists and neurosurgeons at both of the medical centers with which I have been associated where shunts have been performed for NPH. Thus, it has withstood the test of time.

It is useful to consider the possible physiology behind this sign. In a normal brain during diastole, there is space around the brain (occupied by CSF in the subarachnoid spaces and cortical veins) and there is space within the brain (occupied by CSF in the ventricles) (3). During systole, blood flows into the brain under arterial pressure, causing inward and outward expansion. The inward expansion compresses the ventricles, leading to CSF outflow which we observe as a normal aqueductal flow void. In early communicating hydrocephalus, the same mass of brain is now expanded up against the inner table of the calvarium during diastole. When blood flows into the brain during systole, all systolic expansion is directed inward, compressing the enlarged ventricles, leading to much greater outflow of CSF, which we see as a hyperdynamic CSF flow void (3). Because of the tangential shearing forces on the paracentral fibers, these patients experience a gait disturbance. As a result of the radial shearing forces on the cortex, the patients have dementia. Since the ventricles enlarge prior to the compression of cortical convexities, the gait disturbance both precedes and tends to be worse than the dementia in patients with NPH (6, 7). Over time, these patients develop atrophy. With atrophy, there is less brain and, thus, less arterial inflow during systole. As a result, the primary force behind the "CSF pump" decreases, with a concomitant decrease in the aqueductal CSF flow void. With increasing atrophy, the patients obviously become less responsive to CSF diversionary procedures (particularly for dementia). Thus, there is a limited window of opportunity for therapeutic intervention in these patients from the time they initially present until the time that they develop central atrophy and the CSF flow void diminishes. During this entire period, the patients are symptomatic for NPH, all manifesting the clinical triad.

While I agree with Kitagaki et al that NPH is a disease in which radiology can have a significant impact, I would urge these authors and others to maintain clinical perspective when evaluating new radiologic signs. In the case of NPH, the patients first need to have the clinical triad. Patients who only have dementia—but no gait disturbance—should not be shunted for NPH whether or not they have prominent Sylvian cisterns or a hyperdynamic CSF flow void. If the clinical presentation is appropriate, we recommend a routine MR study. If hyperdynamic CSF flow is seen, then these patients should be recommended for ventriculoperitoneal shunting. If a prominent CSF flow void is *not* seen in an appropriately symptomatic patient, there could be several explanations: 1) the patient has already developed central atrophy and will no longer respond to a shunt, or 2) the MR technique is not sensitive enough to detect hyperdynamic flow. Given the current ubiquitous use of flow compensation on conventional spin echo techniques and the increasing use of (naturally-flow compensated) fast spin echo techniques, it is quite possible that we are less sensitive now than we were in the past for the detection of hyperdynamic CSF flow. In such cases, we would recommend a CSF velocity imaging study with high resolution phase contrast techniques. In our second study, such techniques were found to identify twice the number of patients with shunt-responsive NPH who did *not* have a prominent CSF flow void on their conventional MR images (4).

Over the past 25 years, radiology has moved from its humble plain-film analog origins to an ever-increasing number of digital studies. All of these are easily manipulated by modern data processing techniques to yield "derivative images" which no longer merely display simple anatomy. Just as the analog radiologist could potentially get into trouble by just using measurements in a clinical vacuum, however, we are all more likely to make mistakes in our analyses of digital images if we don't maintain our clinical perspective.

References

1. George AE. **Chronic communicating hydrocephalus and periventricular white matter disease: a debate with regard to cause and effect** *AJNR Am J Neuroradiol* 1991;12:42
2. Bradley WG, Kortman KE, Burgoyne B. **Flowing cerebrospinal fluid in normal and hydrocephalic states: appearance on MR images** *Radiology* 1986;159:611–616
3. Bradley WG, Whittemore AR, Kortman KE, et al. **Marked cerebrospinal fluid void: indicator of successful shunt in patients with suspected normal-pressure hydrocephalus** *Radiology* 1991;178:459–466
4. Bradley WG, Scalzo D, Queralt J, Nitz WN, Atkinson DJ, Wong P. **Normal-pressure hydrocephalus: evaluation with cerebrospinal fluid flow measurements at MR imaging** *Radiology* 1996;198:523–529
5. Nitz WR, Bradley WG, Watanabe AS, et al. **Flow dynamics of cerebrospinal fluid: assessment with phase-contrast velocity MR imaging performed with retrospective cardiac gating** *Radiology* 1992; 183:395–405
6. Hakim S, Venegas JG, Burton JD. **The physics of the cranial cavity, hydrocephalus and normal pressure hydrocephalus: mechanical interpretation and mathematical model** *Surg Neurol* 1976;(5)187–210
7. Greenberg JO, Shenkin HA, Adam R. **Idiopathic normal pressure hydrocephalus: a report of 73 patients** *J Neurol Neurosurg Psychiatry* 1977;40:336–341