ECENT advances in endoscopic technology have led to a rise in the performance of third ventriculostomy for noncommunicating hydrocephalus. Although this technique avoids the risks of infection, malfunction, and overfunction associated with the placement of a mechanical shunt, its reliance on the reabsorptive capacity of the arachnoid granulations often translates into a minimal or unappreciable change in ventricular size. This may be true even in patients who experience symptomatic relief following successful surgery. Various invasive or costly techniques have been used to evaluate the patency of the ventriculostomy including radionuclide ventriculography,17,22,23,28,32 radioisotope lumbar scanning,15 computerized tomography (CT) ventriculography,20 sagittal magnetic resonance (MR) imaging,20,26 and two-dimensional cine phase–contrast MR imaging.17,22,25,35 However, assessment of the patency of the fenestration alone may not be relevant to determining the adequacy of treatment. More relevant, but no less invasive, assessment is performed using direct intracranial pressure (ICP) monitoring.20,21,29 This technique has demonstrated that ICP may remain elevated immediately after third ventriculostomy and begins to decrease between 4 to 8 days postoperatively. In an earlier retrospective study,30 we showed that careful measuring of ventricular diameter on standard CT scans will show a consistent decrease in both third and lateral ventricular size if performed later than 1 month after successful surgery (that is, in patients with clinical improvement). We hypothesized that, because volume changes in proportion to the cube of the radius, measurements of ventricular volume might significantly decrease as early as the first 3 weeks after surgery; this would be more useful in evaluating adequacy of treatment and would provide an early indication of successful outcome.

**Object.** Ventricular size often shows no obvious change following third ventriculostomy, particularly in the early postoperative period, making postoperative evaluation difficult without expensive and often invasive testing in patients with equivocal clinical responses. The authors hypothesized that performing careful volumetric measurements would show decreases in size within the first 3 weeks after surgery.

**Methods.** Volumetric measurements were calculated from standard 3 × 3-mm axial computerized tomography (CT) scans obtained immediately before and 3 and 21 days after surgery. Two independent investigators measured third ventricular volume in a series of 16 patients and lateral ventricular volume in 10 of the patients undergoing stereotactically guided endoscopic third ventriculostomy for noncommunicating hydrocephalus. Fifteen patients were symptomatically improved at the time the follow-up scan was obtained. Third ventricular volume decreased in all patients by a mean of 35% (range 7.8–95.1%) and lateral ventricular volume decreased in all patients by a mean of 33% (range 4.5–80.3%). The degree of change correlated with the length of preoperative symptoms (p < 0.005). The one patient who experienced no improvement showed no decrease in third ventricular volume. In seven of 10 patients, the decrease in third ventricular volume exceeded the decrease in lateral ventricular volume. Repeated measurements indicated that the 95% confidence interval for the authors’ calculations varied around the mean by 2.5% for third ventricular volume and 1.2% for lateral ventricular volume. Long-term outcome was excellent, with only one case of delayed failure. The mean follow-up duration was 12 months.

**Conclusions.** Volumetric measurements calculated from standard CT scans will show a demonstrable decrease in ventricular volume soon after successful third ventriculostomy and can be helpful in assessing patients postoperatively. Although the third ventricle may exhibit a greater decrease, the lateral ventricular measurements are more accurate. Patients with more indolent symptoms show the smallest change.

**KEY WORDS • endoscopy • hydrocephalus • stereotaxis • ventriculostomy**
Ventricular volume after third ventriculostomy

**TABLE 1**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Indications for Surgery</th>
<th>Symptom(s)</th>
<th>Duration of Symptoms</th>
<th>Prior Shunt</th>
<th>Early Improvement (≤3 wks)</th>
<th>Follow Up (mos)</th>
<th>Late Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30, F</td>
<td>Chiari I malformation, MM</td>
<td>HA, ataxia</td>
<td>30 yrs</td>
<td>yes</td>
<td>yes</td>
<td>9</td>
<td>yes</td>
</tr>
<tr>
<td>2</td>
<td>54, M</td>
<td>pineal tumor</td>
<td>HA, diplopia</td>
<td>1 yrs</td>
<td>no</td>
<td>yes</td>
<td>22</td>
<td>yes</td>
</tr>
<tr>
<td>3</td>
<td>8, F</td>
<td>tectal mass</td>
<td>HA, N/V, incontinence</td>
<td>6 mos</td>
<td>no</td>
<td>yes</td>
<td>7</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>23, M</td>
<td>cerebellar tumor</td>
<td>HA, N/V, lethargy</td>
<td>1 wk</td>
<td>no</td>
<td>yes</td>
<td>9</td>
<td>yes</td>
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<tr>
<td>5</td>
<td>7, F</td>
<td>tectal mass</td>
<td>developmental delay</td>
<td>6 yrs</td>
<td>no</td>
<td>yes</td>
<td>16</td>
<td>yes</td>
</tr>
<tr>
<td>6</td>
<td>5, M</td>
<td>cerebellar tumor</td>
<td>HA, N/V</td>
<td>1.5 mos</td>
<td>no</td>
<td>yes</td>
<td>20</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>43, M</td>
<td>aqueductal stenosis</td>
<td>HA, cognitive decline</td>
<td>15 yrs</td>
<td>yes</td>
<td>yes</td>
<td>17</td>
<td>yes</td>
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<tr>
<td>8</td>
<td>30, M</td>
<td>pineal cyst</td>
<td>HA, N/V, diplopia</td>
<td>12 yrs</td>
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<td>yes</td>
<td>8</td>
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<tr>
<td>9</td>
<td>0.1, F</td>
<td>Dandy–Walker syndrome</td>
<td>macrocephaly</td>
<td>NA</td>
<td>no</td>
<td>yes</td>
<td>17</td>
<td>yes, sz disorder, microcephaly</td>
</tr>
<tr>
<td>10</td>
<td>36, F</td>
<td>Chiari I malformation</td>
<td>HA, shunt infection</td>
<td>9 mos</td>
<td>yes</td>
<td>yes</td>
<td>25</td>
<td>yes</td>
</tr>
<tr>
<td>11</td>
<td>36, F</td>
<td>aqueductal stenosis</td>
<td>HA, ataxia, incontinence</td>
<td>1.5 yrs</td>
<td>no</td>
<td>yes</td>
<td>10</td>
<td>yes</td>
</tr>
<tr>
<td>12</td>
<td>16, F</td>
<td>pineal tumor</td>
<td>HA, N/V, N/V</td>
<td>9 mos</td>
<td>yes</td>
<td>yes</td>
<td>8</td>
<td>yes</td>
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<tr>
<td>13</td>
<td>71, M</td>
<td>tectal met</td>
<td>ataxia, confusional</td>
<td>3 wks</td>
<td>no</td>
<td>yes</td>
<td>8</td>
<td>yes</td>
</tr>
<tr>
<td>14</td>
<td>41, M</td>
<td>posterior fossa ependymoma</td>
<td>apnea, syncope</td>
<td>4 mos</td>
<td>no</td>
<td>no, NA</td>
<td>no</td>
<td>no</td>
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<tr>
<td>15</td>
<td>62, F</td>
<td>tectal mass</td>
<td>tremor, ataxia</td>
<td>3 yrs</td>
<td>no</td>
<td>yes</td>
<td>7</td>
<td>yes</td>
</tr>
<tr>
<td>16</td>
<td>50, F</td>
<td>pineal tumor</td>
<td>incontinence, ataxia</td>
<td>15 mos</td>
<td>no</td>
<td>yes</td>
<td>7</td>
<td>yes</td>
</tr>
</tbody>
</table>

* HA = headache; met = metastasis; MM = meningomyelocele; NA = not applicable; N/V = nausea and vomiting; sz = seizure.

third ventriculostomy performed 2 years earlier. All patients with mass lesions underwent resective surgery performed either before entering the study or following the postoperative scan.

**Operative Procedure**

The procedure has been outlined in detail elsewhere. All patients underwent CT scanning immediately before surgery. In 15 patients this scanning was performed for stereotactic localization. In a 1-month-old infant (Case 9) third ventriculostomy was performed “free-hand” and the CT scan was obtained for ventricular size assessment. With their heads fixed in a CT-compatible stereotactic head holder patients were administered intravenous iohexol so that we could target the foramen of Monro and the interpeduncular cistern and see the basilar artery. In some patients, previously obtained MR images were coregistered with the CT scans to facilitate targeting. After general or local anesthesia had been induced in the patient, the Cosman-Robert-Wells arc was used to guide a 2.8-mm-diameter rigid endoscope through a No. 12 French peel-away catheter placed into the lateral ventricle through a burr hole over the coronal suture in the midpupillary line. The scope was maneuvered stereotactically through the foramen of Monro toward the floor of the third ventricle by using direct visual guidance. After visualizing and confirming the relevant anatomical structures, the floor of the third ventricle was punctured with the tip of an 0.9-mm flexible scope. The interpeduncular cistern was examined to fenestrate the membrane of Liliequist. The flexible scope was then withdrawn and replaced with a No. 3 French Fogarty catheter that was inflated to enlarge the fenestration, which was accomplished under direct visualization with the rigid scope. In some cases the ventriculostomy was performed using the flexible endoscope and a No. 3 French embolectomy catheter via a 2.5-mm-outer-diameter rigid cannula. If patients previously had been dependent on a shunt, a temporary external ventricular drain was placed; if ICP remained low, this remained clamped until postoperative Day 2, when it was removed. No patient in this study required shunt placement in the immediate postoperative period.

**Volumetric Measurements**

The goal of the study was to obtain a follow-up scan within the first 3 weeks, but at least 3 days after surgery and at least 3 days after the ventricular catheter was removed, if one was placed. In two patients scans were obtained on postoperative Day 3, whereas in the other patients scans were obtained between 1 and 3 weeks after surgery. The patients in whom scans were obtained on postoperative Day 3 did not have a temporary ventricular catheter. In all 16 patients 3-mm contiguous slices through the entire third ventricle were obtained both pre- and postoperatively. After the first six patients had been examined, the decision was made to examine the lateral ventricles as well. In 10 patients 3-mm contiguous slices through the entire lateral ventricles were obtained both pre- and postoperatively. Computerized tomography scans were obtained just prior to the procedure by using one of two scanners (9800 high-speed scanner; General Electric Medical Systems, Milwaukee, WI, or a Somatom Plus 4 scanner; Siemens Medical Imaging, Inc., Needham, MA). A similar protocol was used to obtain postoperative scans. All ventricular measurements were made by two independent observers (T.H.S. and C.J.P.). The images were scanned into a computer (Power Macintosh 6500/250 [Apple Computer, Inc., Cupertino, CA] with a ScanJet IICX/T scanner [Hewlett-Packard, Palo Alto, CA]) at 600 dpi resolution. Using public domain image-processing software (Image version 1.61; National Institutes of Health, Bethesda, MD) at 2× magnification, the area (a) of the lateral and third ventricles was calculated for each axial slice either by determining a threshold for the pixel value of cerebrospinal fluid (CSF) or by manual outlining of a region of interest. The contrast and window settings
were held constant. The scale bar of the scan was used as a reference for standardization and to convert from pixels to cubic centimeters. The area of each ventricle (in square centimeters) on each slice on which it appeared (i) was then summed ($\sum a_i$) and multiplied by the thickness of the slice ($t$) to arrive at a measurement of ventricular volume ($V$): $V = t \times \sum a_i$.

Because 3-mm slices were obtained for this study the equation for volume (in cubic centimeters) was: $V = 0.3 \text{ cm}^3 \times \sum a_i$.

To examine the possibility that early decreases in ventricular volume might be attributable to subgaleal absorption of CSF leaking through the cortical incision, we compared those patients in whom follow-up scans had been obtained within the 1st week with those in whom later scans were obtained. To rule out the possibility that ependymal contrast enhancement on the preoperative scans might alter volumetric measurements we repeatedly measured, with and without addition of contrast agent, scans obtained on the same day in two control patients. Also, repeated measurements of single scans provided us with an indication of the reliability of our measurements.

**Statistical Analysis**

The Wilcoxon signed-rank test, a nonparametric paired statistic, was used to compare ventricular size before and after third ventriculostomy. The Spearman correlation test was used to correlate chronicity of disease with the magnitude of the change in ventricular volume and to evaluate the similarity between the ventricular measurements performed by two separate individuals.

**Results**

Fifteen of the patients showed symptomatic improvement at the time the early follow-up scan was obtained. Among these was a 1-month-old infant (Case 9) with Dandy–Walker syndrome who was asymptomatic before surgery, but had marked macrocephaly and hydrocephalus. Her head circumference stabilized. One patient (Case 14) did not improve. This patient had long-standing hydrocephalus following the resection of a posterior fossa ependymoma that had left him severely ataxic and dependent on a respirator for apneic episodes (Table 1).

Long-term results were also excellent. At a mean follow-up period of 12 months, 14 patients remained symptomatically improved. The patient with Dandy–Walker syndrome (Case 9) developed a seizure disorder but her head circumference decreased from the 95th to the fifth percentile. Another patient (Case 8), who had undergone fenestration 2 years earlier and thus underwent reoperation, was initially improved but treatment failed after 4 months. The patient subsequently underwent shunt placement despite a patent fenestration confirmed by direct visualization as well as a CSF flow study. One patient (Case 14) never improved after third ventriculostomy. The overall long-term success rate was 88%.

On visual inspection, early postoperative CT scans often failed to reveal a definite change in ventricular size (Fig. 1). The mean ± standard deviation (SD) preoperative third and lateral ventricular volumes were $8 \pm 3.9 \text{ cm}^3$ and $184.3 \pm 102.4 \text{ cm}^3$, respectively. At follow-up scanning sessions, all 15 patients with improvement showed a decrease in third ventricular volume according to both observers: by $32.9 \pm 20.1\%$ (range 7.8–81%) for Observer 1 and by $37.4 \pm 21.4\%$ (range 9.1–95.1%) for Observer 2 ($p < 0.0002$; Fig. 2A). The interobserver
Ventricular volume after third ventriculostomy

Spearman’s correlation was $r = 0.9207$ ($p < 0.0005$). The mean postoperative third ventricular volume was $5.3 \pm 3.1 \text{ cm}^3$. Lateral ventricular volume also decreased in the 10 patients in whom it was measured according to both observers: by $32.3 \pm 23.6\%$ (range 4.5–75.3\%) for Observer 1 and by $35.7 \pm 27.1\%$ (range 5.4–80.3\%) for Observer 2 ($p < 0.008$; Fig. 2B). The interobserver Spearman’s correlation was $r = 0.9398$ ($p < 0.0005$). The mean postoperative lateral ventricular volume was $134.5 \pm 110.2 \text{ cm}^3$. Combining the two ventricles provided the most reliable measurements: a decrease of $33.4 \pm 22.5\%$ (range 4.8–74.7\%) according to Observer 1 and $35.9 \pm 27\%$ (range 5–81.3\%) according to Observer 2 ($p < 0.008$; Fig. 2B). The interobserver Spearman’s correlation was $r = 0.9353$ ($p < 0.0005$). The one patient (Case 14) in whom there was no improvement showed no change in third ventricular involvement according to Observer 1 and a 5.8\% increase according to Observer 2. In seven of 10 cases the decrease in third ventricular volume exceeded the decrease in lateral ventricular volume. In three of 10 cases (Cases 11, 13, and 15), the decrease in lateral ventricular volume exceeded the decrease in third ventricular volume. The interobserver agreement was 100\%.

Patients in whom the smallest decreases in ventricular size ($\leq 10\%$) were observed had milder symptoms or indolent pathological entities. Two patients (Cases 5 and 15) had mass lesions that had caused symptoms for longer than 3 years, but had not required a shunt. Two other patients (Cases 1 and 7) had chronic pathological conditions (Chiari I malformation, aqueductal stenosis) that had required them to rely on shunts since childhood. For the whole group, the chronicity of the disease correlated inversely with the magnitude of the decrease in ventricular size (Fig. 3; Spearman’s test $p < 0.002$).

Ventricular volume was measured within the 1st week after surgery in four patients. The mean change ($\pm \text{SD}$) in third ventricular volume in these patients was $31.2 \pm 22.1\%$ according to Observer 1 and $40.1 \pm 23.6\%$ according to Observer 2; this was not significantly different from the rest of the group, which later was measured at $34.6 \pm 15\%$ by Observer 1 and $35.5 \pm 13.9\%$ by Observer 2. The mean change ($\pm \text{SD}$) in lateral ventricular volume for the early group was $29.7 \pm 23.3\%$ according to Observer 1 and $32.6 \pm 24.5\%$ according to Observer 2, compared with $31.3 \pm 24.8\%$ (Observer 1) and $37.2 \pm 30.4\%$ (Observer 2), which was also not significant. In two control patients the third and lateral ventricular volume measurements, obtained both with and without contrast enhancement, showed no significant or consistent change in volume as measured by both observers ($p = 0.91$).

Repeated measurements (15 iterations) of third and lateral ventricular volumes in the same patient indicated that the 95\% confidence interval (CI) for the third ventricular measurements varied by 2.5\% around the mean. The 95\% CI for the lateral ventricular measurements varied by 1.2\% around the mean.

Discussion

Radiographic follow-up examination after third ventricu-
systematic or only the lateral ventricles to assess changes in ventricular size. Hence, we recommend using either the entire ventricular volume measurements than for third ventricular measurements. Observer agreement was also better for lateral ventricular measurements. Because the overall volume of the third ventricle was twice as large as that for the lateral ventricular measurements, the 95% CI for the third ventricular measurements was excellent and the smallest decrease in ventricular volume than those in whom the ventricles were measured after surgery did not have a more significant decrease in volume than those in whom the ventricles were measured in the 2nd and 3rd week. Finally, we purposefully waited at least 3 days to perform our measurements to reduce the possibility of false-positive measurements. Another possible variable in ventricular size was the fact that contrast enhancement that were obtained in control imaging. However, measurements on scans with and without contrast enhancement that were obtained in control individuals showed that this was not an influential factor.

Although the intraobserver reliability for this technique was excellent and the smallest decrease in ventricular volume exceeded the 95% CI for both third and lateral ventricles, the 95% CI for the third ventricular measurements was twice as large as that for the lateral ventricular measurements. Because the overall volume of the third ventricle is small with respect to the fixed distance between axial sections, those measurements may not be optimal to assess very small changes in ventricular volume. Interobserver agreement was also better for lateral ventricular measurements than for third ventricular measurements. Hence, we recommend using either the entire ventricular system or only the lateral ventricles to assess changes in ventricular size to avoid error. In our earlier study we reported that measured changes in ventricular size were more notable for the third ventricle than for the lateral ventricles. In that study, however, we used a linear method to determine ventricular size that is less sensitive to change than volume measurements and the reliability of our measurements was never assessed.

Earlier reports of ventricular size after third ventriculostomy have not found a consistent decrease. Sainte-Rose reported 30 patients after third ventriculostomy with 38 control patients who had shunts and found a 60% rate of persistent ventricular enlargement in the third ventriculostomy group. In a series composed of 84 patients, Dalrymple and Kelly reported that “a decrease in ventricular size on CT or MR imaging has not shown itself to be an accurate indicator of fistula patency—19% of patients in this series have shown no decrease in ventricular size on follow-up scans despite resolution of symptoms and documented patency on ancillary studies.” Musolino, et al., presented a series of 23 patients in whom postfenestration CT scans had been obtained; in seven (30%) there was no decrease in ventricular size. Jaksche and Loew commented that the ventricles were “unchanged or slightly decreased” in a series of 79 patients who underwent ventriculostomy and, in a prospective study of ventricular size using MR imaging, Wilcock and colleagues reported no decrease in ventricular size in five (38%) of 13 patients despite clinical improvement. Some other studies have reported more consistent decreases in ventricular size, but do not specify either how or when these measurements were made.

We chose to assess changes in ventricular size by using standard CT-based volumetric measurements. Subtle but clinically significant changes in ventricular size are difficult to estimate visually because of the irregular shape of the ventricles and the fact that comparisons are often made between scans obtained using different scanners with different scales. Linear-based methods have been used in the past, such as Evans’ ratio (right and left anterior horn width / maximum internal skull width). Which falsely assumes that all ventricles have the same shape and are much less sensitive to changes in size because volume-based measurements change in proportion to the cube of the radius. Although there are a variety of segmentation schemes available to measure ventricular volume with MR imaging, we relied on CT scans as a less expensive, rapid radiographic method of following patients.

Our method could be described as a semiautomated segmentation scheme involving the manual outlining of regions of interest. The computer then automatically counts the pixels within the region of interest and multiplies them by a known constant to provide an area that is integrated over the width of the scan. This technique is similar, although more sensitive, than the stereological method based on Cavalieri’s principle, which states that the volume of any object can be estimated from a set of two-dimensional slices through the object, provided that they are parallel, separated by a known distance, and begin randomly within the object. Any preoperative scan can be used for baseline measurements. We used scans obtained for CT-guided stereotactic localization to optimize the trajectory to avoid trauma to structures surrounding the foramen of Monro and to facilitate perforation of the third ventricular floor away from the basilar artery. Thus, ventriculostomy could be accomplished even when the thickened floor was opaque.

Conclusions

In this prospective study we show that both third and lateral ventricular volumes decrease by anywhere from 5 to 80% (average 30%) within the first 3 weeks after successful third ventriculostomy. However, lateral ventricular volume measurements are more accurate, probably due to the small size of the third ventricle. These changes can be measured as early as 3 days after surgery by using a standard CT scanner and the magnitude of the change corre-
Ventricular volume after third ventriculostomy

lates inversely with the chronicity of the disease. Early decreases in ventricular size do not, however, predict long-term patency and, although we had an 88% success rate, the prospect of delayed closure remains a possibility in a small percentage of patients.

References

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