Cerebral shunt obstruction is extraordinarily common, occurring in more than 30% of patients during the 1st year after shunt insertion. The determination of shunt failure can be difficult, particularly when patients’ symptoms are discordant with radiographic findings. Further complicating clinical decision making, CSF production in adults and children varies throughout the day and may be influenced by the pathophysiological underpinning of hydrocephalus for a particular patient.

Radionuclide shuntography is an adjunct for the evaluation of ventricular shunt patency. Consensus is lacking, however, on the definition of a “normal” shuntogram. Various criteria have been proposed: 1) ventricular radiotracer entry,9,10,12 2) distal cavity runoff between 10 and 20 minutes,12,13 and 3) runoff half-life of < 10 minutes.6 Even details of performing the shuntography procedure vary among institutions. For example, some but not all require pumping the shunt reservoir as part of the shuntogram.1,9,13

The main aim of this study was to determine the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of a variety of shuntography results based on 2 variables: ventricular tracer entry and distal tracer drainage.

Using a 2-variable method in radionuclide shuntography to predict shunt patency

Clinical article

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Object. Radionuclide shuntography interpretation is uncertain when the tracer fails to enter the ventricles but quickly drains distally or when the tracer enters the ventricles but takes longer than 15 minutes to drain distally. The purpose of this study was to aid in the clinical interpretation of a variety of shuntography results and to determine the applicability of shuntography in different patient populations.

Methods. The results of 259 shuntograms were reviewed. Chi-square analysis was performed to evaluate the relationship between clinical variables and shuntography results. Two-by-two binary classification analyses were performed to determine the sensitivity, specificity, positive predictive value, and negative predictive value for 4 different combinatorial types of shuntography results based on 2 variables: ventricular tracer entry and distal tracer drainage.

Results. Median patient age was 19 years, and 51% of patients were male. The most common presentation in patients undergoing shuntography was headache (169/254, 66.5%) with radiographically stable ventricle size. Of 227 patients with available imaging data, 163 (71.8%) presented with the same ventricle size as shown on a previous asymptomatic scan, 43 (18.9%) had larger ventricles, and 21 (9.2%) had smaller ventricles. Within 30 days of shuntography, 74 of 259 patients (28.6%) underwent surgical shunt exploration: 65 were found to have an obstructed shunt and 9 were found to have a patent shunt. Of those patients not undergoing surgery, the median length of benign clinical follow-up was 1051 days. Clinical variables were not significantly associated with shuntography results, including valve type (p = 0.180), ventricle size (p = 0.556), age (p = 0.549), distal drainage site (p = 0.098), and hydrocephalus etiology (p = 0.937). Shuntography results of patients with myelomeningocele were not dissociable from those of the group as a whole. Sensitivity to diagnose shunt failure was lowest (37.5%) but specificity was highest (97.2%) when the definition of a “normal” shuntogram included any tracer movement into the distal site within 45 minutes. Conversely, sensitivity was highest (87.5%) and specificity was lowest (51.4%) when the definition was limited exclusively to tracer entry into the ventricles and distal drainage within 15 minutes.

Conclusions. Even with a stringent definition of a “normal” shuntogram, sensitivity and specificity were relatively low for a diagnostic test. Clinical variables such as valve type, ventricle size, patient age, distal drainage site, and etiology of hydrocephalus were not associated with shuntography results.

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Key Words • hydrocephalus • sensitivity • specificity • shunt obstruction
Two-variable method shuntography to predict shunt patency

Methods

Patient Data Collection

This retrospective review was approved by the Oregon Health & Science University (OHSU) Institutional Review Board. Patients who underwent shuntograms between January 2001 and December 2012 at OHSU Hospital and Doernbecher Children’s Hospital were included. The decision to acquire a shuntogram was at the discretion of 1 of 10 attending neurosurgeons but typically included discordant symptoms and radiographic findings (e.g., headache and nausea with radiographically stable ventricular size). Three pediatric neurosurgeons ordered shuntograms for approximately half of the patients included in this study. To be included in statistical analyses, patients had to have had a ventricular CSF shunt and ≥ 30 days of clinical follow-up after undergoing shuntography. Each shuntogram was interpreted by 1 of 3 board-certified nuclear medicine radiologists who were unaware of the specific indications for performing the shuntography. The following information was obtained from chart review: patient age and sex, valve type (and setting if programmable), ventricle size compared with a previous examination during which the patient was asymptomatic, presenting clinical symptoms, shuntogram reports, intraoperative results (if patient had a ventricular shunt revision within 30 days), and length of follow-up.

Radionuclide Shuntography Technique

The skin overlying the shunt reservoir was prepared with povidone-iodine and alcohol before 2007 and chlorhexidine gluconate and alcohol after 2007. The distal catheter was then occluded by manual compression either immediately distal to the valve or at the clavicle. Approximately 0.5 mCi 111In-DTPA or 1 mCi 99mTc-DTPA in approximately 3 ml CSF or 0.9% NaCl was injected. Patients were placed in a semirecumbent position (approximately 30°) and imaged from head to pelvis every 15 minutes for up to 60 minutes using a Philips Brightview XCT or Philips Precedence SPECT/CT gamma camera system (Koninklijke Philips N.V.).

Study Design

Shuntography results were classified according to tracer entry into the ventricle and the amount of time from tracer injection to distal site drainage (Table 1). Four different definitions of a “normal” shuntogram based on tracer entry into the ventricles and distal tracer drainage were used to calculate sensitivity, specificity, PPV, and NPV. To determine these values, disease presence (shunt failure) and test (shuntogram) were analyzed using a standard 2 × 2 methodology. A true-negative result was defined as a normal shuntogram with at least 30 days of follow-up without a shunt revision. A true-positive result was defined as an abnormal shuntogram with intraoperative confirmation of obstruction. A false negative was defined as a normal shuntogram followed by shunt revision within 30 days with confirmed intraoperative obstruction. A false positive was defined as an abnormal shuntogram that either did not require revision within 30 days or (more rarely) had confirmed intraoperative patency.

Statistical Analysis

Categorical variables (type of shuntogram and clinical variables) were analyzed by chi-square tests using Stata version 10.1 (StataCorp LP). Sensitivity, specificity, PPV, and NPV were determined using basic 2 × 2 table binary classification.

Results

In the specified time period, 1120 shuntograms and approximately 1700 shunt revisions were performed at OHSU; of these, 259 shuntograms meeting inclusion criteria were pseudorandomly selected by medical record number before de-identification, with a target of 25%, and analyzed. No patient had more than 1 shuntogram acquired during a 30-day period. There were 5 episodes of intracranial pressure monitoring. Median age was 19 years, and 132 (51%) of patients were male. The most common presentation in patients undergoing shuntography was headache (169/254, 66.5%) with radiographically stable ventricle size. Data on clinical presentation were missing in 5 patients. Of 227 patients with available imaging data, 163 (71.8%) presented with the same ventricle size as was shown on a previous asymptomatic scan, 43 (18.9%) had larger ventricles, and 21 (9.2%) had smaller ventricles. Data on ventricle size were missing in 32 patients.

Of 259 patients, 74 (28.6%) underwent surgical shunt exploration within 30 days of shuntography (Table 2). Of these patients, 65 were found to have an obstructed shunt and 9 were found to have a patent shunt. Specific intraoperative findings providing more detail than shunt “patent or obstructed” were missing for 9 (12%) of 74 patients. Of those patients not undergoing surgery, the median length of benign clinical follow-up was 1051 days.

Clinical variables were not significantly associated with shuntography results, including valve type (p = 0.180), ventricle size (p = 0.556), age (p = 0.549), distal drainage site (p = 0.098), and hydrocephalus etiology (p = 0.937). In particular, the shuntography results of myelomeningocele patients were not dissociable from those of the group as a whole.

When the definition of a “normal” shuntogram included any radiotracer movement into the distal site within 45 minutes regardless of tracer entry into the ventricles, sensitivity was low but specificity was high (Table 3). Adopting more stringent definitions increased sensitiv-

<table>
<thead>
<tr>
<th>TABLE 1: Summary of shuntogram types</th>
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<tbody>
<tr>
<td>Shuntogram Type</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>delayed I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>delayed II</td>
</tr>
</tbody>
</table>
ity but moderately decreased specificity (Table 3). With more stringent definitions of “normal,” PPVs decreased dramatically. By contrast, NPVs were relatively high in all cases, particularly when the tracer entered the ventricles (Table 3). In a subgroup analysis including only patients who presented with stable ventricle size, values of sensitivity, specificity, PPV, and NPV were similar to those of the entire group (Table 3).

**Discussion**

Sensitivity measures how accurately a test identifies patients with a disease, whereas specificity measures how accurately a test identifies patients who do not have that disease. A clinical test is most useful when the sensitivity and specificity approach 100%. The present study demonstrates that radionuclide shuntography for the detection of ventricular shunt failure in symptomatic patients is highly specific (97%) but very insensitive when using a liberal definition of a “normal” test result. Conversely, shuntography is highly nonspecific and only moderately sensitive (87.5%) when using a strict definition of “normal.”

Our results approximate those previously published with shuntogram sensitivities of 92%–96% and specificities of 59%–89%. However, other diagnostic tests frequently used in the diagnosis of high-risk neurosurgical conditions often yield higher values. Noncontrast head CT to evaluate subarachnoid hemorrhage has a 92.9% sensitivity, 100% specificity, 100% PPV, and 99.4% NPV. Short TI inversion recovery (STIR) MRI to evaluate cervical spine instability in pediatric patients has a 100% sensitivity, 97% specificity, 33% PPV, and 100% NPV.

High sensitivity is important for identifying serious diseases with treatable morbidity or mortality, such as ventricular shunt failure. Adopting a strict definition of a “normal” shuntogram to improve the test’s sensitivity, however, also yields very low specificity. This low specificity is undesirable and will likely result in unnecessary episodes of surgical exploration to confirm shunt patency. Unlike sensitivity and specificity, PPV and NPV depend on the prevalence of the disease studied. Shuntography yields relatively high NPVs in the case of ventricular tracer entry irrespective of the timing to distal runoff. If tracer enters the ventricles, there is a > 90% chance that the shunt is not obstructed, which makes sense considering that most shunt obstructions occur in the ventricular catheter. This finding suggests that shuntography may be used as a source of supportive information for ventricular shunt patency in cases of low clinical and radiographic suspicion for shunt failure. The value of shuntography does not appear to be influenced either positively or negatively by individual patient characteristics, such as hydrocephalus etiology, ventricular size, or valve type.

The consequences of failure to diagnose ventricular shunt malfunction can be catastrophic. The limited sensitivity of shuntography, even when using a strict definition for “normal” results, is therefore of significant concern and emphasizes the importance of experience, clinical

<table>
<thead>
<tr>
<th>Shuntogran Type</th>
<th>Intraop Findings</th>
<th>Distal Catheter/Valve</th>
<th>Total</th>
<th>Distal Catheter/Valve</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disconnected</td>
<td>Obstructed</td>
<td>Patent</td>
<td>Total</td>
<td>Disconnected</td>
</tr>
<tr>
<td>I</td>
<td>10 (9%)</td>
<td>98 (91%)</td>
<td>108</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>II</td>
<td>23 (35%)</td>
<td>42 (65%)</td>
<td>65</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>delayed I</td>
<td>4 (10%)</td>
<td>35 (90%)</td>
<td>39</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>delayed II</td>
<td>9 (56%)</td>
<td>7 (44%)</td>
<td>16</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>all other instances</td>
<td>28 (90%)</td>
<td>3 (10%)</td>
<td>31</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>total</td>
<td>74</td>
<td>185</td>
<td>259</td>
<td>3</td>
<td>43</td>
</tr>
</tbody>
</table>

* Values represent the number (%) of patients.
† Some detailed intraoperative findings missing.

**TABLE 3: Comparison of 4 definitions of a “normal” shuntogram**

<table>
<thead>
<tr>
<th>Definition†</th>
<th>Normal</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I, delayed Type I, Type II, delayed Type II</td>
<td>all other instances</td>
<td>37.5 (37.1)</td>
</tr>
<tr>
<td>Type I, delayed Type I, Type II</td>
<td>delayed Type II, all other instances</td>
<td>51.6 (54.3)</td>
</tr>
<tr>
<td>Type I, delayed Type I</td>
<td>Type II, delayed Type II, all other instances</td>
<td>80.6 (62.9)</td>
</tr>
<tr>
<td>Type I</td>
<td>delayed Type I, Type II, delayed Type II, all other instances</td>
<td>87.5 (85.7)</td>
</tr>
</tbody>
</table>

* Values represent entire subject population (patients with stable ventricle size only). Sensitivity and specificity are defined with regard to detection of the condition “ventriculoperitoneal shunt failure.”
† “All other instances” includes no distal tracer drainage or distal tracer drainage > 45 minutes.
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judgment, additional testing, and ongoing clinical observation in the diagnosis of shunt malfunction in cases of reasonable uncertainty.

Limitations

This study is limited by its retrospective design and heterogeneous cohort. Because each shuntogram was reviewed by only 1 radiologist, and only shuntogram reports were analyzed by the authors, intra- and interobserver validation was not performed. Only selected patients presenting with symptoms of shunt failure underwent shuntography, thereby introducing a profound selection bias. Additionally, the decision to obtain a shuntogram was usually based on incongruous symptoms and radiographically demonstrated ventricle size but was ultimately based on variable criteria by 10 different staff neurosurgeons. This variation in the decision of whether or not to perform shuntography may have affected the sensitivity and specificity results of this study.

In ideal circumstances, a receiver operating curve would be constructed to define test characteristics (minutes to drainage as a continuous variable) and further refine test sensitivity and specificity. Shuntography data, however, are collected in categorical fashion, requiring occasional intermittent imaging for practical reasons.

Although surgery is the gold standard for establishing the definitive diagnosis of ventricular shunt malfunction, uniform surgical intervention is not a reasonable method for systematic evaluation of possible malfunction, particularly in cases of low clinical suspicion. Because only 74 patients (28.6%) in this study underwent surgical shunt exploration within 30 days of shuntography, some experts would argue that true sensitivity, specificity, PPV, and NPV cannot be calculated in this context.12

Conclusions

The sensitivity of radionuclide shuntography to detect ventricular shunt malfunction is increased, but the specificity is significantly decreased, when increasingly stringent definitions of a “normal” result are used. When ventricular tracer entry is noted, the NPV of shuntography to evaluate shunt patency exceeds 90%. However, these values are still relatively low compared with other common neurosurgical diagnostic tests. Additionally, PPV was low regardless of how a “normal” shuntogram was defined. Radionuclide shuntography has limited utility in the confirmation of ventricular shunt patency regardless of patient age, valve type, ventricle size, distal drainage site, and hydrocephalus etiology. Given the severe consequences of failure to diagnose ventricular shunt malfunction, workup should continue to emphasize experience, clinical judgment, and, when relevant, additional testing and ongoing clinical observation.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following: Conception and design: Selden, Thompson. Acquisition of data: Selden, Thompson. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Selden. Statistical analysis: Thompson. Study supervision: Selden.

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