The incidence of idiopathic intracranial hypertension (IIH), or pseudotumor cerebri, in the general population is predicted to be 1–2/100,000 and appears to be increasing. This rate is estimated to be 10-fold higher within specific patient populations, specifically women of childbearing age with a body mass index (BMI) > 30. While the etiology of IIH is yet to be elucidated, its debilitating symptoms—headaches, gait instability, and visual changes—severely impact the quality of life for this population. The diagnostic criteria for IIH consist of the clinical history, radiological imaging findings, ophthalmological examination findings, and results of various procedures, including the use of intraoperative CT (iCT) and frameless stereotaxy, in optimizing postoperative ventricular catheter placement.

**ABSTRACT**

Cerebrospinal fluid shunting can effectively lower intracranial pressure and improve the symptoms of idiopathic intracranial hypertension (IIH). Placement of ventriculoperitoneal (VP) shunts in this patient population can often be difficult due to the small size of the ventricular system. Intraoperative adjuvant techniques can be used to improve the accuracy and safety of VP shunts for these patients. The purpose of this study was to analyze the efficacy of some of these techniques, including the use of intraoperative CT (iCT) and frameless stereotaxy, in optimizing postoperative ventricular catheter placement.

**METHODS**

The authors conducted a retrospective review of 49 patients undergoing initial ventriculoperitoneal shunt placement for the treatment of IIH. The use of the NeuroPEN Neuroendoscope, intraoperative neuronavigation, and iCT was examined. To analyze ventricular catheter placement on postoperative CT imaging, the authors developed a new grading system: Grade 1, catheter tip terminates optimally in the ipsilateral frontal horn or third ventricle; Grade 2, catheter tip terminates in the contralateral frontal horn; Grade 3, catheter terminates in a nontarget CSF space; and Grade 4, catheter tip terminates in brain parenchyma. All shunts had spontaneous CSF flow upon completion of the procedure.

**RESULTS**

The average body mass index among all patients was 37.6 ± 10.9 kg/m². The NeuroPEN Neuroendoscope was used in 44 of 49 patients. Intraoperative CT scans were obtained in 24 patients, and neuronavigation was used in 32 patients. Grade 1 or 2 final postoperative shunt placement was achieved in 90% of patients (44 of 49). In terms of achieving optimal postoperative ventricular catheter placement, the use of iCT was as effective as neuronavigation. Two patients had their ventricular catheter placement modified based on an iCT study. The use of neuronavigation significantly increased time in the operating room (223.4 ± 46.5 vs 190.8 ± 31.7 minutes, p = 0.01). There were no shunt infections in this study.

**CONCLUSIONS**

The use of iCT appears to be equivalent to the use of neuronavigation in optimizing ventricular shunt placement in IIH. Additionally, it may shorten operating room time and limit overall costs.

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**KEY WORDS**

intraoperative CT; idiopathic intracranial hypertension; NeuroPen; ventriculoperitoneal shunt placement
cluded CSF diversion (ventriculoperitoneal [VP], lumbo-
peritoneal [LP] shunting), venous stenting, subtemporal
decompression, and bariatric surgery. Although VP shunts
are preferred for most pathologies requiring permanent
CSF diversion, LP shunts are typically employed for the
treatment of IIH because of the small ventricular size in
this patient population.2,6,10,11 LP shunts, however, have sig-
nificant complication and revision rates,2,6,7,10,11,14 suggest-
ing that any techniques that improve ventricular catheter
placement in IIH would be very beneficial.3

Various intraoperative adjuvant techniques have been
employed in addressing the challenges of accurately can-
nulating the undersized ventricular system in IIH. These
include the use of ultrasound guidance and stereotax-
is.1,2,4,9,13,16,17 These methods have improved ventricular
catheter placement, as demonstrated by postoperative cra-
nial CT imaging.

Traditionally at our institution, frameless stereotaxy
has been used for shunt placement in patients with small
ventricular size, such as in cases of IIH. This has some
inherent limitations, however, including the need for rigid
head fixation and constraints on patient positioning in
patients who are often morbidly obese, the added cost of
compatible preoperative imaging and intraoperative dis-
posable equipment, and added time in the operating room.
Additionally, final intraventricular catheter location is not
confirmed until a CT scan is obtained postoperatively.
We attempted to determine if utilizing intraoperative CT
(iCT) could replace neuronavigation while maintaining
the same level of accuracy and precision of final ventricu-
lar catheter placement.

Methods

Patient Characteristics

We conducted a retrospective review of patients with
IIH who underwent placement of an initial ventriculoperi-
toneal shunt. These patients were all treated at a single in-
stitution (Albany Medical Center) over a 47-month period
(December 2011 to October 2015).

Surgical Decision Making and Technique

In the current series of patients, all patients fulfilled
the modified Dandy diagnostic criteria for IIH with a
documented opening pressure by lumbar puncture greater
than 20 cm H2O and cranial imaging demonstrating no
evidence of ventricular obstruction or intracranial mass
lesion. All patients were symptomatic with headaches,
papilledema, and/or a cranial base CSF fistula requiring
prior repair. Medical therapy had been attempted and was
ineffective, not tolerated, or resulted in poor patient com-
pliance. A right frontal VP shunt with a programmable
valve was placed in all patients.

Because of the small ventricular size in these patients,
several adjuvant techniques were used to optimize ven-
tricular catheter placement at the discretion of the treating
neurosurgeon. These techniques included the NeuroPEN
Neuroendoscope (Medtronic PS Medical), iCT imaging
for confirmation of appropriate catheter placement prior
to completion of the procedure, and/or intraoperative neu-
ronavigation (Brainlab AG). When a CT study was not
performed intraoperatively, it was obtained postopera-
tively prior to the patient’s discharge from the hospital to
confirm the location of the ventricular catheter.

Neuronavigation

After induction of general anesthesia and intubation,
the patient is placed in rigid cranial 3-point fixation, which
is secured to the operating table. Registration to a preop-
erative CT scan using the Brainlab navigation platform
is performed. Cannulation of the lateral ventricle is aided by
a preregistered stylet (Brainlab AG) that is placed within
the proximal catheter. Upon reaching the ventricular tar-
get and after CSF is returned through the catheter, the sty-
let is removed.

NeuroPEN

The NeuroPEN neuroendoscope is a single-use, dispos-
able endoscope with 3 channels, allowing attachment to a
camera and illumination as well as a port for irrigation.
The NeuroPEN is placed within a catheter with a “fish-
mouth” tip (Innervision ventricular catheter, Medtronic
PS Medical). This allows for its advancement through the
catheter within the ventricle, providing direct visualiza-
tion and allowing the catheter to be directed to an optimal
position. The endoscope is then removed, leaving the c ath-
ether in position.

Intraoperative CT

After initial patient positioning, the iCT is advanced to
its final position to ensure that there are not any “colli-
sions” with the patient that would limit image quality or
cause the patient harm. The iCT is then withdrawn into
its storage location in the operating room. The operating
drapes are placed, and the shunt procedure is conducted
under standard sterile conditions. The ventricular catheter
is passed based on anatomical landmarks. Prior to final
skin closure, additional surgical drapes are used to cover
the sterile field, and the iCT study is obtained to confirm
ventricular catheter placement. If the placement is un-
satisfactory, the catheter is placed again and another CT
scan is obtained. Alternatively, if ventricular cannulation
cannot be achieved during initial catheter placement, the
catheter is left in position, a CT scan is obtained and the
catheter trajectory is then adjusted accordingly. A confirm-
atory CT scan is then obtained prior to the completion of
the procedure. A repeat CT scan is not necessary prior to
discharge in the absence of new neurological symptoms.

Patient Demographics

Presenting demographics reviewed for each patient in-
cluded the following: age, sex, and BMI.

Radiological Analysis

For each patient, both the immediate preoperative and
intraoperative/postoperative cranial CT studies were
reviewed. On the preoperative studies, several measure-
ments to characterize ventricular size were made: Evans
ratio, frontal and occipital horn ratio (FOHR),8,12 and bi-
ventricular distance (the maximal width of the frontal
horns of the lateral ventricles) (Fig. 1). The final intraoperative or postoperative CT was analyzed to grade ventricular catheter placement (Table 1, Fig. 2) and identify any postoperative hemorrhage or other complications. To analyze ventricular catheter placement on CT imaging, we developed a new grading system: Grade 1, catheter tip terminates optimally in the ipsilateral frontal horn or third ventricle; Grade 2, catheter tip terminates in the contralateral frontal horn; Grade 3, catheter terminates in a nontarget CSF space; and Grade 4, catheter tip terminates in brain parenchyma (Table 1, Fig. 2).

**Clinical Analysis**

The operating room record was reviewed for each patient to determine the duration of total operating room time (patient entrance to the operating room to patient exit) as well as procedure time (incision to skin closure).

**Statistical Analysis**

Clinical and radiographic characteristics were compared between the iCT and neuronavigation groups. The independent 2-sample t-test was used for comparison of the variables of normal distribution. For nonparametric analysis, the Wilcoxon-Mann-Whitney test was used. Statistical significance was defined as p < 0.05.

**Results**

A total of 49 patients were reviewed (Table 2). Forty-six patients (94%) were female. The mean age was 33.5 ± 12.7 years (± SD), and the mean BMI was 37.6 ± 10.9 kg/m². The NeuroPEN Neuroendoscope was used in the vast majority of patients (44 of 49, 90%). Neuronavigation was used in 32 patients (65%) and iCT in 24 (49%). Using these techniques to make appropriate intraoperative modifications, the ventricular catheters terminated within the lateral ventricles or third ventricle (Grade 1 or 2 placement) in 44 of 49 patients (90%).

**Intraoperative CT**

When comparing those 24 patients in whom iCT was used against the 25 in whom it was not (Table 3), no significant differences (p < 0.05) existed in the preoperative ventricular size. The use of a single iCT study verified satisfactory catheter placement in all but 2 patients after initial placement. In those 2 patients, an intraoperative modification of the catheter was made based on the iCT findings, and an improved placement grade was verified with a second iCT study (Fig. 3). Thus, the iCT study ensured that the patient’s ventricular catheter was appropriately placed before the patient left the operating room. Obtaining an iCT did not increase operating room times, and, when used in conjunction with the NeuroPEN, resulted in comparable ventricular catheter placement. A Grade 1 or 2 final catheter placement was achieved in 23 of 24 patients (96%) when iCT was used. One patient in this group had a Grade 4 placement as noted on iCT, as the catheter traversed the contralateral frontal horn and its tip terminated a few millimeters within the brain parenchyma. A decision was made to not revise this, as brisk CSF flow was returned upon its placement, which had necessitated 2 passes, and it was felt that all of the catheter’s drainage holes were located within the lateral ventricle’s frontal horn.

**Neuronavigation**

When comparing those 32 patients in whom frameless stereotactic guidance was used with the 17 patients in whom it was not (Table 4), no significant differences (p < 0.05) existed in terms of preoperative ventricular size. The use of neuronavigation did significantly increase time in the operating room (223.4 ± 46.5 vs 190.8 ± 31.7 minutes, p = 0.01). Comparable ventricular catheter placement was achieved in both the group in which neuronavigation was used (Grade 1 or 2 placement in 28 of 32 patients, or 88%) and the group in which it was not.

**Complications**

One patient in this study had an asymptomatic hemorrhage as demonstrated on the postoperative CT along a shunt pass tract lateral to the ipsilateral lateral ventricle.
This patient was in the non-iCT, neuronavigation group. Another patient required a return to the operating room on the same day as the initial shunt placement because a postoperative CT study demonstrated the ventricular catheter to be in the contralateral opticocarotid cistern. Although brisk CSF flow had been obtained during the initial shunt placement and the patient was asymptomatic, there were concerns regarding its long-term effectiveness and its potential for future morbidity. On reoperation, the catheter was withdrawn into the ipsilateral frontal horn under direct visualization with the NeuroPEN (Fig. 4). This patient was in the non-iCT group and was the only patient in the study in whom ultrasound guidance was used.

Discussion

Idiopathic intracranial hypertension, or pseudotumor cerebri, is a syndrome of increased intracranial pressure whose exact etiology is unclear. Most commonly affected are morbidly obese females of childbearing age. The modified Dandy diagnostic criteria require 1) symptoms and signs of increased intracranial pressure; 2) no localizing neurological signs, except for unilateral or bilateral sixth cranial nerve palsies; 3) increased CSF opening pressure but normal CSF composition; 4) no evidence of hydrocephalus, mass, structural, or vascular lesion on imaging; and 5) no other cause of increased ICP identified. Symptoms typically consist of headaches and visual symptoms, including vision loss and papilledema.

The main goals of IIH treatment are symptomatic improvement and visual preservation. Initially, this can be achieved with medical therapy and weight loss. For those patients intolerant of or noncompliant with these treatments or whose signs and symptoms are not responsive, surgical treatment is often required. Surgical options include bariatric surgery, subtemporal decompression, and/or CSF shunting. The final option, although typically the initial surgical option, is often problematic because of the extremely small size of the ventricular system in these patients, making placement of ventricular catheters difficult; the morbid obesity in these patients complicates LP shunt placement. Historically, LP shunts have been used
for CSF diversion in IIH, but recently additional operative techniques, including ultrasound-guidance and stereotaxy have been used to optimize the effectiveness of VP shunts in these patients. With these additional methods, the accuracy and precision of ventricular catheter placement can be significantly improved, and the difficulties associated with LP shunts may be avoided.

Even with these additional methods to aid VP shunt placement in IIH patients, the procedures are still more complicated than typical shunt procedures. In this series, the operative times were longer than would be typically expected of a shunt operation (median 100 minutes, range 54–208 minutes), reflecting their complexity in this patient population. Despite this, we did not have any shunt infections in this series. Increased operative time, however, is a noted risk factor for shunt infection, and any technique to limit this duration, without sacrificing the accuracy of shunt placement, would be beneficial.

After VP shunt placement, CT imaging is required postoperatively to definitively confirm ventricular catheter placement, even if stereotaxy or ultrasound guidance is used intraoperatively. Ideal shunt placement involves the ventricular catheter terminating within the ipsilateral frontal horn of the lateral ventricle or the third ventricle (a Grade 1 placement based on our scale). This is considered optimal based on the assumption that this location will result in the best long-term shunt patency and function, and that other catheter positions, despite the initial return of CSF, may fail over time and require replacement. This is the principle upon which we based our grading scale for final ventricular catheter positioning following VP shunt placement.

In one patient early in this study (Fig. 4), a routine postoperative CT scan demonstrated the ventricular catheter to be suboptimally placed despite the use of ultrasound guidance and brisk CSF flow return upon its placement. The need for surgical revision in this patient and additional imaging after this second operation prompted an investigation into the sole use of the NeuroPEN for catheter placement and then obtaining a cranial CT scan intraoperatively prior to extubation. Initially, this was coupled with neuronavigation for 5 patients. As the use of frameless stereotaxy adds additional time and cost (for disposable spheres and the shunt stylet) and requires rigid head fixation, limiting the utility of the anatomical landmarks to which neurosurgeons are accustomed when placing ventricular catheters, its use was eventually abandoned and iCT alone was used. Two authors (J.C.D. and M.A.A.) continued to mainly use neuronavigation coupled with the NeuroPEN intraoperatively, and, after the patient had left the operating room, obtained a postoperative CT scan to confirm ventricular catheter placement.

### Table 2. Characteristics of the 49 patients with IIH*

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<td>No. of patients</td>
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<td>Mean age (yrs)</td>
<td>33.5 ± 12.7</td>
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<td>Sex (M/F)</td>
<td>3/46</td>
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<td>Mean BMI</td>
<td>37.6 ± 10.9</td>
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<tr>
<td>Mean Evans ratio</td>
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<tr>
<td>Mean FOHR</td>
<td>0.32 ± 0.02</td>
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<tr>
<td>Mean biventricular distance (mm)</td>
<td>30.5 ± 2.7</td>
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<tr>
<td>Mean total OR time (mins)</td>
<td>208.6 ± 49.4</td>
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<tr>
<td>Mean procedure time (mins)</td>
<td>112.5 ± 40.3</td>
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<tr>
<td>NeuroPEN</td>
<td>44 of 49</td>
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<td>iCT</td>
<td>24 of 49</td>
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<tr>
<td>Neuronavigation</td>
<td>32 of 49</td>
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* OR = operating room.

* Values are number of patients unless noted otherwise. Mean values are presented ± SD.

### Table 3. Comparison of patients in whom iCT was used and those in whom it was not*

<table>
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<tr>
<td>Mean Evans ratio</td>
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<tr>
<td>Mean FOHR</td>
<td>0.32 ± 0.02</td>
<td>0.33 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>Mean biventricular distance (mm)</td>
<td>30.2 ± 2.7</td>
<td>30.5 ± 2.8</td>
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<tr>
<td>Mean total OR time (mins)</td>
<td>208.4 ± 52.6</td>
<td>215.6 ± 35.7</td>
<td>NS</td>
</tr>
<tr>
<td>Mean procedure time (mins)</td>
<td>112.0 ± 45.6</td>
<td>113.0 ± 35.4</td>
<td>NS</td>
</tr>
<tr>
<td>Placement grade</td>
<td>14</td>
<td>13</td>
<td></td>
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<tr>
<td>4</td>
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</table>

NS = not significant.

* Values are number of patients unless noted otherwise. Mean values are presented ± SD.

### Table 4. Comparison of patients in whom neuronavigation was used and those in whom it was not*

<table>
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<th>Variable</th>
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<th>No Navigation</th>
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</thead>
<tbody>
<tr>
<td>No. of patients</td>
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<tr>
<td>Mean Evans ratio</td>
<td>0.25 ± 0.02</td>
<td>0.25 ± 0.02</td>
<td>NS</td>
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<tr>
<td>Mean FOHR</td>
<td>0.32 ± 0.02</td>
<td>0.33 ± 0.02</td>
<td>NS</td>
</tr>
<tr>
<td>Mean biventricular distance (mm)</td>
<td>30.6 ± 2.8</td>
<td>30.2 ± 2.5</td>
<td></td>
</tr>
<tr>
<td>Mean total OR time (mins)</td>
<td>223.4 ± 46.5</td>
<td>190.8 ± 31.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Mean procedure time (mins)</td>
<td>117.4 ± 38.6</td>
<td>103.4 ± 43.0</td>
<td>NS</td>
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<tr>
<td>Placement grade</td>
<td>11</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>1</td>
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</table>

* Values are number of patients unless noted otherwise. Mean values are presented ± SD.
In all but 5 of the earliest patients in this study, the NeuroPEN Neuroendoscope was used. A statistical analysis of its effectiveness here is therefore limited, but its use in our practice has proven to be unequivocally advantageous for proper ventricular catheter placement in IIH patients and others with undersized ventricles. Unfortunately, due to the retrospective nature of this study, we were unable to determine the number of intraoperative modifications made to ventricular catheters based on its use. Through direct visualization, however, the NeuroPEN does permit recognition of the ventricular ependymal surface and even allows for small adjustments to be made to position the catheter within the frontal horn or advanced into the third ventricle. An objective assessment of this value, even in a prospective study, might be difficult. Additionally, ultrasound guidance was used in only one patient, again limiting any analysis of its utility in this setting. Therefore, this study largely sought to determine if iCT could effectively be used in lieu of neuronavigation to optimize ventricular catheter placement in IIH patients.

In our study, there was no difference in ventricular size between patients in whom neuronavigation was used and those in whom other techniques were employed. The intraoperative adjunct used was therefore not predetermined by a patient’s ventricular size. Instead, this decision was made based on surgeon preference, as detailed above.

In the current study, the use of frameless stereotaxy in combination with the NeuroPEN Neuroendoscope yielded similar accuracy rates of ventricular placement to those previously reported. When compared with the other methods we analyzed in this study, stereotaxy did not yield significantly better ventricular catheter placement grades, but it did increase the time in the operating room. Much of this time was committed prior to incision, placing the patient in cranial fixation and registering the navigation system. This finding, which has been previously reported, along with the cost of compatible preoperative imaging and the approximately $400 committed to disposable intraoperative materials, results in an increased cost to these procedures when neuronavigation is used.

Like the use of the frameless stereotaxy system, use of the NeuroPEN Neuroendoscope alone and then confirmed by iCT resulted in excellent ventricular placement grades (96% Grade 1 or 2). The preoperative setup and performance of the CT scanner did not significantly increase operating room times. As a postoperative CT scan was obtained at some point prior to discharge in all patients in this study, having the study performed intraoperatively...
rather than after extubation did not typically result in additional radiological imaging or radiation exposure. Admittedly, for those patients in whom intraoperative modifications were made to the ventricular catheter based on iCT findings, a second scan was obtained to confirm final catheter placement. If these modifications were not made, however, it could be argued that, without iCT, these patients would have likely returned to the operating room either after their initial postoperative CT scan or at a later date because of shunt failure due to a suboptimally placed ventricular catheter. At least one additional CT study would likely be performed perioperatively for these subsequent interventions.

Based on iCT findings, the catheters in 2 patients in this study were adjusted intraoperatively, resulting in improved placement grades (Fig. 3). In one patient, the catheter, which had been placed too deeply into the suprasellar cistern (Grade 3), was withdrawn into a more optimal position in the third ventricle (Grade 1). In another patient, CSF return was not obtained after 2 ventricular catheter passes. The catheter was then left in position and an iCT scan was obtained. Based on the demonstrated trajectory, the catheter was then effectively redirected into the ipsilateral frontal horn (Grade 1). No new symptoms or deficits were related to this intraoperative manipulation. The benefit of iCT scanning is that it can identify suboptimal placement that can be fixed while the patient is still in the operating room. A suboptimal shunt placement is more likely to be accepted if it is discovered on a postoperative CT study, as opposed to an iCT study, rather than returning the patient to the operating room for correction, as doing so is often viewed negatively. In these situations, iCT can result in improved shunt placement grades and better long-term shunt survival rates.

Study Limitations

The limitations of this study include its retrospective nonrandomized nature, limited size, and lack of long-term outcomes. The operative decision making was not uniform as the operative technique was at the discretion of the treating neurosurgeon. There was some overlap in the techniques used, limiting the strength of our statistical analysis. In coordination with a statistician, attempts were made to best delineate the effects of each of the operative techniques.

Conclusions

Our results suggest that the use of the NeuroPEN Neuroendoscope alone and then confirmed by iCT results in precise and accurate ventricular catheter placement in undersized ventricles, such as in IIH. This combination may avoid the additional cost and time in the operating room that accompanies the use of frameless stereotaxy. This is the first reported study investigating the efficacy of iCT for shunt placement in this patient population. Long-term outcome analysis as well as a randomized, prospective study is still required.

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5. Curry WT Jr, Butler WE, Barker FG II: Rapidly rising

Disclosures
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
Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: Kenning, Yim, Gooch. Drafting the article: Kenning, Yim, Gooch. Critical revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kenning. Statistical analysis: Kenning. Administrative/technical/material support: Kenning. Study supervision: Kenning.

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