Robotics applications hold great promise for improving clinical outcomes and reducing the complications of surgery. To date, however, there have been few widespread applications of robotic technology in neurosurgery. The authors hypothesized that image-guided robotic placement of a ventriculostomy catheter is safe, highly accurate, and highly reproducible.

Methods. Sixteen patients requiring catheter ventriculostomy for ventriculoperitoneal (VP) shunt or reservoir placement were included in this retrospective study. All patients underwent image-guided robotic placement of a ventricular catheter, using a preoperatively defined trajectory.

Results. All catheters were placed successfully in a single pass. There were no catheter-related hemorrhages and no injuries to adjacent neural structures. The mean distance of the catheter tip from the target was 1.5 mm. The mean operative times were 112 minutes for VP shunt placement and 42.3 minutes for reservoir placement. The mean operative times decreased over the course of the study by 49% for VP shunts and by 19% for reservoir placement.

Conclusions. The robotic placement of a ventriculostomy catheter using a preplanned trajectory is safe, highly accurate, and highly reliable. This makes single-pass ventriculostomy possible in all patients, even in those with very small ventricles, and may permit catheter-based therapies in patients who would otherwise be deemed poor surgical candidates because of ventricle size. Robotic placement also permits careful preoperative study and optimization of the catheter trajectory, which may help minimize the risks to bridging veins and sulcal vessels.

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Abbreviations used in this paper: CT = computed tomography; MR = magnetic resonance; VP = ventriculoperitoneal.
cation (Fig. 1 left). A 3/16-in drill positioned by the insertion guide or, in the first 2 patients, a craniotome perforator drill was used to access the cranial vault. The dura and pia mater were cauterized with monopolar cautery. A standard ventriculostomy catheter was cut to a length prescribed by the planned trajectory and carefully passed, via the carrier, to its intended target using a central stylet. Once clear cerebrospinal fluid was returned, the ventriculostomy catheter was attached to either the valve assembly or a Selker reservoir, and all incisions were closed.

The SurgiScope is a dual-use, robotically driven microscope with 7 degrees of freedom. In microscope mode, the robot’s movements are directly controlled by the operating surgeon. Although “active” in the sense that physical energy for movement is supplied by the robot rather than the surgeon, this function is still constrained by a direct master–slave relationship between the two. In biopsy mode, the robot is given prescribed information about a target and trajectory from preoperative imaging studies. After coregistration, the robot is activated to move a biopsy arm along this prescribed trajectory to the desired target. For our purposes, a Leksell model G carrier unit was attached to this biopsy arm and served as a guide for drilling and catheter passage (Fig. 1 right).

Of the patients who underwent VP shunt placement, 6 received a Codman Hakim precision-fixed medium-pressure valve (Codman, Johnson & Johnson), and 3 received a Codman Hakim programmable valve. A peritoneal terminus was used in all patients who underwent cerebrospinal fluid shunt placement. For patients undergoing reservoir placement, a Selker reservoir (Codman, Johnson & Johnson) was used in all cases.

All patients underwent postoperative head CT scanning within 24 hours of surgery to verify correct ventriculostomy catheter placement. The distance of the catheter tip from the target was determined by direct measurement on the postoperative CT scan. When the target and catheter tip were located on adjacent slices, the distance was calculated as the hypotenuse of a triangle consisting of the horizontal distance (determined from a single axial cut) and the vertical distance (determined from the slice thickness). The patients attended follow-up in the neurosurgery clinic for as long as deemed clinically necessary. For patients who underwent reservoir placement, follow-up involved a single visit 7–10 days postoperatively for suture removal and wound inspection. Patients whose VP shunt placement was uncomplicated were seen 1 month after surgery and on an annual or semiannual basis thereafter. One patient from out-of-state received his follow-up with a local neurosurgeon; this patient was contacted by telephone and reported no complications of VP shunting.

Patient Selection

The only criteria for inclusion in this study were: 1) an appropriate indication for VP shunt or reservoir placement; and 2) adequate medical status to undergo the operation. In the early stage of patient accrual, robotic ventriculostomy was reserved for patients with normal or small ventricles. However, after the first 3 patients, robotic ventriculostomy was used in all patients regardless of ventricle size. Preoperative patient characteristics are detailed in Table 1. The median patient age was 44 years. Nine (56%) of 16 patients were women. Ten (63%) of 16 had undergone a previous surgery for their condition; 6 (38%) had undergone prior cranial neurosurgery for their condition. The median American Society of Anesthesiologist class was 3 (range 2–4).

The preoperative frontal horn width was measured from CT scans or MR imaging in all patients. Measurements were taken at the site of maximal thickness of the frontal horn ipsilateral to surgery, perpendicular to the axis of the frontal horn itself. Median ipsilateral preoperative frontal horn thickness was 5 mm (range 1–16 mm).

Results

All ventricular catheters were successfully placed with a single pass. All catheters entered the targeted structure, and no catheter intruded on adjacent parenchyma (Figs. 2 and

![Fig. 1. Left: Photograph of the SurgiScope robot with biopsy arm attachment. Right: Close-up view of the biopsy arm with Leksell model G insertion guide attached. A probe has been substituted for the ventricular catheter.](image-url)
Robotic catheter ventriculostomy

### TABLE 1

Summary of preoperative characteristics and postoperative outcomes in 16 patients*

<table>
<thead>
<tr>
<th>Case No</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Type of Surgery</th>
<th>Frontal Horn Width (mm), Modality</th>
<th>Distance From Target (mm), Modality</th>
<th>Time in OR (min)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>F</td>
<td>pseudotumor cerebri</td>
<td>VP shunt</td>
<td>3, CT</td>
<td>7, CT</td>
<td>132</td>
<td>persistent headache</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>F</td>
<td>perilymphatic fistula</td>
<td>VP shunt</td>
<td>4, MR</td>
<td>0, CT</td>
<td>107</td>
<td>imbalance improved</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>F</td>
<td>pseudotumor cerebri</td>
<td>VP shunt</td>
<td>1, CT</td>
<td>0, CT</td>
<td>188</td>
<td>headache improved</td>
</tr>
<tr>
<td>4</td>
<td>66</td>
<td>M</td>
<td>CNS lymphoma</td>
<td>Selker reservoir</td>
<td>12, MR</td>
<td>3, CT</td>
<td>32</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
<td>F</td>
<td>pseudotumor cerebri</td>
<td>VP shunt</td>
<td>5, MR</td>
<td>9, CT</td>
<td>130</td>
<td>headache resolved</td>
</tr>
<tr>
<td>6</td>
<td>69</td>
<td>F</td>
<td>CNS lymphoma</td>
<td>Selker reservoir</td>
<td>16, MR</td>
<td>0, CT</td>
<td>55</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>7</td>
<td>71</td>
<td>F</td>
<td>CNS lymphoma</td>
<td>Selker reservoir</td>
<td>2, MR</td>
<td>0, CT</td>
<td>48</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>8</td>
<td>44</td>
<td>M</td>
<td>Burkitt lymphoma</td>
<td>Selker reservoir</td>
<td>2, MR</td>
<td>0, CT</td>
<td>52</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>9</td>
<td>60</td>
<td>M</td>
<td>glioma</td>
<td>concurrent bilat VP shunt placement &amp; stereotactic biopsy</td>
<td>12, MR</td>
<td>0, CT</td>
<td>135</td>
<td>headache resolved</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>F</td>
<td>pseudotumor cerebri</td>
<td>VP shunt</td>
<td>3, MR</td>
<td>0, CT</td>
<td>95</td>
<td>improved headache, diplopia resolved</td>
</tr>
<tr>
<td>11</td>
<td>29</td>
<td>M</td>
<td>posterior fossa hemorrhage, hydrocephalus</td>
<td>VP shunt</td>
<td>8, CT</td>
<td>5, CT</td>
<td>56</td>
<td>persistent headache</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>F</td>
<td>Burkitt lymphoma</td>
<td>Selker reservoir</td>
<td>3, MR</td>
<td>0, CT</td>
<td>40</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>13</td>
<td>45</td>
<td>F</td>
<td>mixed glioma, 3rd ventricular cyst</td>
<td>Selker reservoir</td>
<td>2, MR</td>
<td>0, CT</td>
<td>29</td>
<td>Selker reservoir in cyst cavity</td>
</tr>
<tr>
<td>14</td>
<td>57</td>
<td>M</td>
<td>acute lymphoblastic lymphoma</td>
<td>Selker reservoir</td>
<td>8, CT</td>
<td>0, CT</td>
<td>40</td>
<td>intraventricular chemo</td>
</tr>
<tr>
<td>15</td>
<td>47</td>
<td>M</td>
<td>AVM with hemorrhage, hydrocephalus</td>
<td>VP shunt</td>
<td>8, CT</td>
<td>0, CT</td>
<td>102</td>
<td>hydrocephalus resolved, patient died of subsequent rebleeding</td>
</tr>
<tr>
<td>16</td>
<td>22</td>
<td>M</td>
<td>traumatic brain injury, hydrocephalus</td>
<td>VP shunt</td>
<td>14, CT</td>
<td>2, CT</td>
<td>59</td>
<td>hydrocephalus resolved</td>
</tr>
</tbody>
</table>

* AVM = arteriovenous malformation; chemo = chemotherapy; CNS = central nervous system; OR = operating room.

3). No catheter-related hemorrhages were evident on routine postoperative head CT scanning. Data regarding distance of catheter tip from target, operative time, and clinical outcome are detailed in Table 1. The mean distance of the catheter tip from the target was 1.5 ± 2.8 mm. (All mean values are presented ± standard deviations.) In 2 patients who underwent right frontal VP shunt placement, the catheter tip was greater than 5 mm from the target; in both of these patients, the actual catheter trajectory traversed the target and the error was attributable to an oversized catheter. In both cases, the position of the catheter tip in the superior third ventricle was deemed an acceptable placement. The mean operative times were 112 ± 41 minutes for VP shunt placement (including a single bilateral procedure), and 42.3 ± 9.8 minutes for reservoir placement. Operative times generally decreased over the course of the series. The mean operative time for the first 3 VP shunt placements was 142 ± 41.5 minutes, and for the last 3 was 72.3 ± 25.7 minutes. In the first 3 reservoir placements, the mean operative time was 45.0 ± 11.8 minutes, which was reduced to a mean of 36.3 ± 6.4 minutes for the last 3 placements. The operative goal was achieved in all patients. All patients who underwent shunt placement demonstrated improvement in hydrocephalus. All patients who received reservoirs for intraventricular therapy underwent planned intraventricular chemotherapy. One patient underwent successful reservoir placement in a third ventricular cyst for possible aspiration of the cyst at a later date.

One patient died 17 days after VP shunt placement of postoperative head CT scanning. Data regarding distance of catheter tip from target, operative time, and clinical outcome are detailed in Table 1. The mean distance of the catheter tip from the target was 1.5 ± 2.8 mm. (All mean values are presented ± standard deviations.) In 2 patients who underwent right frontal VP shunt placement, the catheter tip was greater than 5 mm from the target; in both of these patients, the actual catheter trajectory traversed the target and the error was attributable to an oversized catheter. In both cases, the position of the catheter tip in the superior third ventricle was deemed an acceptable placement. The mean operative times were 112 ± 41 minutes for VP shunt placement (including a single bilateral procedure), and 42.3 ± 9.8 minutes for reservoir placement. Operative times generally decreased over the course of the series. The mean operative time for the first 3 VP shunt placements was 142 ± 41.5 minutes, and for the last 3 was 72.3 ± 25.7 minutes. In the first 3 reservoir placements, the mean operative time was 45.0 ± 11.8 minutes, which was reduced to a mean of 36.3 ± 6.4 minutes for the last 3 placements. The operative goal was achieved in all patients. All patients who underwent shunt placement demonstrated improvement in hydrocephalus. All patients who received reservoirs for intraventricular therapy underwent planned intraventricular chemotherapy. One patient underwent successful reservoir placement in a third ventricular cyst for possible aspiration of the cyst at a later date.

In the present study we demonstrate the safe use of an image-guided neurosurgical robot for ventriculostomy catheter placement in a single pass, even in patients with small ventricles. Our patient population included patients with a variety of diagnoses and some variation in ventricular size; 9 (56%) of 16 patients had a ventricular diameter of 5 mm or less. Data in the literature regarding number of passes to cannulate the ventricle are sparse and highly confounded by the indications for the procedure. One study of bedside ventriculostomies performed by neurosurgeons residents described a mean of 1.5 freehand passes; 53% of the patients in the study had hydrocephalus, and only 12% had slit ventricles. A more recent study of nonrobotic, image-guided catheter ventriculostomy in 36 patients with pseudotumor cerebri described a 10% incidence of multiple passes.

The robotic technique permits preoperative selection and examination of a single catheter trajectory. Using conventional triplanar images as well as reconstructed planes perpendicular to and along the trajectory, the operator can plan the precise entry and target points before commencing the operation. Once the trajectory is chosen, it can be inspected for proximate hazards using the probe view. On multiple occasions in the present study, an initial trajectory was modified during the preoperative planning process when a...
survey of the probe view revealed a previously unappreciated vessel or sulcus. Although nonrobotic image-guidance systems permit entry point selection and trajectory selection, the choice of trajectory requires the iterative, freehand manipulation of a stereotactic probe during the surgical procedure. It is not clear whether the same in-depth study of a given trajectory is possible under these circumstances. We believe that the careful study and review of a surgical plan at a workstation before the operation begins is invaluable in identifying and minimizing all possible hazards—the principal benefit of the robotic technique. Other advantages include stability of the guide and ease of use, along with all the advantages of a conventional image-guidance system.

This study is not designed or powered to demonstrate reduction in the rate of catheter-related hemorrhages; however, this series compares favorably with existing literature, which estimates an acute catheter-related hemorrhage rate between 0.4 and 4%.

One study of 107 Ommaya reservoir placements in which routine postoperative CT scans were obtained documented a hemorrhage rate of 2.8%. In the present study, all patients underwent postoperative CT scanning and no acute catheter-related hemorrhages were identified.

Disadvantages of the current technique relate principally to extended preoperative planning and operative time and increased cost. Although no control group is available for direct comparison, the mean operative times of 112 minutes for VP shunting, and 42 minutes for reservoir placement are probably longer than most nonrobotic surgeries. Additionally, the operative time reflects only time spent in surgery and does not incorporate time spent loading im-
aging data, coregistering the patient, and planning the trajectory. Nevertheless, the data reflects an ongoing learning curve on the part of surgeons, with a 49% reduction in operative time for VP shunt placement, and a 19% reduction in the operative time for reservoir placement over the course of the study. Thus, the true presurgical and surgical times of robotic catheter ventriculostomy for a practiced surgical team have yet to be defined. Cost is a variable that is more difficult to quantify. The bulk of the cost associated with a surgical robot resides in the initial capital investment, not its day-to-day usage, and therefore must be amortized over the lifetime of the robot.

The quantitative assessment of error in this study is somewhat limited by the slice thickness of a standard 5-mm axial CT scan. In 3 patients, the catheter tip was visible on a CT slice adjacent to the slice demonstrating the foramina of Monro. When this occurred, the vertical component of the error was assumed to be 5 mm; however, because each slice represents a collapsed view of a 5-mm slab, the true vertical distance between the foramen of Monro and the catheter tip cannot be known.

Our use of a robot for identification of the catheter trajectory is a relatively simple application of robotics to neurosurgery; indeed, the first recorded medical application of a robot to surgery was Kwoh and colleagues’ use of a Puma 560 industrial robot (Advance Research and Robotics) to define the trajectory of a frame-based biopsy. In the 2 decades since, the field has experienced rapid growth.
In the 1980s and 1990s, there were a number of experiences with relatively large-scale robots in stereotactic, image-guided procedures. Among these were the experiences in Grenoble, the Minerva project, and the application of an industrial robot to tumor retraction during resection of thalamic astrocytomas. Subsequent efforts have focused not only on refinement of stereotactic technology, but also the addition of telemanipulation, force-control and haptics, endoscopy, microtechnology, and radiosurgical applications. Through the refinement and synthesis of these various technologies, neuroroboticists hope to offer practical improvements in surgical efficacy with reductions in surgical risk and invasiveness. As surgical robots gain widespread acceptance among members of the medical community and the public, and as their applications are expanded, it is likely that cheaper and more time-efficient robots will be integrated into the common practice of neurosurgery.

**Conclusions**

Robotic placement of a ventriculostomy catheter using a preplanned trajectory is feasible, highly accurate, and highly reliable. This makes single-pass ventriculostomy possible in all patients, even those with very small ventricles, and may thus permit catheter-based therapies in patients who would otherwise be deemed poor surgical candidates because of small ventricle size. Robotic placement also permits careful preoperative study and optimization of the catheter trajectory, with special attention to hazards such as bridging veins and sulcal vessels.

**References**


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