Comparison of endoscope- versus microscope-assisted resection of deep-seated intracranial lesions using a minimally invasive port retractor system

Christopher S. Hong, BA, Daniel M. Prevedello, MD, and J. Bradley Elder, MD

OBJECTIVE Tubular brain retractors may improve access to deep-seated brain lesions while potentially reducing the risks of collateral neurological injury associated with standard microsurgical approaches. Here, microscope-assisted resection of lesions using tubular retractors is assessed to determine if it is superior to endoscope-assisted surgery due to the technological advancements associated with modern tubular ports and surgical microscopes.

METHODS Following institutional approval of the tubular port, data obtained from the initial 20 patients to undergo transportal resection of deep-seated brain lesions were analyzed in this study. The pathological entities of the resected tissues included metastatic tumors (8 patients), glioma (7), meningoima (1), neurocytoma (1), radiation necrosis (1), primitive neuroectodermal tumor (1), and hemangioblastoma (1). Surgery incorporated endoscopic (5 patients) or microscopic (15) assistance. The locations included the basal ganglia (11 patients), cerebellum (4), frontal lobe (2), temporal lobe (2), and parietal lobe (1). Cases were reviewed for neurological outcomes, extent of resection (EOR), and complications.

RESULTS EOR was considered total in 14 (70%), near total (> 95%) in 4 (20%), and subtotal (< 90%) in 2 (10%) of 20 patients. Incomplete resection was associated with the basal ganglia location (p < 0.05) and use of the endoscope (p < 0.002). Four of 5 (80%) endoscope-assisted cases were near-total (2) or subtotal (2) resection. Histopathological diagnosis, presenting neurological symptoms, and demographics were not associated with EOR. Complication rates were low and similar between groups.

CONCLUSIONS Initial experience with tubular retractors favors use of the microscope rather than the endoscope due to a wider and 3D field of view. Improved microscope optics and tubular retractor design allows for binocular vision with improved lighting for the resection of deep-seated brain lesions.

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KEY WORDS minimally invasive; tubular retractor; port retractor; operative microscope; endoscope; diagnostic and operative techniques

Since the first use of the operative microscope over 50 years ago, microsurgery has evolved into an indispensable technique in neurosurgery. In any surgical procedure, adequate visualization of the operative field is paramount for the surgeon. Traditionally, surgeons have employed “retractor” devices to create and maintain a visual corridor in order to access deep-seated lesions. Within neurosurgery, those designed for intracranial use include the well-known Greenberg, Leyla, and Budde Halo retractor systems. Like other highly sensitive tissues, the brain is prone to injury from the prolonged and excessive pressures that are potentially imposed by the retractor devices. Particularly, during approaches to deep-seated intracranial lesions, the surrounding white matter that comprises the surgical corridor is vulnerable to retractor-induced insult. The mechanism of injury is thought to be excessively prolonged compression of the cerebral vasculature, thereby inducing ischemia in the normally perfused brain tissue. To avoid this, pharmaceutical agents like mannitol, nimodipine, and corticosteroids are widely used to protect against ischemic injury, both from retraction and other etiologies like cerebral edema and hemorrhage. The technical aspects of the retractor systems—such as stereotactic frame systems, the Leyla flexible retractor arm, and cylindrical-shaped retractors, the latter of which is the basis of this study—have also advanced considerably and thereby reduced retractor-induced injury.
VICES was modeled after the curves of the gynecological speculum.17 These first tubular retractors introduced the concept of safely dilating the brain with progressively larger cylinders, creating a surgical corridor to access deep lesions. This design has since been commonly referred to as a tubular retractor. A novel feature of this original retractor design is its compatibility with stereotactic frame systems as both a fixed stereotactic reference point and as a retractor.16,17 Modified versions of this original design have gained wide use in spinal surgeries performed using a minimally invasive approach to repair herniated discs, vertebral interbody fusions, and decompression of spinal stenosis, among other conditions.2,10,19,29 Although the tubular brain retractor was introduced more than 3 decades ago, these devices have only recently gained ground as a tool to access deep-seated brain lesions. To date, most of the literature regarding the tubular retractors used in brain surgery is comprised of individual case reports that describe the successful resection of deep-seated lesions such as thalamic pilocytic astrocytomas, colloid cysts in the third ventricle, hematomas, and cavernous angiomas.5,18,25,27,28,35 Recently, Vycor Medical Inc. developed a new tubular retractor designed specifically for intracranial use, which is called the Viewsite Brain Access System and referred to in this study as the port. Unlike the original tubular retractor, the port is fully transparent, allows visualization of the entire surgical corridor, and is compatible with the majority of current frameless neuronavigation systems.

While a few recent case series have documented surgical experiences with the port, there have been no reports thus far comparing endoscope-assisted to microscope-assisted port procedures in regards to operative outcomes. Comparisons between the 2 modalities have been a topic of debate in other areas of interest, including approaches to the sella turcica, cerebellopontine angle, and posterior fossa.14,22,30,34 Previous reports on the port technique have documented visualization with multiple modalities, suggesting that intraoperative visualization is largely dependent on surgeon preference. The initial use of the port at our institution was evenly split between microscope-assisted surgery and endoscope-assisted surgery. However, we now exclusively use the microscope during surgery with the port because our initial experience led us to the belief that microscope-assisted surgery held definitive advantages over the endoscope when utilizing the port as the surgical corridor. With this study, we aimed to validate our impressions by retrospectively comparing surgical outcomes after port surgery using the endoscope or microscope. We also evaluated the literature and present our findings with the intent to optimize successful application of the port.

Methods

Twenty consecutive patients were identified who underwent the resection of a deep-seated brain lesion located within the basal ganglia, thalamus, cerebellum, or deep cortical lobes using the port between September 2010 and April 2011 at The Ohio State University Wexner Medical Center. The collected data included patient demographics, anatomic location of the lesion, and postoperative neuro-logical outcomes. Extent of resection (EOR) was determined based on routine postoperative MRI performed within 24 hours after surgery. Postoperative T1-weighted images with diffusion restriction and T2-weighted FLAIR images were used to evaluate ischemic injury in the normal brain and the regression of surgical edema at 2 or more months after surgery. Gross-total resection (GTR) was defined as the resection of 100% of the target lesion, near-total resection (NTR) as greater than 95% but not 100% volumetric reduction of the lesion, and subtotal resection (STR) as less than 95% resection on postoperative MRI.

Statistics were calculated using GraphPad Prism 6 (GraphPad Software, Inc.). The p values were calculated using the Fisher exact test for retrospective data analyses.

Technical Data

The Viewsite Brain Access System (Vycor Medical Inc.) was used for surgical access in all patients. The retractor is available in 4 widths at the distal opening (12 mm, 17 mm, 21 mm, and 28 mm) and 3 lengths (3 cm, 5 cm, and 7 cm). Construction with transparent plastic allows for intraoperative visualization of the surrounding brain traversing the entire depth of the port. The system consists of an introducer and working channel port that can be inserted while distributing the brain tissue evenly in a 360° dispersion pattern. The attachment flange is compatible with most surgical arms in order to facilitate secure fixation of the port during surgery. All cases presented in this manuscript were operated on using the 12-mm retractor. In some cases, the 17-mm retractor was substituted later in the surgery to increase visualization. The retractors with 21-mm or 28-mm widths were never used in this series.

The OPMI Pentero 900 (Carl Zeiss Meditec AG) microscope was used for microscopic visualization of the surgical bed during port surgery, and the technical specifications of the microscope were evaluated for their potential impact on intraoperative visualization. For example, an integrated, electronically controlled, double-iris diaphragm offered a choice between maximum light and resolution or depth of field, which could be tailored to the specific size of the port being used. A 2-channel illumination design reduced shadowing in the deep cavities, primarily provided illumination of the field of interest, and automatically limited brightness to prevent inadvertent light exposure.

Endoscopic dissections were performed using 0°, 30°, and 45° Hopkins II rod-lens endoscopes (Karl Storz Endoscopy) measuring 4 mm × 18 cm. The endoscope was connected to a light source through a fiber optic cable and a camera fitted with 3 charge-couple device sensors. The endoscope system consisted of an endoscope, a working sheath, and an obturator, all of which were easily accommodated by the port and still permitted the bimanual technique. There was excellent illumination of the surgical field by virtue of the endoscope’s proximity to the anatomical structures. Wide-angle optics from the Hopkins II rod-lens provided high-resolution images. The availability of multiple-angle endoscopes facilitated the examination of areas that would be otherwise obscured from the operative microscope or the naked eye.
Port Technique

There are a number of ways a tubular retractor can be used, and surgeons familiar with the port likely have unique nuances to their surgical techniques. For deep-seated intraaxial brain tumors, we employ the following general techniques at our institution. Preoperative imaging is used to select the optimal trajectory toward the tumor that minimizes transgression of the eloquent areas of the brain, avoids ventricles, and optimizes visualization of the tumor. A curvilinear incision that provides sufficient access for a 3 × 3–cm craniotomy is performed. After bone flap removal and dural opening, the best entry point is determined either on a gyrus or through a sulcus. For the sylvian approach, the initial superficial portion of the pathway is dissected under the microscope to approximately 1.5 cm wide and all the way down to its fundus, where a linear opening is performed and any vessel that could be present is avoided. For approach through a gyrus, a 1.5-cm linear pial incision is performed and then dissected bluntly for up to 2 cm in depth to provide an initial dissection for the port. The navigation wand is secured within the port using navigation guidance. The navigation wand and cannula of the port are removed, and the port is secured to a snake retractor arm which is locked to a Mayfield head clamp. At this point, either the microscope or endoscope is used to visualize and remove the tumor through the port. The length of the port is selected by measuring the distance from the surface of the brain to the far edge of the tumor. The smallest diameter port (12 mm) is always used initially. After debulking the tumor, if a larger diameter port is felt to be useful then the small-diameter port is exchanged for a port that is 1 size larger (17 mm). Further increases in port size during surgery have not been necessary. The angulation of the port can be altered as often as necessary during the procedure. Typically, small changes are made in angulation with the surface of the brain serving as the “fulcrum” for these changes. After removing the tumor, hemostasis within the resection cavity is achieved using standard techniques. The port is removed, and hemostasis along the wall of the trajectory is confirmed. Closure then proceeds per standard techniques.

Technique

Case Illustration 1

A 61-year-old male patient presented at our institution due to new-onset seizures. He was found to have moderate expressive aphasia and right-sided hemiparesis (Table 1; Case 14). Preoperative MRI demonstrated multiple small lesions and 1 dominant, symptomatic, heterogeneously enhancing lesion measuring 2.8 × 2.4 cm with significant vasogenic edema involving the left parietooccipital region (Fig. 1A). The patient had been recently diagnosed with cutaneous melanoma, and, therefore, these brain lesions were highly suspicious of melanoma metastases. Given the size of the dominant lesion and the patient’s clinical symptoms, resection was recommended as the initial management, to be followed by adjuvant radiation. The patient underwent left parietal craniotomy and minimally invasive microscope-assisted transportal surgery for GTR of the dominant lesion. A 3 × 3–cm craniotomy was performed and a 1-cm linear opening was made in the pia of 1 gyrus. The port was inserted via this pial opening to the surface of the tumor using navigation guidance (Fig. 2) and attached to a retractor arm to maintain positioning. The microscope was then used to visualize and remove the tumor at the depth of the port. Immediate postoperative imaging demonstrated GTR with minimal evidence of the surgical corridor (Fig. 1B and C). There were no complications associated with the surgery, and the patient subsequently received adjuvant radiation and chemotherapy. The final pathology was metastatic melanoma. At the 3-month follow-up visit, the patient’s presenting neurological symptoms had resolved. Diffusion-weighted MRI at that time demonstrated no evidence of recurrent tumor or postsurgical ischemic injury and only minimal residual edema (Fig. 1D and E).

Case Illustration 2

A 74-year-old female patient with a known history of Stage III ovarian cancer developed new-onset slurred speech (Case 13). Subsequently, brain MRI was performed, which demonstrated a heterogeneously enhancing mass centered in the right thalamus, measuring 2.7 cm × 2.5 cm, and extending into the lateral portion of the right thalamus (Fig. 3A). After discussion with the patient and neuro-oncology tumor board, the patient was taken to the operating room for GTR of her single lesion via microscope-assisted port surgery. Navigation to the tumor bed and placement of the port were performed similarly to that described for Case Illustration 1, with the exception that intraoperative brain mapping was performed to identify the central sulcus and avoid injury to the surrounding eloquent structures. After proper positioning, the port was locked into place using the Greenberg retractor system. Under microscopic visualization, central debulking of the tumor proceeded with tumor forceps in a piecemeal fashion. Given the spongy nature of the tumor, minute resections of the port encouraged the tumor tissue to come into view within the port lumen. This technique yielded efficient resection of the tumor without compromising the normal brain tissue and is depicted in detail in Fig. 4, as well as Video 1.

VIDEO 1. We demonstrate a minimally invasive neurosurgical approach utilizing a transparent, tubular, port retractor (Vycor Medical Inc.) with microscopic visualization. The index patient is a 74-year-old female with suspected brain metastasis to the right basal ganglia from Stage III ovarian cancer. Accurate guidance of the port to the target of interest is shown utilizing a neuronavigation probe placed within the confines of the 12-mm × 7-cm port. There is adequate room within the port for manipulation of at least 2 instruments, such as the illustrated suction tip and tumor forceps. The ease of repositioning the port is also demonstrated, which encourages additional tumor tissue to appear within the operative field. Postoperative MRI showed GTR with evidence of a minimal surgical corridor on T2-weighted MRI and no diffusion restriction, indicative of ischemic injury. Copyright J. Bradley Elder. Published with permission. Click here to view with Media Player. Click here to view with Quicktime.

Final pathology confirmed metastatic ovarian cancer. Immediate postoperative MRI demonstrated GTR of the
TABLE 1. Patient characteristics and outcomes

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yrs), Sex</th>
<th>Pathology</th>
<th>Location</th>
<th>Presenting Symptoms</th>
<th>EOR or Endoscope</th>
<th>Size of Ports Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75, M</td>
<td>Metastasis (lung)</td>
<td>Rt cerebellum</td>
<td>Ataxia</td>
<td>GTR</td>
<td>Microscope 12 mm × 7 cm</td>
</tr>
<tr>
<td>2</td>
<td>37, F</td>
<td>GBM</td>
<td>Rt cerebellum</td>
<td>Ataxia</td>
<td>NTR Endoscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>24, M</td>
<td>Neurocytoma</td>
<td>Rt basal ganglia</td>
<td>Altered mental status</td>
<td>STR Endoscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>50, M</td>
<td>PNET</td>
<td>Lt frontal</td>
<td>Headaches, nausea, vomiting</td>
<td>STR Endoscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>59, F</td>
<td>GBM</td>
<td>Rt basal ganglia</td>
<td>Asymptomatic</td>
<td>NTR Endoscope 12 mm × 7 cm; 17 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>57, F</td>
<td>GBM</td>
<td>Lt basal ganglia</td>
<td>Seizures</td>
<td>NTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>64, F</td>
<td>Hemangioblastoma</td>
<td>Lt cerebellum</td>
<td>Headaches, nausea, vomiting</td>
<td>GTR Microscope 12 mm × 5 cm; 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>63, M</td>
<td>Metastasis (lung)</td>
<td>Lt basal ganglia</td>
<td>Altered mental status, visual changes</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>41, M</td>
<td>Astrocytoma (fibillary)</td>
<td>Rt temporal</td>
<td>Seizures</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
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<tr>
<td>10</td>
<td>62, M</td>
<td>Metastasis (lung)</td>
<td>Lt frontal</td>
<td>Rt arm weakness</td>
<td>GTR Microscope 12 mm × 5 cm</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>86, F</td>
<td>Metastasis (lung)</td>
<td>Lt cerebellum</td>
<td>Ataxia</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>62, M</td>
<td>GBM</td>
<td>Rt tempo-occipital</td>
<td>Headache, nausea, vomiting</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>74, F</td>
<td>Metastasis (ovarian)</td>
<td>Rt basal ganglia</td>
<td>Lt side weakness, dysarthria</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
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<tr>
<td>14</td>
<td>61, M</td>
<td>Metastasis (melanoma)</td>
<td>Rt parietal</td>
<td>Seizures, aphasia</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>53, F</td>
<td>Meningioma</td>
<td>Lt basal ganglia</td>
<td>Headache, nausea, vomiting</td>
<td>GTR Microscope 12 mm × 7 cm; 17 mm × 7 cm</td>
<td></td>
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<tr>
<td>16</td>
<td>24, M</td>
<td>GBM</td>
<td>Rt basal ganglia, thalamus</td>
<td>Altered mental status</td>
<td>NTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>31, M</td>
<td>Metastasis (melanoma)</td>
<td>Lt basal ganglia</td>
<td>Headache, nausea, vomiting</td>
<td>GTR Microscope 12 mm × 7 cm; 17 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>65, M</td>
<td>GBM</td>
<td>Lt basal ganglia</td>
<td>Rt side weakness</td>
<td>GTR Microscope 12 mm × 5 cm; 12 mm × 7 cm; 17 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>73, F</td>
<td>GBM</td>
<td>Rt basal ganglia</td>
<td>Seizure</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>24, M</td>
<td>Radiation necrosis</td>
<td>Rt basal ganglia</td>
<td>Altered mental status</td>
<td>GTR Microscope 12 mm × 7 cm</td>
<td></td>
</tr>
</tbody>
</table>

GBM = glioblastoma multiforme; PNET = primitive neuroectodermal tumor.

lesion without new ischemic changes or complications and only minimal evidence of a surgical corridor (Fig. 3B–D).

Additional Case Illustrations

An additional 8 cases are illustrated (Figs. 5–12). In lieu of providing imaging of all 20 cases, which we felt would be redundant, these additional 8 cases are representative of the spectrum of STR, NTR, and GTR obtained using both endoscopic and microscopic visualization.

Results

GTR was the goal in all 20 patients. EOR was considered GTR in 14 of 20 (70%), NTR (> 95%) in 4 of 20 (20%), and STR (< 90%) in 2 of 20 patients (10%). Incomplete resection was associated with basal ganglia location (p < 0.05) and the use of the endoscope (p < 0.002). Four of 5 (80%) endoscopic cases were NTR (2) or STR (2). Histology, presenting neurological symptoms, and demographics were not associated with EOR. The rates of postoperative complications, including new neurological deficits and MRI evidence of brain injury, were low and similar between groups. These data are outlined in Table 1.

The most common location operated on using the port was the basal ganglia (11 patients), followed by the cerebellum (4), frontal lobe (2), temporal lobe (2), and parietal lobe (1). The final pathology of the resected lesion included metastatic tumors (8 patients), glioma (7), meningioma (1), neurocytoma (1), radiation necrosis (1), primitive neuroectodermal tumor (1), and hemangioblastoma (1). Neurological symptoms at the time of presentation included headache (5 patients), altered mental status (4), seizures (4), ataxia (3), motor weakness (3), visual changes (1), dysarthria (1), and asymptomatic presentation (1).

There were no significant differences in the histology of the resected lesion in the endoscope- versus microscope-assisted cases. The most common histology represented metastasis, which comprised 2 of 5 (40%) endoscope-assisted cases and 6 of 15 (40%) microscope-assisted cases. Likewise, lesion location was represented similarly between endoscope- and microscope-assisted cases. The basal ganglia was the most common site of operation and comprised 2 of 5 (40%) and 9 of 15 (60%) of the endoscope- and microscope-assisted resections, respectively. The location of the lesion within the basal ganglia was
significantly associated with incomplete resection, irrespective of using an endoscope or microscope. Of the 6 cases of incomplete resection (Cases 2, 3, 4, 5, 6, and 16), a significant majority (4 of 6; 66%) involved lesions within the basal ganglia (p < 0.05).

All cases began with use of the 12 mm × 5 cm or 7 cm-sized port. Four cases, all of which involved lesions within the basal ganglia, required the additional use of a larger diameter 17-mm port (Cases 5, 15, 17, and 18). GTR was achieved in 3 of these 4 cases. The lone case with NTR involved endoscopic visualization through the port (Case 5).

Discussion

At our institution, we initially performed port surgery utilizing both the microscope and endoscope. In addition to extensive use of the microscope in nonport procedures, we have extensive experience using the endoscope for minimally invasive, transnasal approaches to the anterior skull base, which we have described in the past.6,15,30 We also detailed the endoscopic port technique in a 2-case series: 1 resection of a third ventricular colloid cyst, and 1 resection of parenchymal brain metastasis.23 Briefly, we use the microscope to assist traversing the depth of the sulcus, after which we proceeded with cannulation and endoscopic visualization through the port. We found that a 4-mm rigid endoscope and 2 instruments could ade-

FIG. 1. Case 14. Microscopic transportal GTR of melanoma metastasis. Preoperative axial T1-weighted MR image (A) after Gd contrast administration demonstrates a left parietal metastasis from melanoma with significant vasogenic edema. Axial T1- (B) and T2-weighted (C) images after Gd contrast administration obtained 1 day after surgery demonstrate complete resection with a minimal surgical corridor and expected postoperative FLAIR changes. Axial T2- (D) and diffusion-weighted (E) images demonstrate the significant reduction of surgical edema and no evidence of ischemia along the surgical corridor 2 months after surgery.

FIG. 2. Vycor port with Stryker navigation wand embedded in bone wax (inset, top left), which allows for navigation guidance of the port into the tumor, as depicted on the navigation screen to the right of the surgeon. Once the port has achieved the desired position, either the endoscope or microscope can be used for tumor resection via the port. Figure is available in color online only.
c. S. hong, d. m. prevedello, and j. b. elder

quately fit through the port cannula, allowing for bimanual surgical techniques. However, the presence of the endoscope inside the port was noted to decrease the freedom of movement of the other instruments, limit fine dissection, and prolong surgery. Our initial impression was that to perform surgery with the microscope using tubular retractors would require larger tubes greater than 20 mm in diameter as originally described by Patrick Kelly. At that time, the rationale for a large tube was based on the optical and lighting physics of the microscope, such that only with a certain minimal port diameter would the surgeon be able to triangulate the vision of both eyes on the depth of the cylinder in order to provide 3D visualization. Based on this assumption, endoscopic assistance was thought to be the optimal choice for minimally invasive port-assisted surgery using smaller diameter ports. However, with recent improvements in microscope technology, the possibility of stereoscopic visualization through narrow spaces became possible, conferring the potential advantage for microscope-assisted port surgery. Without an endoscope occupying the space inside the port, the freedom of movement increases and adequate visualization is possible with modern microscopes. It is important to mention that, for specific cases, it is certainly possible to use the endoscope at the end of the resection through the port to inspect the final cavity and confirm total resection. This technique may be particularly helpful when resecting intraventricular tumors.

Noting the advantages of microscopic visualization, we started to exclusively use the microscope during port surgery and performed the current retrospective analysis to evaluate our hypothesis. All of the data in this report stem from our initial 8 months of performing port surgery in order to limit the learning curve as a confounding factor. Our results suggest that incomplete resection of target lesions was significantly associated with endoscope-assisted visualization during port surgery and that microscope-assisted visualization afforded higher rates of total resection. Similarly, other groups have described successful results using the microscope with the port to resect lesions. Herrera et al. described 10 patients undergoing microscope-assisted resection of brain tumors with the port. They reported GTR in all but 1 patient. Similarly, Raza et al. achieved total resection with microscope-assisted port surgery in 6 of 7 patients, as well as 2 additional patients undergoing biopsy. Similar to our first case illustration (Case 14), these authors presented postoperative diffusion-weighted MRI to demonstrate minimal ischemic injury to the normal brain parenchyma after microscope-assisted port surgery. Lastly, in a case series of 4 patients, Recinos et al. documented the successful use of port surgery with the microscope in a pediatric population. Total resection was achieved in 2 of 4 patients, both of whom had deep-seated gliomas. Our data builds on these prior reports by providing results for a different range of pathological entities and comparing the results to an alternative technique for visualization using the port.

Our data also indicate that STR was more commonly achieved with lesions located deep within the basal gan-

FIG. 3. Case 13. Microscopic transportal GTR of ovarian cancer metastasis. Preoperative axial T1-weighted image (A) after Gd contrast administration demonstrates a heterogeneously enhancing metastatic lesion deep within the right basal ganglia. Axial T1-weighted image after Gd contrast administration (B) and axial T2-weighted FLAIR image (C) obtained 1 day after surgery showing total resection of the lesion and decompression of the ventricles. Postoperative coronal T1-weighted image (D) after Gd contrast administration demonstrates a minimal surgical corridor (white arrow).

FIG. 4. An intraoperative photograph of a 12-mm (width) × 7-cm (length) Vycor port maintaining the surgical corridor. Cotton is seen within the port. The port is attached to a flexible snake-arm retractor allowing for self-retaining but easily adjustable retraction during surgery. The normal brain is readily seen through the transparent walls of the port (arrowhead) and is evenly distributed along the rounded edges of the port (left-pointing arrow). Minute retractions of the port encourage spongy tumor tissue to emerge into view (right-pointing arrow). Figure is available in color online only.
Among the aforementioned studies, incomplete resection associated with the basal ganglia location was described in a 10-year-old male patient who had NTR of a dysembryoplastic neuroepithelial tumor. Likewise, STR was documented in 3 adult patients with gliomas, although the locations of their lesions were not reported. These cases all involved visualization with loupe magnification, suggesting that port surgery with loupes may lead to suboptimal surgical outcomes. Interestingly, among the 2 reported cases of microscopic port surgery for papillary tumors within the pineal region, neither achieved GTR. Furthermore, 1 patient, a 15-month-old male, developed an aqueductal hematoma that caused hydrocephalus, although this clot was successfully removed via the port with minimal gross injury to the brain parenchyma. Although no further details were given, one possibility is that the port may be too bulky of a structure to access the pineal region via a typical midline infratentorial-supracerebellar approach. This is supported by the fact that both patients had evidence of adverse FLAIR changes and diffusion restriction on postoperative MRI.

The results presented in this study indicate 3 major advantages that the microscope confers over the endoscope during port surgery. First, the microscope allows a binocular 3D impression of the surgical field, which facilitates accurate and efficient manipulation of the surgical instruments. In support of this notion, compared with traditional 2D endoscopic views, newer 3D endoscopes reduce operating times and shorten learning curves. Second, the absence of an endoscope frees up additional space within the port for more instruments. As such, we often perform...
microsurgery with a third assisting hand to provide additional suction or microretraction. Third, the independent positioning of the microscope permits faster and more precise readjustments of the port during surgery. Use of the endoscope requires the removal of the scope prior to port manipulation, which prohibits continued close-up views of the surgical bed during the repositioning of the port. As such, in most circumstances, the microscope is preferable to the endoscope during port surgery. However, certain older microscopes may preclude microscope-assisted port surgery due to a wider aperture distance between each eye, which prevents adequate binocular depth perception through the limited diameter of the port. Current microscopes decrease this width and provide more optimally focused lighting, thereby allowing for clear views of the surgical bed.

When evaluating patients for possible port-assisted surgery, a number of factors are considered. The anatomic location of the tumor and presumed histology are 2 key factors that guide this decision. In general, we found tumors located in the cerebellar hemispheres, deep white matter of the cerebral hemispheres, and basal ganglia to be ideal candidates for port-assisted surgery. Superficial hemispheric lesions (< 3 cm from the surface at the deepest point) can be removed using standard open microsurgical techniques, and the addition of the port is unlikely to confer an advantage. Deep white matter and basal ganglia lesions allow the advantages of the port to be realized, including minimizing collateral tissue damage by evenly distributing the radial retraction of surrounding tissue along the white matter tracts in combination with a minimally sized craniotomy. Imaging such as functional MRI

**FIG. 7.** Case 4. Endoscopic transportal STR of a primitive neuroectodermal tumor. Preoperative sagittal (A) and axial (B) T1-weighted images after Gd contrast administration demonstrate a large lesion within the left frontal lobe. Postoperative axial T1-weighted images pre- (C) and (D) post-Gd contrast administration demonstrate residual enhancement (white arrows). Residual enhancement is further visualized on the postoperative sagittal T1-weighted MR image (E) and demonstrative of STR.

**FIG. 8.** Case 8. Microscopic transportal GTR of lung cancer metastasis. Axial (A) and sagittal (B) T1-weighted images obtained after the administration of the Gd contrast agent demonstrate a lesion within the left basal ganglia. T1-weighted images after Gd contrast administration obtained 1 day after surgery demonstrate GTR. The punctate area of enhancement (white arrows) seen on the axial image (C) represents normal choroid plexus, which is better visualized on the coronal image (D).
and diffusion tensor imaging are commonly used in coordination with standard neuro-navigation MRI to preoperatively plan the entry point and trajectory of the port. This planning is used to determine the appropriate incision and craniotomy. The advantages of the port are somewhat different for cerebellar lesions. The primary advantage of the port for approaching cerebellar tumors is the minimization of the incision and craniotomy, which we have anecdotally found to decrease postoperative pain, although pain was not an outcome evaluated in this study. Preoperative planning for posterior fossa lesions involved developing a trajectory that minimized the length of the aperture while avoiding vascular structures such as the transverse sinus, rather than critical neural structures as with supratentorial approaches. Another difference involved techniques to minimize the risk of cerebrospinal fluid leak, which was less of a concern with supratentorial approaches.

An advantage of microscope-assisted transportal surgery, as described here, in comparison with endoscope-assisted port surgery is the freedom to make small adjustments in the trajectory of the port during surgery in order to visualize various parts of the target lesion. With a fixed endoscope, the endoscope-port apparatus must first be disconnected, readjusted without direct visualization, and then reconnected. With the microscope, small adjustments in the port can be made under direct visualization. This is often either the depth of the port or the trajectory. If the trajectory is adjusted, such as for large tumors or to visualize the walls of the resection cavity, the surface of the brain is typically considered the “fulcrum” during movement with the distal tip of the port moving radially outward from its baseline position. Thus, the distal end of the port moves the greatest distance during any adjustment, which is safest since the tip is typically within the lesion. In reality, the actual movements are small, likely no more than 15° in any direction. Avoiding morbidity when adjusting the port requires preventing translational movement of the proximal aspect of the port across/into the surface of the brain (i.e., keeping the entry point into the brain as the “fulcrum” of any port movements), carefully selecting the entry point through the sulcus near the target or the midpoint of a gyrus, and selecting a trajectory parallel to the white matter tracts while avoiding the eloquent structures as much as possible. We also periodically check the entry point of the port under direct visualization to ensure that brain relaxation during surgery has not negatively impacted positioning.

The presumed histological diagnosis is the other main factor that impacts the decision to use the port to access deep-seated lesions. Histological entities felt to favor the use of the port include tumors with a “soft” or “suckable” consistency, such as many metastatic tumors (e.g., breast cancer and melanoma; Cases 2, 14, and 17) and high-grade gliomas (Cases 5, 6, 12, 16, 18, and 19). Nonneoplastic entities such as hematomas are also amenable to the use of the port, as the soft consistency facilitates the use of the suction instrument to assist with resection and promotes collapse of the surrounding brain around the resection cavity during surgery, thereby minimizing the need for manipulation of the port. Firm tumors, such as meningiomas, recurrent glial tumors with significant scar tissue, or metastatic sarcoma, are more likely to be less amenable to the use of the port due to the difficulty of manipulating these lesions within the aperture of the port. Nevertheless, the utilization of an ultrasonic aspirator and suction cutter device, such as the Nico Myriad, can facilitate the resection of these dense tumors through port access (Cases 15 and 16). Lesions associated with a significant potential for hemorrhage, such as renal cell carcinoma metastases,
Fig. 11. Case 16. Microscopic transportal NTR of glioblastoma multiforme. Preoperative axial (A), coronal (B), and sagittal (C) T1-weighted images after Gd contrast administration demonstrate a lesion within the right basal ganglia and thalamus. Postoperative sagittal (D) and axial (E) T1-weighted images before contrast administration are shown. After contrast administration, axial (F) and coronal (G) images demonstrate residual enhancement (white arrows) suggestive of NTR.

Fig. 12. Case 6. Microscopic transportal NTR of glioblastoma multiforme. Preoperative axial (A) and coronal (B) T1-weighted images after Gd contrast administration demonstrate a lesion within the left basal ganglia. Postoperative axial (C), sagittal (D), and coronal (E) T1-weighted images after contrast administration demonstrate NTR of the lesion and minimal evidence of a surgical corridor. However, residual enhancement (white arrow) is seen on the axial T1-weighted image (F) within the tumor bed.
may present difficulties when using the port, as intrale-
sional piecemeal resection would likely be complicated by
significant bleeding, thereby increasing the difficulty and
time of the surgery through the port. Tumor size was felt
to be less important than histology and anatomical loca-
tion in achieving the successful surgical resection of deep-
seated lesions. Generally, a safe trajectory toward a tumor
with an appropriately soft consistency renders size less im-
portant because the tumor is easily dissected and removed
through the port. Typically, pressure from the surrounding
brain assists with coaxing the peripheral portions of the
tumor toward the central aspects of the visualized cavity,
thereby facilitating removal. Firmer tumors—such as me-
ningiomas, certain gliomas, firmer metastases, and recur-
tent tumors with associated scar tissue and greater size—
may increase the difficulty of achieving total resection or
increase the risks of morbidity due to a greater degree of
manipulation of the port needed to visualize the entire tu-
mor. Soft consistency definitely mitigates size as a factor
in achieving GTR. Future work will be necessary to ac-
curately determine the impact of tumor size on the EOR in
port-assisted surgery.

These considerations were factored into decisions re-
garding how to approach the lesions using the port in this
case series, and we did not have to abort the use of the port
and convert to open surgery or expand craniotomy during
any of the 20 cases reported here. However, for each case,
the surgical field was prepared such that we could easily ex-
and craniotomy for open surgery. One complication that
we did not encounter was herniation of the brain through
limited craniotomy, which was a concern given that many
of the lesions were associated with significant cerebral ede-
ma. This was likely avoided due to the minimal dural open-
ing and careful attention to measures taken prior to surgery,
including positioning and osmotic diuresis.

Future work, which has already begun, will involve prospective assessments of microscope-assisted port sur-
gery to include variables such as length of hospital stay,
postoperative pain, and preoperative variables that influ-
ence the decision to perform a surgical approach, includ-
ing whether to use the port and the chosen trajectory. This
prospective analysis may yield additional factors impor-
tant for transportal surgical planning and lead to the devel-
opment of a classification scheme for deep-seated lesions,
which may be candidates for surgical resection.

Conclusions
A minimally invasive neurosurgical approach using a
transparent tubular port can provide a safe and effective
option for patients with deep-seated brain tumors. Options
for visualization through the port include loupes, endo-
scopic assistance, and microscopic assistance. Using cur-
rent technology, our results show that EOR was improved
with the use of the microscope in comparison with the
endoscope for visualization. The factors underlying the
advantages of the microscope include the 3D field of view,
improved lighting, increased freedom of movements, and
greater efficiency of manipulation during angle readjust-
ments and repositioning. At this point, we have largely
abandoned the endoscope as the main visualization tool
for transportal brain surgery. As such, our findings fur-
ther define the technical considerations for minimally
invasive, transportal resection of intracranial lesions, and
may impact operative decisions in neurosurgical patients.
In the future, further work will be necessary to determine
if additional advancements in surgical field visualization,
such as the use of 2D endoscopes and 3D endoscopes, can
improve on the results of the 2D endoscope and compare
favorably to the microscope.

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Author Contributions
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Supplemental Information
Videos

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