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CLINICAL STUDY

Minimally invasive resection of intracranial lesions using tubular retractors: a large, multi-surgeon, multi-institutional series

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Abstract

Purpose Lesions located in subcortical areas are difficult to safely access. Tubular retractors have been increasingly used successfully with low complication profile to access lesions by minimizing brain retraction trauma and distributing pressure radially. Both binocular operative microscope and monocular exoscope are utilized for lesion visualization through tubular retractors. We present the largest multi-surgeon, multi-institutional series to determine the efficacy and safety profile of a transcortical-transtubular approach for intracranial lesion resections with both microscopic and exoscopic visualization.

Methods We reviewed a multi-surgeon, multi-institutional case series including transcortical-transtubular resection of intracranial lesions using either BrainPath (NICO, Indianapolis, Indiana) or ViewSite Brain Access System (VBAS, Vycor Medical, Boca Raton, Florida) tubular retractors (n = 113).

Results One hundred thirteen transtubular resections for intracranial lesions were performed. Patients presented with a diverse number of pathologies including 25 cavernous hemangiomas (21.2%), 15 colloid cysts (13.3%), 26 GBM (23.0%), two meningiomas (1.8%), 27 metastases (23.9%), 9 gliomas (7.9%) and 9 other lesions (7.9%). Mean lesion depth below the cortical surface was 4.4 cm, and mean lesion size was 2.7 cm. A gross total resection was achieved in 81 (71.7%) cases. Permanent complication rate was 4.4%. One patient (0.8%) experienced one early postoperative seizure (< 1 week postop). No patients experienced late seizures (> 1 week follow-up). Mean post-operative hospitalization length was 4.1 days.

Conclusion Tubular retractors provide a minimally invasive operative corridor for resection of intracranial lesions. They provide an effective tool in the neurosurgical armamentarium to resect subcortical lesions with a low complication profile.

Keywords Tubular retractor · Minimally invasive surgery · Brain tumor · Exoscope · Microsurgery · Neurosurgery

Introduction

The resection of deep-seated brain lesions presents unique operative challenges to the neurosurgeon. The effect of extent of resection on patient outcome and overall survival has been well documented [1–7]. Gross total resection of other lesions is also required to minimize risk of complications such as endocrine dysfunction, hydrocephalus, and memory impairment. Retraction of normal brain parenchyma is often necessary to establish an adequate operative window for visualization of the lesion and surrounding critical vascular structures [8–11]. However, there is a balance between improved visibility and potential damage to surrounding healthy brain tissue. Metal blade retractors have conventionally been used to create surgical corridors for resection of deep-seated lesions, although such retractors may exert focal pressure on the surrounding healthy

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parenchyma causing trauma and infarction which may result in increased morbidity, peri-operative complication, and permanent neurologic deficit [12, 13]. Additionally, the brain can herniate around these retractors and be damaged. Surgeries that require extensive retraction may include resection of deep-seated aneurysms, colloid cysts, cavernous hemangiomas, and primary and metastatic brain tumors. Previous studies have shown that resection of these lesions may be significantly complicated by trauma from retraction [9, 12–15]. Thus, there is a clear need to create a sizeable operating window that will allow clear visualization for resection without damaging local brain tissue or diminishing blood flow.

Tubular retractors present a promising alternative to traditional blade retractors in establishing a surgical corridor. Unlike paddle retractors that exert pressure on a focal point, tubular retractors distribute pressure radially along their circumference. Theoretically, this would decrease the risk of local trauma and minimize vascular disruption and ischemia. A variety of commercial tubular retractor systems are currently available that are unique in material used, malleability, and design. Several of these have been used in the resection of intracranial tumors including colloid cysts, deep-seated gliomas, and cavernous hemangiomas [11, 13, 15–22]. However, most of these studies have been small sample, single-surgeon case series describing the use of tubular retractors in the resection of specific lesions. Small series may also fail to capture less common complications like the risk of seizures with a transcortical approach. Thus, there remains a paucity of data describing the use of tubular retractors in large, heterogeneous patient samples distributed amongst surgeons of variable proficiency.

Previously, we have reported single surgeon case series of the use of tubular retractors to resect cerebral tumors, colloid cysts, and cavernomas [16–18]. Here we present our updated results of a larger, multi-surgeon and multi-institutional cohort of patients. Forty patients included in the current series were included in previously published series [17, 18]. To our knowledge this is the largest multi-surgeon series of tubular retractor-mediated resection of intracranial lesions including primary and secondary brain tumors, colloid cysts, and cavernomas. In addition, we also describe the technicalities of the procedure.

Methods

Patient selection

Between August 2013 to April 2019, all patients that underwent resection of an intracranial lesion with use of a minimally invasive tubular retractor system at the University of Miami Jackson Memorial Hospital, Jackson Memorial Hospital, and Mayo Clinic, Jacksonville were included in this study. Intracranial lesions included were those whose most superficial component had a depth of 1.0 cm or more below the cortical surface that were resected with a tubular retractor. The Institutional Review Board approved the study and due to the retrospective nature of this review the consent process was waived. The electronic medical database was reviewed to identify eligible patients and pertinent clinical data was sourced including age at surgery, lesion depth and size, underlying pathology, tubular retractors used, and outcome data.

Tubular retractors

Several commercially available minimally invasive tubular retractor systems were employed for this study including the BrainPath system (NICO Crop, Indianopolis, Indiana) and the ViewSite Brain Access System (VBAS; Vycor Medical Inc, Boca Raton, Florida). The VBAS retractor was used in 56 cases and the BrainPath system was used in 57 cases.

Retractor technique

Preoperatively, anatomical landmarks are identified and used to avoid damaging eloquent brain areas when establishing retractor trajectory. When necessary, diffusion tensor imaging may be used to avoid damaging essential white matter tracts. The entry point is created through a curvilinear incision and fishhooks and a Leyla bar are used to retract the subsequent skin flap. With the aid of neuronavigation guidance, an approximate 3-cm craniotomy centered along the planned retractor trajectory is made. After dural exposure, a sulcal dissection centered along the established entry point is made whenever possible to minimize the amount of gray matter transgressed (Figs. 1, 2, 3, Video 1). If the trajectory is prohibited by venous anatomy, a small corticotomy is made into which the retractor is advanced. Then, the tubular retractor system is advanced transsulcally toward the location of the lesion using neuronavigation trajectory guidance. Specifically, the neuronavigation wand is held coaxial with the tubular retractor with the wand tip in a groove in the tip of the tubular retractor obturator. The BrainPath tubular retractor has a locking mechanism that holds the neuronavigation wand in place. The VBAS tubular retractor does not have a locking mechanism, so it is held manually coaxial to the tubular retractor as the retractor is advanced. Once the lesion is reached, standard microsurgical technique is used for resection. An operative microscope or exoscope may be used for improved visualization of the tumor, depending on surgeon preference. For softer lesions, resection begins distally and advances proximally towards the surgeon. For lesions that are firm and well circumscribed, the retractor is advanced towards the proximal edge and resection

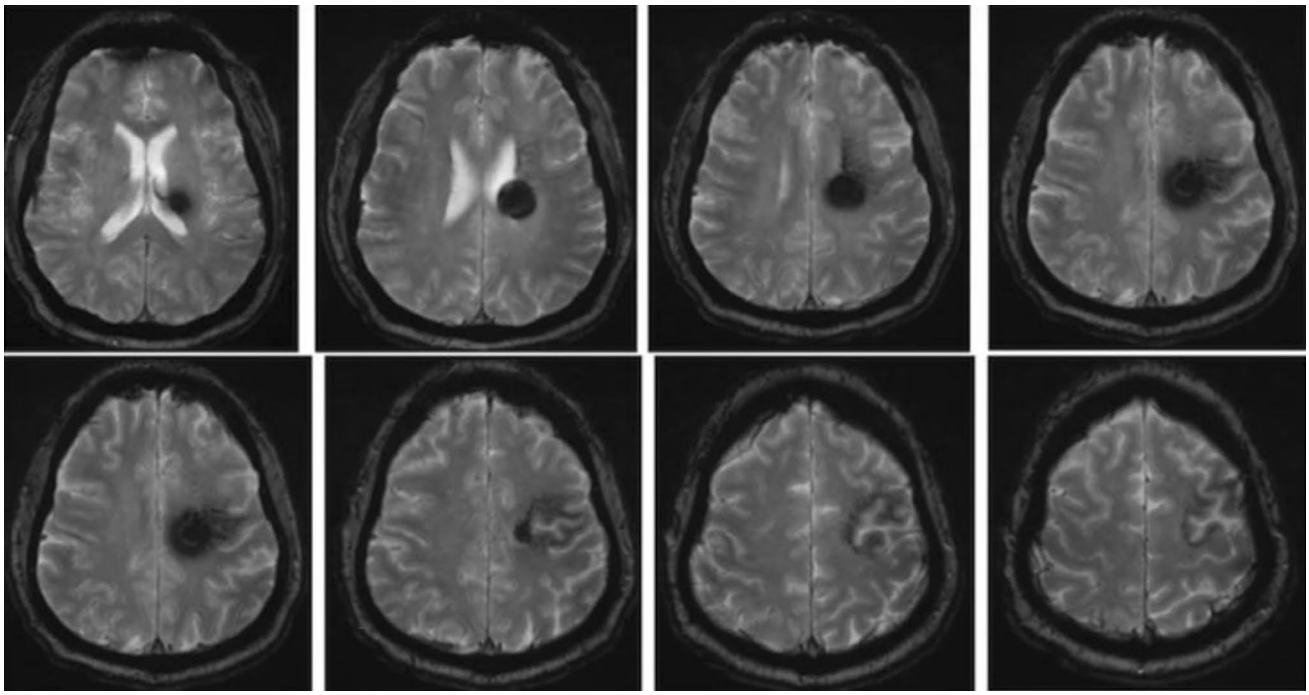

Fig. 1 Preoperative axial SWI sequence MRI of a 50 year old right handed male who presented with a first time seizure, and was found to have a periventricular left frontal cavernous malformation anterior to the motor strip

progresses distally. Circumferential inspection of the resection cavity is then performed with an angled endoscope to confirm complete resection of tumor. The retractor is then withdrawn in increments coupled with meticulous hemostasis along the surgical corridor.

Radiographic analysis

Extent of resection was determined by a blinded board-certified neurosurgeon who reviewed the pre- and post-operative MRIs. Extent of resection was also confirmed by reviewing the official postoperative MRI report in the medical record as written by a board-certified neuroradiologist. Gross total resection (GTR) was defined as when all enhancing lesion was resected, maximal safe resection (MSR) when 90–99% was removed, and subtotal resection when less than 90% of the lesion was resected. Open biopsy was defined as when only enough tissue to be sent for pathologic analysis was resected.

Statistical analysis

All statistical analysis was performed using IBM SPSS Statistics v.24.0 (IBM, Armonk, NY). Post-operative outcome was compared between VBAS and BrainPath cases with pre-operative risk factors controlled for. Comparison between continuous variables was conducted using independent sample t-tests or Wilcoxon rank sum test if data was not normally distributed. A Pearson's Chi square or Fisher's exact test was used to compare categorical variables as appropriate.

Results

One-hundred and thirteen transcortical-transtubular resections for intracranial lesions were performed. Sixty-one, twenty-two, twenty, and eight cases were performed at University of Miami (University of Miami Hospital or Jackson Memorial Hospital); Johns Hopkins Hospital, Baltimore (JHH); Mayo Clinic, Jacksonville (MCJ); and Johns Hopkins Medical Center, Bayview (BV) respectively, from August 2013 to April 2019 (Table 1). Of all patients, 55 patients were male, and 58 patients were female. The average age of patients was 51.6 years with a standard deviation of 16.7 years, maximum of 85 years, and minimum age of 18 years. Patients most commonly presented with metastasis (23.9%), followed by GBM (23.0%) and cavernous hemangioma (22.1%). A summary of patient demographic and neuro-oncological data is detailed in Table 2.

There was a total of 49 left-sided lesions, 41 right-sided lesions, and 23 bilateral or midline lesions. Mean lesion depth below the cortical surface was 4.35 cm, and mean lesion size was 2.68 cm. A comprehensive list of lesion sites and imaging features may be reviewed in Table 3. Overall, VBAS and BrainPath minimally invasive tubular retractors

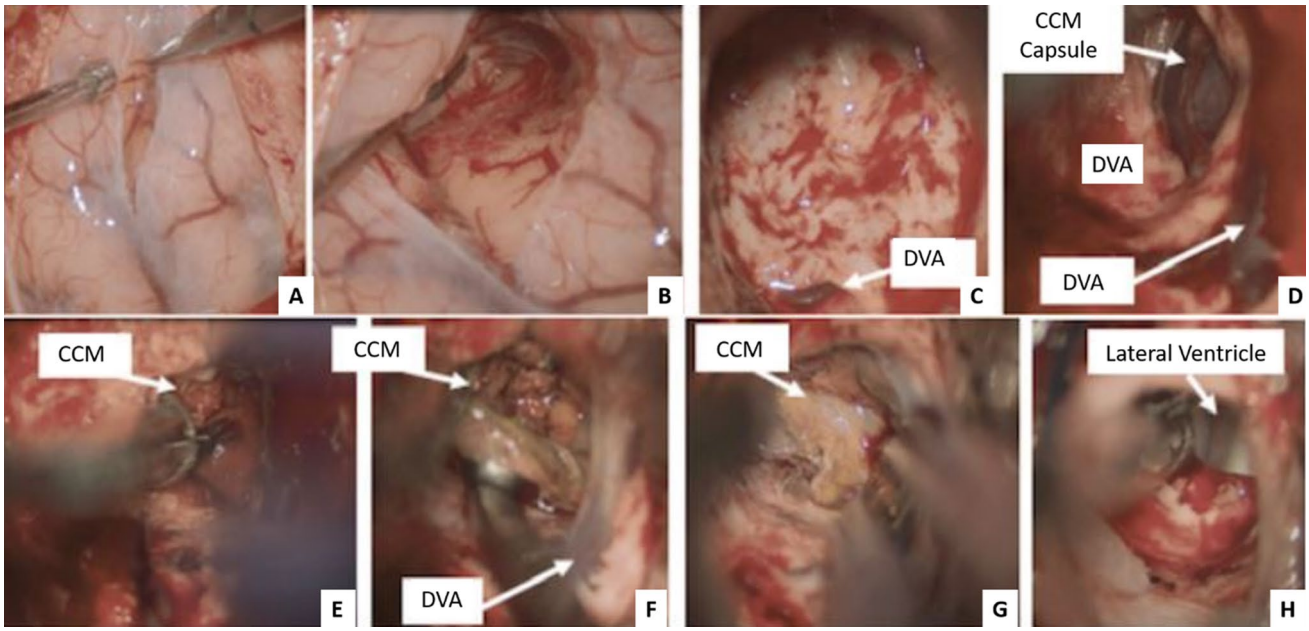

Fig. 2 Intraoperative photographs taken during resection of the left frontal cavernous malformation. **a** craniotomy centered around the lesion is turned and a transsulcal dissection is performed, which avoids cortical injury (Panels **a** and **b**). A transsulcal trajectory through the superior frontal sulcus under the premotor area, was planned to the lesion, and neuronavigation was used to aim the tubular retractor toward the cavernous malformation along the planned trajectory. Next, the tubular retractor is advanced atraumatically through the sulcus. In this case, a 7 × 17 Viewsite Brain Access System retractor was used. Care is taken to protect the large developmental venous anomaly that is encountered (Panel **c**). Soon, the cavernous malformation capsule is visualized (Panel **d**). An Ojemann cortical stimulator was used along the posterior and medial edge to ensure that the motor strip and the corticospinal tracts were not violated. As signal was only detected at 5 milliAmps in all directions, we felt it was safe to attempt a gross total resection. Standard microsurgical technique was utilized to resect the lesion (Panels **e**, **f**, and **g**). Good visualization of the cavernous malformation is achieved through the tubular retractor working space. The operative microscope provides three dimensional visualization. However, some surgeons prefer to use the exoscope when utilizing tubular retractors. Although the exoscope provides a monocular image, benefits over the operative microscope include wider focal distance, higher magnification, and improved ergonomics. It is possible to safely gimbal the tubular retractor to augment the visualized area of interest. After resection was completed, the inside of the lateral ventricle is able to be visualized (Panel **h**). Finally, meticulous hemostasis was achieved as the tubular retractor was slowly withdrawn. Abbreviations: *CCM* cerebral cavernous malformation, *DVA* developmental venous anomaly

were used in 56 (49.6%) and 57 (50.4%) cases, respectively. Patient outcome data is summarized in Table 4. Extent of resection corresponded in 100% of cases between blinded review by the blinded board-certified neurosurgeon and with the official MRI report in the medical record as written by a board-certified neuroradiologist. A gross total resection was achieved in 81 (71.7%) cases, near total resection in 12 patients (10.6%), maximal safe resection in eight patients (7.1%), and subtotal resection in 10 patients (8.8%). Open biopsy was performed for two patients (1.8%). There were eleven instances of early post-operative complications and five instances of permanent post-operative complications (> 1 week follow up). These may be reviewed in Table 5. Mean post-operative stay length was 4.1 days and mean length to follow up was 4.7 months.

Outcome was compared between patients that underwent resection using VBAS and BrainPath tubular retractor systems. Pre-operative mean age and tumor size were not significantly different ($P > 0.05$) between VBAS and BrainPath cases. However, lesions resected using BrainPath were significantly deeper than lesions resected with VBAS (4.8 ± 1.6 vs. 3.9 ± 2.3; $P = 0.022$) Pathology at final diagnosis was significantly different between VBAS and BrainPath cases, with the VBAS tubular retractor being more frequently used in cavernoma resection ($P = 0.015$) and BrainPath being more frequently used in glioma and metastatic tumor resections ($P = 0.014$; $P = 0.013$). There was no significant difference between tubular retractor system used and rates of gross total resection, early complications, or post-operative stay length ($P = 0.895$, $P = 0.053$, $P = 0.502$). However, permanent complications were observed in five out of 56(8.9%) BrainPath cases but there were no instances of permanent complications observed in VBAS cases. This association between rate of permanent complications and tubular retractor system used was significant ($P = 0.027$). These data are further detailed in Table 5.

Additionally, a binary logistic regression analysis was performed to determine the association between retractor

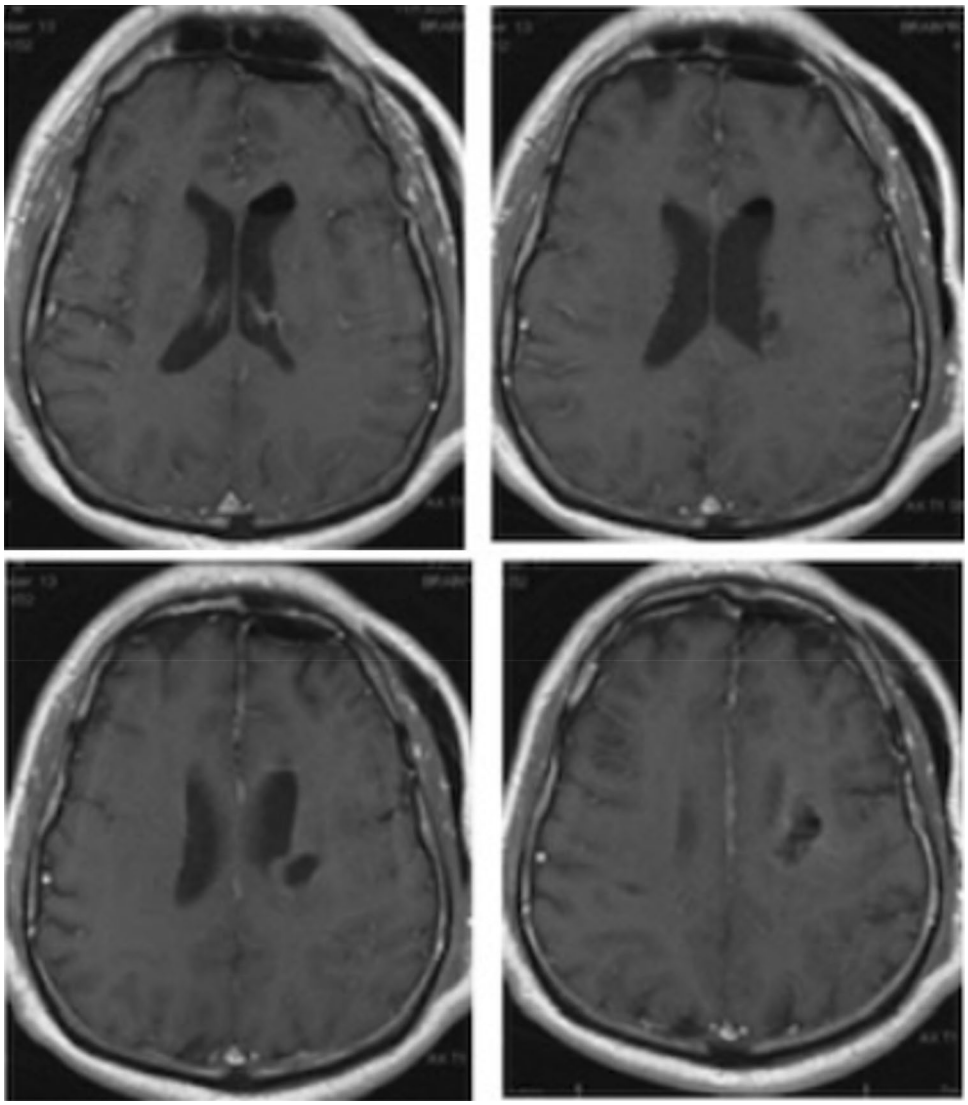

Fig. 3 Postoperative post contrast axial MRI of a left frontal cavernous malformation that was resected with a ViewSite Brain Access System tubular retractor. A gross total resection was achieved. The patient tolerated the procedure well with no complications

Table 1 Case breakdown by institution

Institution	MCJ	JHBV	JHH	UM
Total patients (n)	20	9	23	61
VBAS	4 (20%)	2 (22.2%)	8 (34.8%)	42 (68.8%)
BrainPath	16 (80%)	7 (77.8%)	15 (65.2%)	19 (31.2%)

MCJ Mayo Clinic Jacksonville, *JHBV* Johns Hopkins Bayview, *JHH* Johns Hopkins Hospital, *UM* University of Miami

Mayo Clinic Florida, Bayview, Johns Hopkins hospital, UMH

system and perioperative and permanent complication rate. Age at surgery, lesion depth, and maximal tumor diameter were included as covariates. Tubular retractor system used did not significantly predict the occurrence of perioperative complications (B = − 1.334, P = 0.119) nor permanent complications (B = 18.861, P = .997).

Discussion

In almost all intraparenchymal, intracranial neurosurgical procedures, brain retraction is necessary to develop an adequate surgical window for visualization of the underlying lesion as well as surrounding neurovasculature and eloquent brain area. Unfortunately, with increased access and visualization of the surgical corridor, there is concomitant pressure and strain on the adjacent normal brain. Permanent tissue damage from blunt trauma or compression of vasculature leading to ischemia may result [23]. Preclinical studies in rats by Rosenørn and Diemer investigated the effect of brain retractor pressures (BRP) on cerebral blood flow by means of autoradiography [24]. With BRPs as low as 20 mm Hg CBF was reduced from 55–150 ml/100 gm/min to 10–75 ml/100 gm/mins in tissue underlying the retractor. Electroencephalographic changes and blood-brain barrier disruption resulted with external pressures as low as 25 mm

Table 2 Patient demographic data

Characteristic	Value	
Tubular retractor	VBAS	BrainPath
Total patients (N)	57 (50.4)	56 (49.6)
Male	27	28
Female	30	28
Age at surgery (years)		
Mean ± SD	50.54 ± 16.42	52.61 ± 16.97
Pathology		
Cavernoma	18	7
Colloid cyst	11	4
GBM	13	13
Meningioma	2	0
Metastasis	8	19
Glioma	1	8
Other	4	5
Presenting symptoms		
Headache	31	23
Seizures	10	6
Visual disturbance	6	5
Cognitive deficit	8	7
Language deficit	4	2
Motor weakness	3	3
Sensory deficit	10	15
Gait difficulty	0	4
Incontinence	0	1
Mental status alteration	1	0
Asymptomatic/incidental	2	1

Table 3 Preoperative data

Characteristic	Value (%)
Laterality	
Left	49 (43.4)
Right	41 (36.3)
Bilateral/midline	23 (20.3)
Site	
Frontal	16 (14.2)
Frontotemporal	1 (0.9)
Frontoparietal	5 (4.4)
Insular	1 (0.9)
Occipital	3 (2.7)
Parietal	23 (20.3)
Parietooccipital	2 (1.8)
Parietotemporal	1 (0.9)
Pituitary	1 (0.9)
Subcortical	36 (31.8)
Temporal	13 (11.5)
Temporoparietal	2 (1.8)
Cerebellum	9 (7.9)
Imaging features	
Mean depth to target (± SD)	4.35 ± 2.06
Mean lesion size	2.68 ± 1.38
Ventriculomegaly	23 (20.4)
T2 FLAIR hyperintensity	68 (60.2)

Table 4 Post-operative outcome data

Characteristic	Value (%)
Intraoperative EVD placement	14 (12.4)
Extent of resection	
GTR	81 (71.7)
MSR	20 (17.7)
STR	10 (8.8)
NS	2 (1.8)
Transient complications (resolved at last followup)	11 (9.7)
Permanent complications	5 (4.4)
Early postoperative seizures (< 1 week postop)	1 (0.8)
Long term seizures (>1 week followup)	0 (0)
Mean post-operative length of stay (days ± SD)	4.1 ± 6.11
Length to follow-up (months ± SD)	4.64 ± 8.55

Hg applied to the cortical surface. Similar results were found when measuring decreased EEG activity from retraction in dogs and humans [25, 26].

There is a clear clinical correlate of these findings. Indeed, in an estimated 10% of skull base surgeries and 5% of intracranial aneurysm resections, brain retraction results in infarction or contusion of surrounding normal parenchyma.[3] In addition, manipulation of white matter tracts and extended pressure exerted on the surrounding brain parenchyma and vasculature may lead to post-operative venous injury (POVI), edema, and seizure [23, 27]. Currently, methods at measuring retraction pressure, CBF, and electroenecphelaography are not frequently used and, if implemented, may exacerbate surgical complexity and increase operative time which is costly [28].

Minimally invasive tubular retractor systems offer several advantages over traditional metal, bladed retractors. Theoretically, the pressure exerted by a retractor is equal to the force of retraction applied over the surface area of brain opposed. Bladed retractors exert pressure along a single focus and thus distribute force unequally across the field of retraction. Force from retraction may cause focal infarction and trauma particularly along the sharp edges of the retractor. In contrast, tubular retractors exert pressure all along their circumference and thus distribute the force of retraction across a greater surface area of brain. While the differential in pressure distribution between tubular retractors and blade retractors has never been verified experimentally, in a quantitative analysis of fluid attenuated inversion recovery signal (FLAIR) hyperintensity and diffusion co-efficient

Table 5 Peri-operative and permanent complications

ID	Sex	Age	Retractor	Lesion depth/size (cm)	Pathology	EOR	Complication	Permanent?
1	F	73	BrainPath	4.69/4	Met	GTR	Postoperative stroke of unclear etiology	Y
6	F	69	BrainPath	3.78/2.8	Met	GTR	Intraventricular hemorrhage, hydrocephalus; left sided weakness, neglect	Y
28	M	59	Brainpath	6.4/3.8	Met	STR	Right sided weakness and speaking problems from injury to a perforating vessel to the thalamus	Y
49	F	57	Brainpath	3.7/3.8	Glioma	GTR	Left superior field cut	Y
56	F	72	Brainpath	7.7/5.3	Glioma	NTR	Right sided weakness and speaking problems slightly worse than preop	Y
27	F	18	BrainPath	7.0/4.12	Glioma	NTR	Motor weakness	N
55	F	59	BrainPath	7/1.7	Glioma	NTR	Left foot numbness	N
68	F	40	VBAS	3.59/2.2	Met	GTR	Mild left to right confusion, finger agnosia	N
58	F	29	VBAS	3.15/0.7	Cavernoma	GTR	Difficulty with recall and some cognition	N
60	F	30	VBAS	2.6/2.2	Cavernoma	GTR	Difficulty with word finding	N
61	F	30	VBAS	2.7/2.3	Cavernoma	GTR	Difficulty with word finding	N
63	M	43	VBAS	1.1/2.2	Cavernoma	GTR	Post-op seizure	N
66	F	53	VBAS	7.59/1.22	Colloid cyst	GTR	Short term memory difficulty	N
71	F	39	VBAS	2.65/0.94	Colloid cyst	GTR	Memory loss	N
97	M	84	VBAS	3.89/4	GBM	MSR	Hemianopsia	N
95	M	18	VBAS	4.97/4.5	Other	STR	Left SMA syndrome. R facial droop and UE weakness. Hydrocephalus	N

maps, Bander et al. showed that tubular retractors do not significantly increase post-operative FLAIR intensity volume and result in noticeably less diffusion-weighted imaging (DWI) intensity volume than paddle retractors [29]. With tubular retractors, white matter tracts may also be preserved using a progressive dilation technique with a blunt tip passing instrument and traversed as opposed to transection [30]. Finally, minimally invasive techniques result in less blood loss compared with open surgery and may provide the added benefit of reduced surgical times [31–33]. As extended time under anesthesia has been known to be associated with increase peri-operative complications, minimally invasive techniques may ultimate reduce surgical morbidity and hasten post-operative recovery [31–33].

In our study, we describe the use of two different tubular retractor systems designed for minimally invasive retraction of brain tissue: VBAS and BrainPath. Both include an outer and inner cannula. The outer cannula may be affixed to a holder while the inner cannula may be used for the blunt dissection of white matter tracts as has been described [18]. Both systems include an obturator to transverse brain parenchyma. The VBAS obturator is transparent allowing for visualization of tissue during insertion. Contrarily, the BrainPath obturator is made of aluminum and may be repeatedly sterilized and reused. Nevertheless, there is no difference in technique or surgical approach when using either retractor. In our sample, we found no significant difference in extent of resection or rate of immediate complications. However, both of these cases involved the resection of an intracranial metastasis and tumor grade, pathology, and whether it is of primary or secondary origin has a dramatic effect on patient outcome [34, 35]. It is more likely the complications that resulted were more related to each patient's presenting pathology as opposed to the tubular retractor used. Thus, in concordance with previous findings, we conclude there is no difference in patient outcome when using either Vycor or BrainPath tubular retractor systems.

While both tubular retractor systems have afforded good results, in our opinion the VBAS aperture more easily facilitates bipolar electrocautery, as its elliptical conformation is more amenable to the bipolar forcep tines. Additionally, the larger diameter VBAS retractors (specifically the 17 mm, 2 mm, and 28 mm diameters) are subjectively easier to work through due to their greater working areas compared to the smaller 13.5 mm BrainPath aperture diameter. The neuronavigation wand locking mechanism of BrainPath tubular retractor, however, makes it far easier to introduce the BrainPath tubular retractor along the planned trajectory than the VBAS system, as the VBAS system does not have such a neuronavigation wand locking mechanism.

We reported a 4.4 cm mean lesion depth below the cortical surface, although we included lesions resected with a tubular retractor whose most superficial component was 1.0 cm or more below the cortical surface. Although lesions

as superficial as 1.0 cm below the cortical surface do not necessarily require a tubular retractor for resection, we do find that the tubular retractor is useful for mobilizing the surrounding cortical lip to allow for improved visualization, particularly for large lesions with significant deep components. In our series, we employed both operative microscopes and exoscopes for visualization within the tubular retractor, as per surgeon's preference. Operative microscopes allow for a binocular, three-dimensional visualization of the surgical corridor with added depth-of-field. Illumination of the surgical cavity may be adjusted to provide maximal illumination the field of interest while reducing shadowing that may obscure vision. Manipulation and re-positioning of operative microscopes is intuitive and adjustments may be made quickly and efficiently. Endoscopes and exoscopes may also be used to improve visualization with added advantages and disadvantages to each. Endoscopes allow for the visualization of a wider surgical field [36]. While previous endoscope models were limited by nonstereoscopic vision, newly available three-dimensional endoscopes offer superb stereoscopic vision, often with improved depth of field and ergonomics. Previous comparisons between microscopic and endoscopic transtubular resections have been described. Hong et al. described the use of endoscope-assisted resections using the VBAS port retractor system and a 45° Hopkins II rod-lens endoscope (Karl Storz Endoscopy, Tuttlingen, Germany) [37]. The presence of the endoscope inside the retractor port noticeably limited instrument manipulation and hindered fine dissection. As a result, endoscope-associated visualization was associated with higher rates of incomplete resection. Exoscopes have been developed in the past decade and is emerging as a promising alternative to the operative microscope and somewhat of a cross between the endoscope and operative microscope. Similar to the microscope, the exoscope is positioned outside of the body cavity and provides improved ergonomics, higher magnification, and wider focal distance. However, the exoscope suffers from nonstereoscopic vision and thus loss of depth perception [36]. The use of the exoscope in transtubular resection of deep-seated intracranial lesions is still being explored [38, 39]. Recently, Gassie et al. published a consecutive, single-surgeons series of 50 patients describing the use of tubular retractors with exoscopic visualization. The median percent of resection was 100% with an interquartile range of 95%-100% resection. Post-operatively, 36% of patients showed improved KPS scores, 29% were stable, and 6% of patients worsened. Additional studies comparing the use of operative microscopes and exoscopes can provide further insight in the advantages and disadvantages of each surgical tool.

Here, we presented a large, multi-institutional series detailing the resection of intracranial lesions using minimally-invasive, tubular retractors. We detail the procedural nuances of our technique and compare two of the most commonly used, commercially-available tubular retractors: BrainPath and VBAS. Our study is inherently limited by its retrospective, non-randomized design. In addition, heterogeneity within our patient samples may preclude any true effective comparison between the BrainPath and VBAS tubular retractor systems. Propensity-matched studies that consider tumor pathology, lesion laterality, and eloquence grade may provide a more controlled comparison between retractor systems. Finally, we are unable to make any conclusions regarding efficacy of tubular retractors in relation to traditional paddle retractors. Future prospective, randomized studies are needed to determine the efficacy of tubular retractors in improving patient outcome in the resection of intracranial lesions.

Conclusion

Pressure from brain retraction, especially for deep-seated lesions where wider operative windows are needed, may result in focal infarction and trauma to normal brain parenchyma. Tubular retractors offer an alternative to traditional retractors—hypothetically minimizing iatrogenic injury while affording the surgeon the ability to employ standard bimanual, microsurgical technique. Here, we report a series of 113 patients who underwent transcortical-transtubular resections for intracranial lesions. We report promising safety and efficacy outcomes and no difference in outcome between VBAS and BrainPath retractor systems, although studies comparing use of tubular retractors to blade retractors are required to confirm tubular retractor superiority. Both operating microscope and exoscope provided adequate visualization within the tubular retractor.

Author contributions Conception and design: all authors. Acquisition of data: all authors. 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 of behalf of all authors: DE. Statistical analysis: DE, LDI, AS. Study supervision: MI, RS, RK.

Compliance with ethical standards

Conflict of interest Robert M. Starke has the following disclosures: RMS research is supported by the NREF, Joe Niekro Foundation, Brain Aneurysm Foundation, Bee Foundation, and by National Institute of Health (UL1TR002736, KL2TR002737) through the Miami Clinical and Translational Science Institute, from the National Center for Advancing Translational Sciences and the National Institute on Minority Health and Health Disparities. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH. RMS has consulting and teaching agreements with Penumbra, Abbott, Medtronic, InNeuroCo and Cerenovus. Michael E. Ivan: Consultant to and receiving research funding from Medtronic

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