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Minimally Invasive Trans-Portal Resection of Deep Intracranial Lesions

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Key words
- intraventricular
- basal ganglia/thalamus
- tube retractor
- minimally invasive
- frameless stereotaxis

Abstract

Background: The surgical management of deep intra-axial lesions still requires microsurgical approaches that utilize retraction of deep white matter to obtain adequate visualization. We report our experience with a new tubular retractor system, designed specifically for intracranial applications, linked with frameless neuronavigation for a cohort of intraventricular and deep intra-axial tumors.

Methods: The ViewSite Brain Access System (Vycor, Inc) was used in a series of 9 adult and pediatric patients with a variety of pathologies. Histological diagnoses either resected or biopsied with the system included: colloid cyst, DNET, papillary pineal tumor, anaplastic astrocytoma, toxoplasmosis and lymphoma. The locations of the lesions approached include: lateral ventricle, basal ganglia, pulvinar/posterior thalamus and insular cortex. Post-operative imaging was assessed to determine extent of resection and extent of white matter damage along the surgical trajectory (based on T_2/FLAIR and diffusion restriction/ADC signal).

Results: Satisfactory resection or biopsy was obtained in all patients. Radiographic analysis demonstrated evidence of white matter damage along the surgical trajectory in one patient. None of the patients experienced neurological deficits as a result of white matter retraction/manipulation.

Conclusion: Based on a retrospective review of our experience, we feel that this accesss system, when used in conjunction with frameless neuronavigational systems, provides adequate visualization for tumor resection while permitting the use of standard microsurgical techniques through minimally invasive craniotomies. Our initial data indicate that this system may minimize white matter injury, but further studies are necessary.

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Introduction

Recent technological advancements and an improved anatomic understanding have provided an impetus for the growth of minimally invasive approaches to the central nervous system. The contemporary development of minimally invasive approaches for cranial base lesions includes endonasal endoscopic techniques and keyhole craniotomies. Alternatively, the development of minimally invasive approaches for intra-axial lesions has been limited. Despite attempts to adapt endoscopic techniques to intra-axial tumors, it is becoming increasingly evident that microsurgical approaches should still be part of the surgical armamentarium.

Open microsurgical approaches have a role in the management of intracranial lesions and brain retraction is a necessary technique for approaching deep intra-axial lesions. Greenberg introduced the first self-retaining retractor for neurosurgery in 1981 [1]. The traditional retractor systems, such as the Greenberg or Leyla retractors, can often be bulky and cumbersome to use. In addition, aggressive retraction has been demonstrated to cause significant cortical and vascular damage in animal studies [2–4]. In an effort to address these issues, tubular retractors have been developed to minimize retraction injury [5–7]. Kelly and Moshel first described the use of a tubular system for stereotactic resection of intracranial tumors [6, 7]. They have employed their system for years to remove deep-seated lesions such as thalamic pilocytic astrocytomas [6, 8]. While appealing, this system was initially described with frame-based stereotaxis systems, which are not in widespread use, in addition to metallic retractors. More recently, several groups have reported their experience with tubular tractors in the management of deeper intracranial

Table 1 Outcomes (extent of resection, T_2/FLAIR and ADC/diffusion restriction) in operated patients.

					Surgical Outcomes		
Patient Number	**Diagnosis**	**Lesion Location**	**Lesion Size (AP × CC × ML) (cm)**	**Surgical Approach**	**Extent of Resection**	**T_2/FLAIR Change**	**ADC/Diffusion Restriction**
1	necrosis due to subacute infarct	basal ganglia	4.29 × 2.07 × 3.7	supraorbital craniotomy	excision biopsy	none	none
2	toxoplasmosis	basal ganglia	2.46 × 2.01 × 2.35	supraorbital craniotomy	gross total	none	none
3	DNET	basal ganglia	2.97 × 2.86 × 2.11	frontal craniotomy	gross total	none	none
4	colloid cyst	foramen of Monro	1.0 × 0.5 × 0.7	frontal craniotomy	gross total	none	none
5	colloid cyst	foramen of Monro	0.7 × 0.6 × 0.6	frontal craniotomy	gross total	none	none
6	lymphoma	insular cortex	2.56 × 1.82 × 2.01	temporal craniotomy	excision biopsy	none	none
7	subependymoma	lateral ventricle	3.47 × 2.99 × 2.44	frontal craniotomy	gross total	none	none
8	papillary tumor	pineal region	3.22 × 3.35 × 2.6	frontal craniotomy	subtotal	yes	yes
9	anaplastic astrocytoma	pulvinar/posterior thalamus	2.6 × 3.4 × 2.6	parietal craniotomy	gross total	none	none

lesions [5,9]. These studies, with their relatively smaller cohorts, have demonstrated safe efficacy. However these previously published studies have assessed retractors systems designed primarily for spinal surgery as opposed to intracranial procedures – as such, design of the retractors utilized are more adept to dilating and retracting paraspinal musculature as opposed to neural tissue. In addition, these previous studies have addressed the need to use these retractors with current frameless stereotactic guidance and microsurgical/endoscopic techniques.

Since the initial reports of tubular retractors, a commercially available system specifically designed for intracranial surgery with frameless stereotaxis is now available – primarily the ViewSite manufactured by Vycor Inc (New York, USA) [10]. This retractor system has several advantages over currently available systems – including its low profile and its transparent walls – which provide several technical advantages that are outlined in this paper. We describe the application of the ViewSite tubular retractor system paired with frameless navigation (BrainLab, Germany) to the management of a variety of intraventricular and intra-axial (basal ganglia and thalamic lesions) with a further discussion on avenues of improvement and other potential applications. While this system has been previously described [10], our results provide further insight into operative technique and the retractor's utility with regards to surgical outcomes, white matter damage and extent of resection. The goal of this retrospective study was to assess if this retractor system, when used in conjunction with conventional frameless neuronavigational systems, provides adequate tumor visualization, permits the use of standard microsurgical technique, and minimizes white matter injury.

Patients and Methods

Patient population

9 patients underwent either surgical resection or excisional biopsy of deep-seated intra-axial lesions with the Vycor tubular retractor system (**Table 1**). The decision for excisional biopsy was primarily for those patients with infiltrative lesions in the basal ganglia and thalamus; while all remaining patients underwent surgery with the intent for resection. As several of these lesions could be managed through several management paradigms, it is important to note that the decision for open exicisional biopsy as opposed to stereotactic biopsy is reflective of the practice trends at our institution. The patients' ages ranged from 28 months to 70 years; there were 8 males and 1 female. One patient with a pineal region tumor underwent an initial open biopsy with the retractor via a right frontal craniotomy which was non-diagnostic; a second open biopsy was performed followed by a third surgery for resection. The location of the lesions treated included the foramen of Monro, lateral ventricle (frontal horn), caudate head of the basal ganglia, thalamus (pulvinar) and insular cortex. The diagnoses treated are listed in **Table 1**.

Fig. 1 Picture of Viewsite Brain Access System.
Permission obtained from Vycor, Inc.

Retractor system

The ViewSite Brain Access System (Vycor Medical Inc) was used in all cases. This is a tubular retractor system designed specifically for intracranial applications. Consisting of an introducer that permits entry into the tissue and a working channel, it also has transparent plastic walls that permit visualization of surrounding tissue (**Fig. 1**). The retractor is available in 4 widths – 12 mm, 17 mm, 21 mm and 28 mm; it is also available in 3 lengths – 3 cm, 5 cm and 7 cm. We primarily used the 17 mm width retractor in either the 5 or 7 cm lengths.

Technique (see supplemental Video 1, demonstrating operative technique)

All patients underwent pre-operative magnetic resonance imaging (including gadolinium enhanced and fluid-attenuated inversion recovery sequences) with fiducial markers to be used with BrainLab stereotactic navigation and pre-operative trajectory planning. After intubation and anesthesia induction, patients were immobilized in a Mayfield headholder and registered with the navigation system. The incision and craniotomy were planned based on the location of the lesion using navigation. Patients with lesions in the basal ganglia underwent an eyebrow incision with a supraorbital craniotomy (▶ **Fig. 2**), while all other patients underwent a small linear incision and craniotomy based on an entry point selected based on image guidance. After a small craniotomy flap had been raised, a corticectomy was planned such that any major veins/arterial structures would not be sacrificed, a non-eloquent gyrus was entered and major white fiber tracts would be avoided at the depths of the trajectory.

Supplemental Video 1

Video demonstrates operative technique.
Author: Alfredo Quinones-Hinojosa
Videographer: Nathaniel Tippens
Participants: Shaan M Raza, Pablo F Recinos, Javier Avendano, George Jallo, Alfredo Quinones-Hinojosa
Length: 1 min, 52 s
Size: 18.8 MB

The corticectomy was performed such that a small pial incision was made roughly equal to the final diameter of the retractor tube. In order to create the surgical trajectory, after performing the corticectomy, a 14-fr peel-away sheath cannulated with the navigation probe was advanced into the brain along the desired trajectory (▶ **Fig. 3a, b**). After reaching the target lesion with the sheath, a minimal amount of surrounding brain was then resected to create a path large enough to insert and advance the retractor system (▶ **Fig. 4**). Given the retractor's tubular elliptical shape, a large amount of white matter did not have to be resected since the retractor gently splits as it is advanced into white matter without further damage or transection.

After an adequate path had been created, the assembled tubular system was inserted slowly through the pial incision corticectomy with intermittent stereotactic feedback to ensure appropriate placement. Typically, the retractor was advanced several millimeters past the target depth in order to prevent surrounding white matter from encroaching into the operative field of view as tumor resection proceeds. The retractor length was

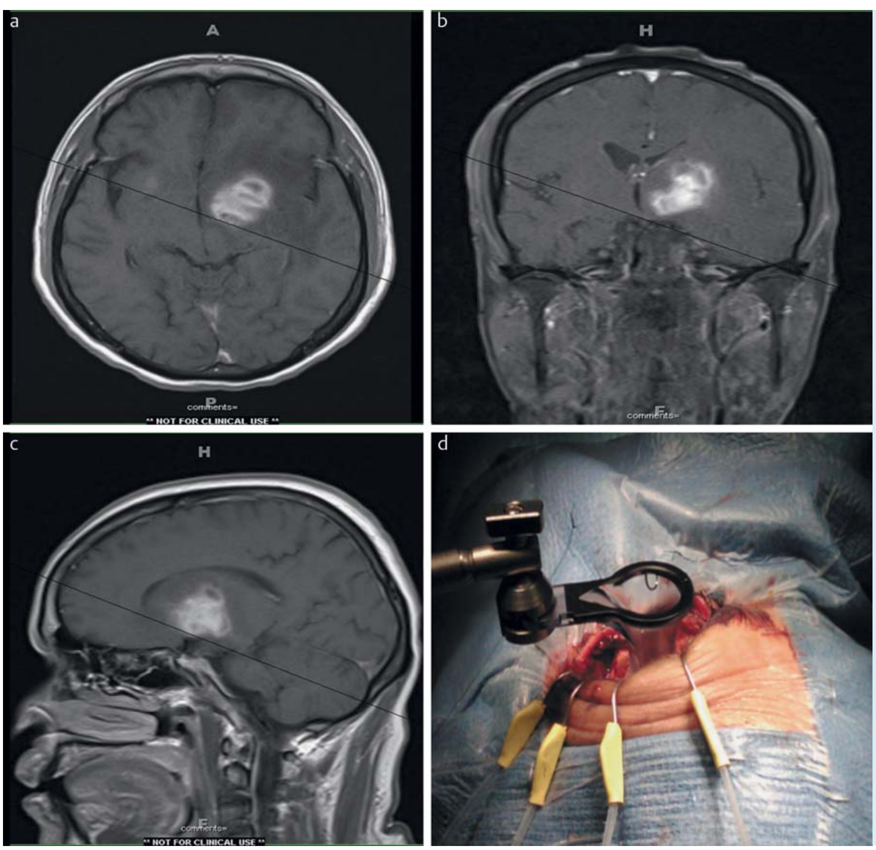

Fig. 2 Pre-operative T_1-weighted contrast enhanced MRI with axial (**a**), coronal (**b**) and sagittal (**c**) slices demonstrating contrast enhancing lesion with the left caudate head. An excisional biopsy was performed as a left supraorbital craniotomy via eyebrow incision (**d**).

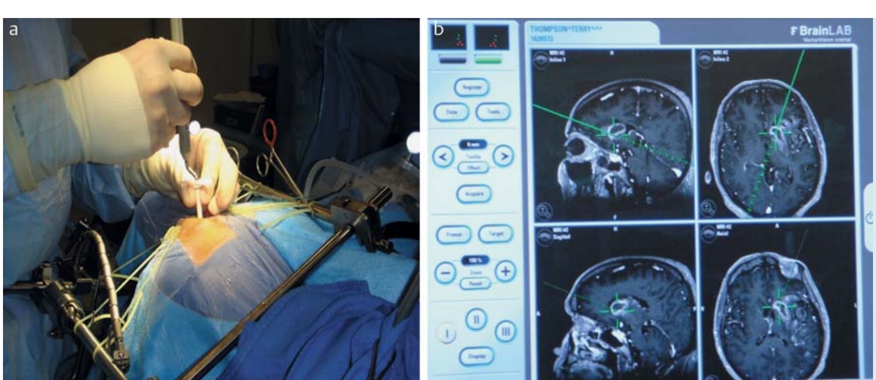

Fig. 3 Technique of utilizing frameless navigation probe with a sheath to perform a safe and efficiently guided corticetomy (**a**). Navigation screen shot demonstrating advancement of probe and sheath towards target lesion (**b**).

selected based on pre-operative analysis of the surgical trajectory on MR imaging. The length selected was several millimeters longer than the trajectory from the cortical surface to the target lesion – this avoided inadvertent cortical laceration, while also providing additional room for retractor manipulation. Once in place, the retractor was held in place using the Greenberg retractor system (**Fig. 5**).

After retractor insertion, the microscope was subsequently brought in for tumor debulking/resection. We perform a significant internal tumor debulking prior to dissection of the outer capsule. As debulking and dissection proceeds, the trajectory of the retractor can be adjusted to reach/visualize the margins of the tumor. During the course of resection, we found that bayoneted instruments – such as those used in transphenoidal resections – were most useful given the relatively small working space/visualization of the retractor.

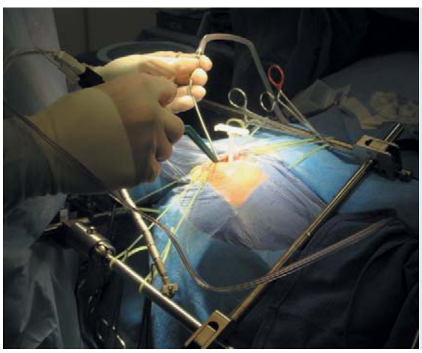

Fig. 4 After the target lesion is reached with the navigation probe, the probe is removed leaving the sheath in place. The surrounding white matter tract is expanded to accommodate the tubular retractor.

At the conclusion of tumor resection, hemostasis was obtained easily using bipolar cautery, Floseal (Baxter, Inc) and thrombin-soaked cotton balls. After obtaining hemostasis in the tumor bed, the retractor was loosened and slowly elevated in millimeter increments. Given the transparent walls of the retractor, the bleeding points in the surrounding parenchyma can be easily visualized and cauterized as the retractor is removed.

Results

Case illustration

The patient is a 70-year-old male who presented to our service with one month of left lower extremity weakness and numbness along with headaches, short-term memory difficulty, and blurry vision. Pre-operative MR imaging demonstrated a heterogeneously ring enhancing mass in the right pulvinar/posterior thalamus – measuring 2.6 cm × 3.4 cm × 2.6 cm – with associated vasogenic edema (**Fig. 6a–c**). Due to the need for diagnosis and his symptomatology, the patient was taken to the operating room with intra-operative neuromonitoring for a right parietal craniotomy done via a linear incision. A small corticectomy was made, through which a 17 mm × 7 cm tubular retractor was advanced (using the technique described earlier). No intraoperative issues were encountered. Post-operatively, imaging demonstrated gross total resection while clinically the patient's weakness improved (**Fig. 6d–f**). Final pathology was anaplastic astrocytoma.

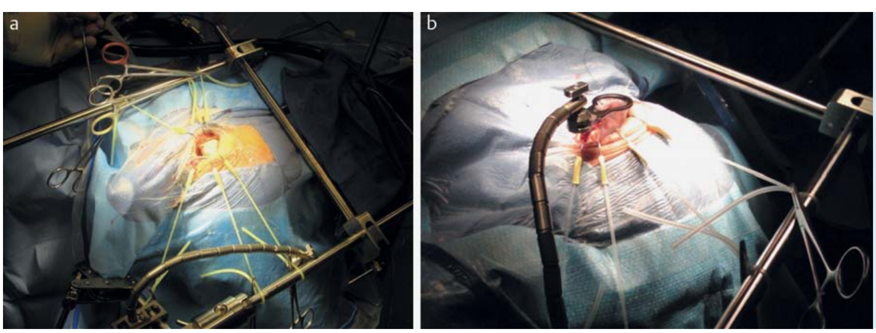

Fig. 5 Intra-operative images demonstrating set-up of the Greenberg system to hold the retractor in place during lesional resection.

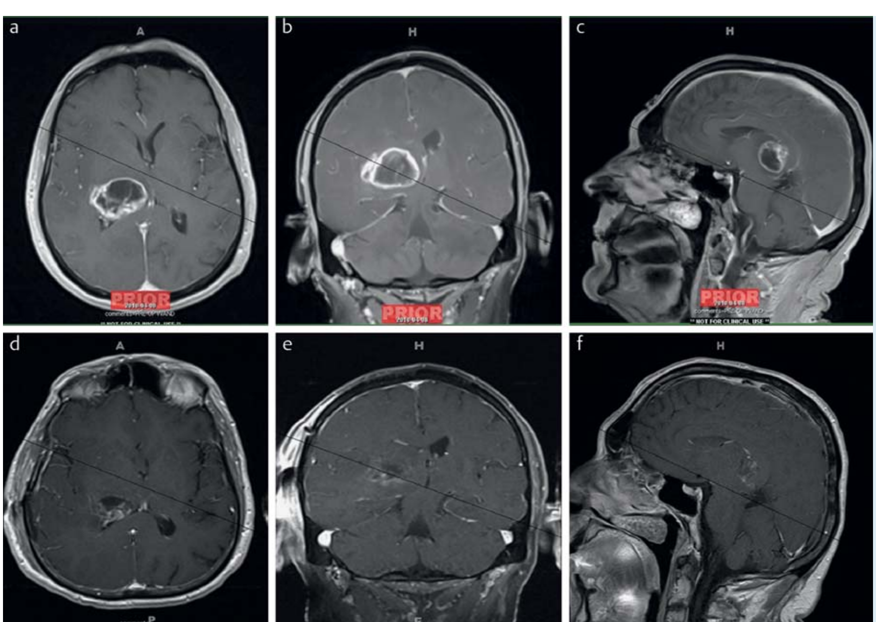

Fig. 6 Pre-operative T_1-weighted contrast enhanced MRI with axial (**a**), coronal (**b**) and sagittal (**c**) slices demonstrating heterogeneously enhancing lesions (measuring 2.6 cm × 3.4 cm × 2.6 cm) in the right pulvinar/posterior thalamus. Post-operative MRI axial (**d**), coronal (**e**) and sagittal (**f**) slices demonstrating gross total resection performed via right parietal craniotomy.

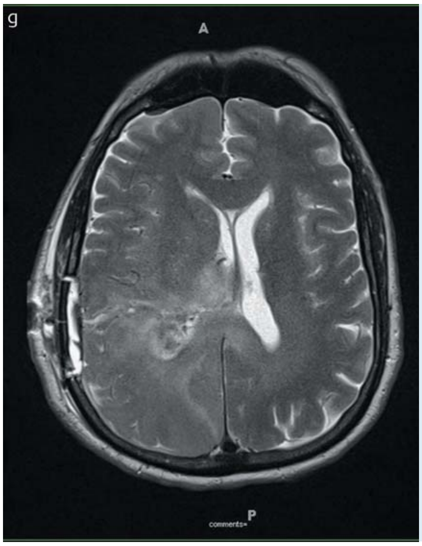

Fig. 6g Post-operative T_2/FLAIR imaging demonstrating minimal signal change along surgical tract.

Image analysis

Pre-operative and post-operative MR images were reviewed to assess the following outcomes: extent of resection (to assess surgical efficacy and visualization), new FLAIR/T_2 change (to assess extent of white matter manipulation) and new ischemia based on analysis of diffusion-weighted imaging (to assess local tissue ischemia) beyond the extent of the surgical trajectory (**Fig. 6g**). Extent of resection was determined by comparing pre-operative MR imaging with immediate post-operative imaging (obtained within 48 h of surgery).

Surgical results

The results from the 3 measures of surgical outcome – extent of resection, T2/FLAIR change and diffusion restriction – are highlighted in **Table 1**. With regards to extent of resection, gross total resection was achieved in 6 patients, subtotal resection in 1 patient and biopsy was performed in 2 patients. In those patients with the final result of "biopsy", this was consistent with the goals of intervention pre-operatively. One patient with a pineal region tumor underwent an initial non-diagnostic biopsy followed by second surgery for a successful biopsy and a third surgery for debulking; all 3 operations were performed utilizing the retractor system. With regards to assessment of white matter damage based on T_2/FLAIR and diffusion restriction, 1 patient who underwent resection for a papillary tumor in the pineal region experienced imaging evidence of white matter manipulation; although this did not result in any clinical appreciable deficits.

Discussion

With an improved understanding that additional neurological deficit and patient morbidity are derived from additional tissue manipulation, the goal of minimally invasive surgery is to reduce surgical morbidity through smaller incisions, tailored craniotomies, and more efficient microsurgical approaches that minimize collateral damage. While advancements in endoscopy for intracranial surgery have been applied to the surgical management of selected lesions (i.e., colloid cysts) and hematomas, radical resection and meticulous hemostasis is often difficult. This underscores the fact that microsurgical techniques are still an effective strategy for the management of deeper and more complicated lesions. Ultimately, the microsurgical resection of deep brain lesions, such as intraventricular tumors and thalamic lesions, relies on the use of brain retraction to maintain a long passage traversing through surrounding white matter. The introduction of the self-locking retractor system by Greenberg in the 1980 s improved access to tumors and vascular malformations in particular locations [1]. However, retractor-associated injury is a well known phenomenon that can result from improper use.

The risk of retractor injury has been well documented [2–4, 11, 12]. Consequently injury is often a result of direct pressure and local ischemia [4]. Rosenorn et al. have documented pressures up to 30 mmHg in parenchyma under spatula retractors which could ultimately lead to stretch and shearing [2, 3]. In addition, the direct occlusion of regional vasculature from retraction diminishes perfusion pressures down to 25–30 mmHg – the threshold at which tissue infarction occurs [2, 3]. Realistically, in the operating room, this local ischemia can be exacerbated by systemic factors – such as hypotension – further aggravating the extent to which tissue damage occurs in patients. A fine balance between obtaining adequate exposure of the lesion and surrounding structures and not retracting excessively is continuous consideration with traditional retractor systems in order to minimize the risk of retractor injury. In light of this, tubular retractor systems were introduced to mitigate the effects of excessive retraction on the cortex and the underlying white matter tracts.

Development of tubular retractor systems (frame based stereotactic systems)

The belief that cylindrical systems cause minimal focal tissue damage is based on the premise that the pressure of retraction is distributed evenly over a wider area of compression. Barlas et al. have confirmed the minimal forces exerted by tubular retractors on surrounding tissue [13]. The initial tubular retractor systems described by Kelly et al. and Moshel et al. were affixed to frame-based stereotaxis systems through which deep-seated lesions, such as thalamic tumors, were resected [6–8, 14]. These retractors were placed after an initial corticectomy, incision in the white matter and progressive dilation. The use of a tubular system was thought to minimize white matter damage since the fibers could be split (with a CO_2 laser) and dilated as opposed to transected and removed – necessary for the traditional spatula retractor systems.

Despite its apparent advantages, the previously described tubular retractor systems had several disadvantages that prevented their widespread acceptance. While the use of a frame-based stereotactic system permitted more accurate targeting of deep lesions, the bulky and fixed nature of the systems prevented the use of a corridor that could be intermittently adjusted for tumors that extended beyond the scope of the diameter of the retractor. In addition, especially in the modern era, by using a frame-based system, these previously described systems incur the additional cost of obtaining a separate navigation system. With regards to the actual retractors, aside from their fixed nature, they were manufactured in metal or plastic with opaque walls – prohibiting visualization of surrounding tissue.

A tubular retractor system linked with conventional neuronavigation

Considering the growing role of minimally invasive techniques, there is a need for a tubular retractor system that will not only provide adequate visualization of deep-seated and larger lesions but can also be used in conjunction with modern neuronavigational systems and smaller craniotomies. The system we used in our series has several advantages over previously described systems. This is the first commercially available tubular retractor system specifically designed for intracranial applications. Its thin-walled design with transparent walls permits the surgeon to maintain visualization of underlying tissue while its low profile does not limit the surgeon's working space – which can be limited in situations where multiple traditional retractors blades/arms are used. Its minimal tissue disruption is supported by the minimal FLAIR/T_2 change and diffusion restriction (evidence of local ischemia) noted along the surgical trajectories on post-operative imaging; however, further studies employed diffusion tensor imaging are necessary to better gauge the extent of white matter manipulation. Clinically speaking, there was no evidence of new post-operative neurological deficits related to disruption of the deep white fiber tracts (i.e., corticospinal fibers, arcuate fasciculus, optic radiations, etc).

While previous concerns with similar retractor systems have been the inadequate exposure, we found that the option of multiple lengths and diameters permits adequate visualization. A diameter of 17 mm allows stereoscopic vision with surgical microscopes while also permitting 2-handed surgery with standard microsurgical instruments. In order to resect larger tumors, we found that the angle/trajectory of the retractor could be safely adjusted as dissection proceeded in order to visualize the edge of the tumor capsule. However, as with other minimally invasive procedures with limited visualization, we found that a certain degree of internal debulking was necessary before proceeding with extracapsular dissection. Furthermore, we found the use of bayoneted or transphenoidal instruments permitted efficient use of the system's restricted diameter. Through the use of these techniques we were able to obtain adequate resection with minimal vascular and tissue injury.

By linking the retractor system with a conventional frameless neuronavigation system, we were able to obtain accurate targeting and efficiently develop our surgical corridor. Using a 14-fr peel-away sheath along with the navigation probe to create the surgical trajectory provided several advantages: 1) minimal white matter disruption by only requiring a minimal amount of tissue to be removed around the sheath allowing the retractor to be inserted over the sheath and 2) efficient and direct development of a surgical corridor as inserting and targeting the sheath towards the lesion quickly outlines the center around which the surgical path can be created. As minimal tissue disruption was necessary, intra-operatively we found that the white matter passage closed quickly after the retractor system was removed – a phenomenon which is not typically noted with the traditional retractor systems after longer cases. Ultimately, the use of the tubular retractor system with neuronavigation in such a means prevented misguided cortical incision and white matter resection.

Considerations

The system we describe is the first designed specifically for intra-cranial applications and has many advantages that permit its use for a selected cohort of deeper lesions. There are several considerations that should be addressed. Particularly when using the longer retractors with the microscope, we found that illumination was often limited at the greatest depths. While this did not necessitate switching retractor systems or using an endoscope intra-operatively, it did diminish visualization and require slowing down of resection. Similar to some commercially available spine retractor systems, the addition of a light source would improve visualization and surgeon ease.

While we primarily used a microsurgical technique, an endoscope could also be employed with this system. The current design would permit a single surgeon to employ endoscopic illumination in order to resect selected lesions or perform microsurgical resection along with endoscope assistance at certain stages of tumor resection.

Lastly, it is important to recognize that the use of this rectractor is not a substitute for appreciating cortical and white fiber anatomy in planning surgical trajectories to deep lesions. Depending on the lesion's location in relation to surface anatomy, a trans-sulcal approach is the preferred approach as opposed to trans-cortical entry. In addition, approaches to deep targets require careful consideration of white fiber tracts (i.e., corticospinal tracts) that may serve as obstacles. Traditionally, surgeons have modified their approach in order to circumvent these fibers as much as possible. The use of the tubular retractor does not eliminate the need to consider the location of these anatomic structures.

Study limitations and future studies

This study, while primarily an operative technique report, has several limitations. Another radiographic methodology for assessing white matter displacement and damage would be diffusion tensor imaging/white fiber tractography. While analyzing T_2/FLAIR and ADC/diffusion sequences provides surrogate markers of parenchymal injury, DTI sequences provide a more accurate means of determining damage not resulting in edema or ischemia. Since diffusion tensor imaging is not routinely performed post-operatively and due to the retrospective nature of the study, we were not able to accurately assess the extent of white matter manipulation. Future prospective studies should be aimed at comparing such tubular retractors with traditional retractor systems on the basis of assessing white matter manipulation – including the use of DTI. This information will be necessary to support the hypothesis that tubular retractors minimize pressure on surrounding tissue in comparison to traditional spatula retractors.

Conclusions

▼

Recognizing the consequences of tissue manipulation, the goal of minimally invasive approaches is to improve morbidity by tailoring approaches and minimizing tissue disruption. While endoscopy has established its role in the management of selected cranial base and intra-axial lesions, microsurgical approaches are still the foundation in the treatment of many tumors. Fundamental to these approaches is not only selecting appropriate trajectories that avoid crossing critical white fiber tracts but also avoiding damage to underlying white matter through an appropriately selected cortical entry. The issue of direct and vascular injury as a result of overzealous retraction – even in expert hands – is well documented. While tubular retractors linked with frame-based navigation systems have been described, their acceptance was not widespread due to several reasons highlighted earlier, such as their need for frame-based stereotactic systems, their bulky and metallic nature (preventing visualization of surrounding tissue). The tubular retractor system is the first modern system designed specifically for intra-cranial applications and due to its low profile, thin-walled, transparent construction lends its self well to minimally invasive microsurgical approaches. When used in combination with conventional frameless navigational systems, we have found that the system provides adequate visualization while minimizing tissue morbidity for select lesions. The use of navigation permits not only the creation of a smaller craniotomy but also facilitates the creation of a trajectory that provides an efficient and safe means for splitting white fiber tracts. It must be kept in mind that several microsurgical corridors and techniques can be used for deep lesions; for selected lesions amenable to minimally invasive approaches, one option is a tubular-based retractor system. Future studies should focus on prospectively comparing this tubular retractor system with traditional systems with an emphasis on analyzing white matter manipulation through T_2/FLAIR, ADC/diffusion restriction and diffusion tensor imaging.

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