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Original Investigation

Keyhole Transsylvian Resection of Infiltrative Insular Gliomas: Technique and Anatomic Results

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To watch the surgical videoclip, please visit http://turkishneurosurgery.org.tr/images/14534_video.mp4

ABSTRACT

AIM: Insular gliomas have traditionally been approached through variations of large frontotemporal craniotomies exposing much of the Sylvian fissure. Due to the importance of many structures exposed by such an approach, a less-invasive approach to these lesions is a viable alternative for resection. We present the technique and results of our keyhole transsylvian approach to remove infiltrating insular tumors.

MATERIAL and METHODS: A small linear incision and keyhole craniotomy is planned under image guidance to open a transsylvian window. Using a combination of the microscope and endoscope, we remove the insula circumferentially outward. We present our results of 20 patients with gliomas confined to the insula evaluated with volumetric imaging analysis.

RESULTS: There were 12 right-sided and 8 left-sided tumors. The median skin-to-skin operative time was 215 minutes. 15/20 patients were discharged from the hospital on or before post-operative day 3, with 5 of those going home the day after surgery. Greater than 90% of the tumor was removed in 18 of 20 cases, with an additional case achieving 89.5% resection. In no case was the residual tumor volume greater than 3 cc. Permanent weakness occurred in 2 patients (10%). Despite a significant number of left-sided tumors, temporary dysphasia occurred in only 1 patient (12.5%), which resolved by first follow up.

CONCLUSION: Localized insular gliomas can be effectively removed through a minimally invasive approach without increasing the risk of neurological morbidity. This minimizes manipulation of uninvolved, potentially eloquent cortices, and minimizes damage to the overlying soft tissue.

KEYWORDS: Keyhole, Minimally invasive, Insular, Glioma, Transsylvian

INTRODUCTON

Surgery in the insula is challenging in anyone's hands using any technique. While removal of the insula is generally well tolerated, the deep and central location of the insula forces the surgeon to avoid and/or manipulate a number of important brain structures, including the middle cerebral vasculature, the internal capsule, the basal ganglia, and the overlying opercular cortices, many of which contain eloquent brain regions (12). For this reason, insular tumors were long considered inoperable, and even today are generally only gross totally resected in experienced hands at large volume centers (4, 9, 12, 21, 23).

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Insular gliomas are traditionally approached through some variation of a large frontotemporal craniotomy that exposes all or most of the Sylvian fissure (4, 9, 12, 21). The insula can then be exposed through either a transopercular route, in which the overlying opercular cortices are removed, usually after intraoperative mapping confirms their non-eloquence (12), or through a transsylvian route which utilizes arachnoidal dissection to open the Sylvian cleft and define and isolate the middle cerebral branches, in order to remove the insula between these branches (23). The frontal paracortical route has been described, but is mostly used for frontal-predominant insular-involving multilobar tumors (14).

Large craniotomies have generally been used to approach the insula in the transsylvian approach because it was felt that a wide Sylvian split was needed to create working room and to clearly define the Sylvian vascular anatomy (20). While smaller craniotomies and less extensive Sylvian splits can be performed to address small focal insular masses, such as cavernous malformations (2, 19), infiltrating tumors are more extensive, and many feel that they require more exposure. However, given the depth of the insula, we would propose that such wide working angles are unnecessary at the bone and dura, as frequent manipulations of the microscope can allow for a remarkably wide angle of visualization at the depth of interest, a fact that does not hold true for more superficial masses (Figure 1A-C). Given the importance of many of the brain structures exposed through a large frontotemporal craniotomy, namely speech and motor cortices (11), it seems wise to attempt to expose as little of the brain as is necessary to achieve the surgical goal, as approach-related cortical injury can occur during a craniotomy even in experienced and capable hands. Further, large exposures in this region require extensive manipulation of the temporalis muscle, which can lead to atrophy (6). Finally, larger craniotomies raise the risk of postoperative epidural or subdural hematomas (10), which in our experience almost never happens with small craniotomies. For all of the above reasons, we have developed and optimized a frontotemporal keyhole transsylvian approach to remove infiltrating insular tumors, and here we present our technique and results with localized insular gliomas.

■ MATERIAL and METHODS

Surgical Technique

Patients are positioned supine or 10-20° semilateral (depending on degree of neck rotation). The head is turned approximately 30° in the Mayfield frame so that the highest point on the head is the portion of the Sylvian fissure directly overlying the long axis of the tumor (Figure 2C). This will allow gravity to concentrically pull the overlying brain away from the area of interest, similar to a banana peel falling away from a banana as it stands on its point. Proper positioning makes the use of fixed brain retraction of the opercular cortices unnecessary.

Using image guidance, the tumor location and the location of the Sylvian fissure are thoroughly mapped out and an ideal keyhole craniotomy is planned to center the craniotomy over the long axis of the tumor (Figure 1A-C). If the overlying opercular cortices are involved with tumor, the craniotomy must be widened to include the bone overlying cortices, as these are too close to the surface for the two-point concept to translate to comfortable working angles.

After selecting the craniotomy site, an incision is planned which is linear or slightly curved hidden just behind the edge of the hairline (Figures 2D, 3C). This rarely needs to be made longer than 5 cm, and is never significantly curved, maximizing the angle of potential vascular inflow to both sides of the wound with a linear incision. After skin incision, the underlying

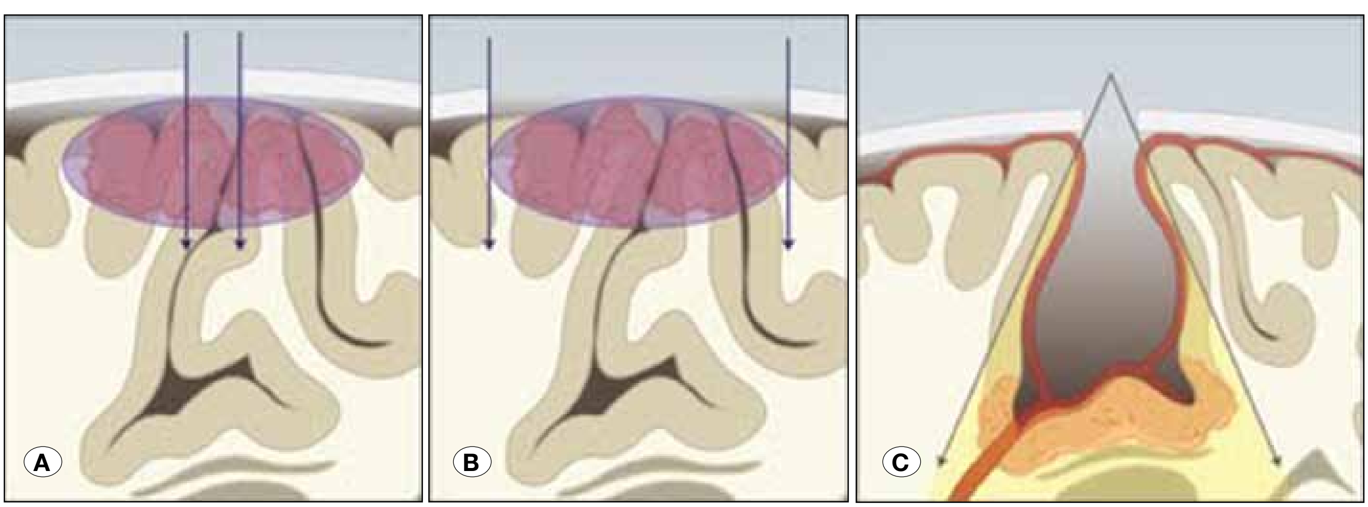


Figure 1: Schematic demonstrating the keyhole concept applied to tumors at superficial depth. **A)** Note that, like looking through a keyhole, it is difficult to see directly around the corner, and thus the ability to address superficially-placed tumors with a small bone flap is limited. **B)** A more appropriate bone flap for superficially-based tumors exposes the entire extent of superficial involvement. **C)** The keyhole concept applied to removing tumors from a deep structure like the insula. Note that, like looking through a keyhole, it is possible to obtain a much wider view and set of working angles for tumors located at depth versus working superficially, and thus minimally-sized bone flaps can be made to address these lesions.

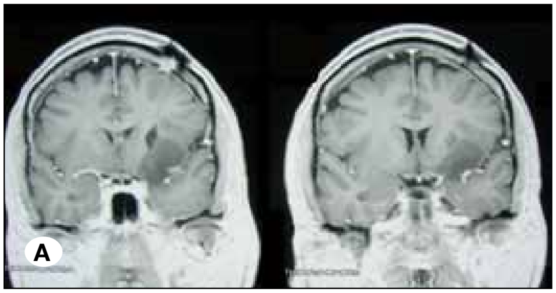
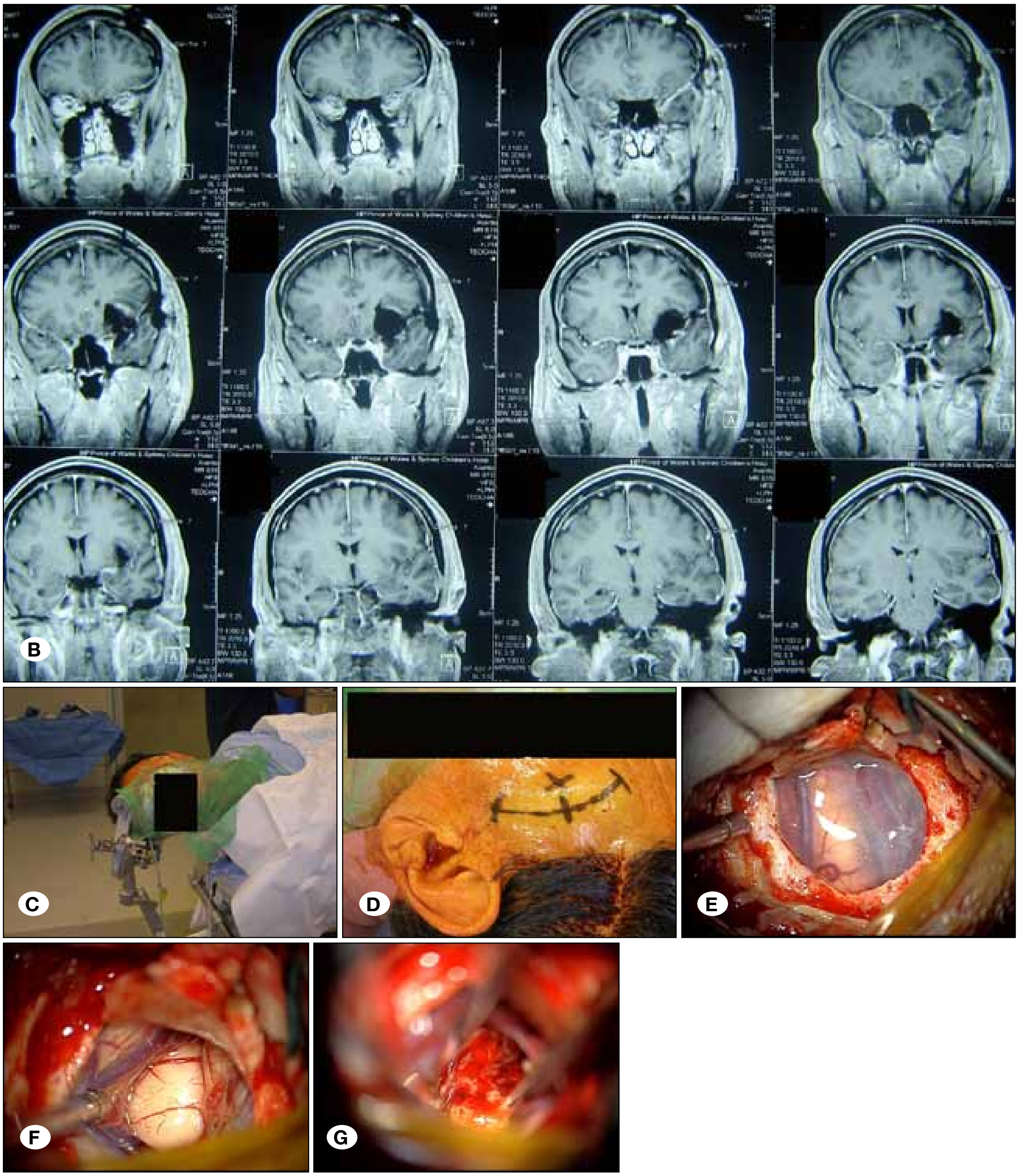


Figure 2: Keyhole transsylvian resection of a low grade insular glioma. **A)** Preoperative images demonstrate a low grade astrocytoma localized to the anterior insula. **B)** Post-operative images demonstrate an excellent resection. **C,D)** Photos demonstrating patient positioning and skin incision, with X marking the site of the bone flap; note that the hair has been shaved, and the incision is behind the hairline. **E)** Intraoperative photo demonstrating the Sylvian venous system exposed through the keyhole craniotomy, **F)** appearance following the Sylvian split and identification of the window into the insula, and **G**) resection of the insular tumor; note the insular vessels in the foreground of this picture.



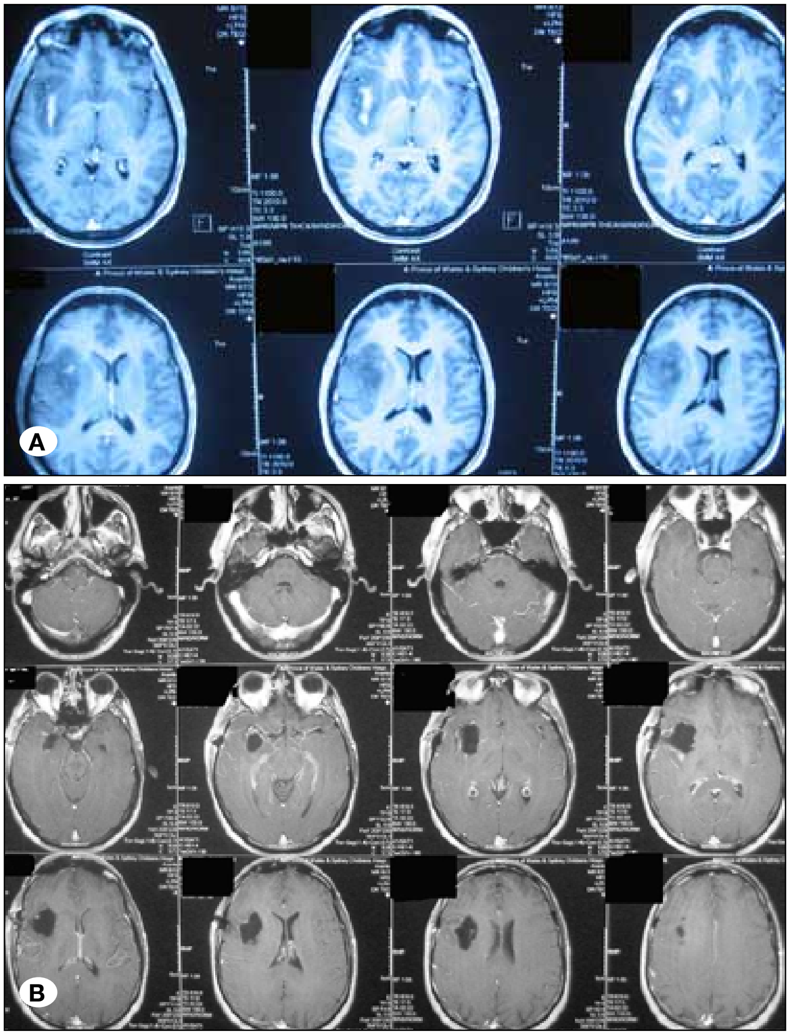
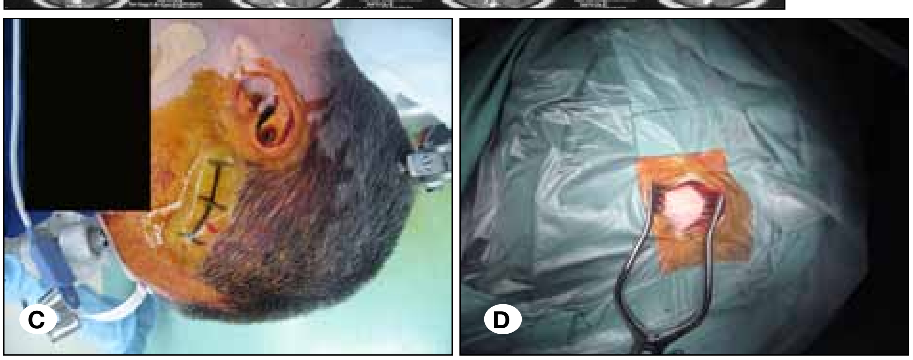
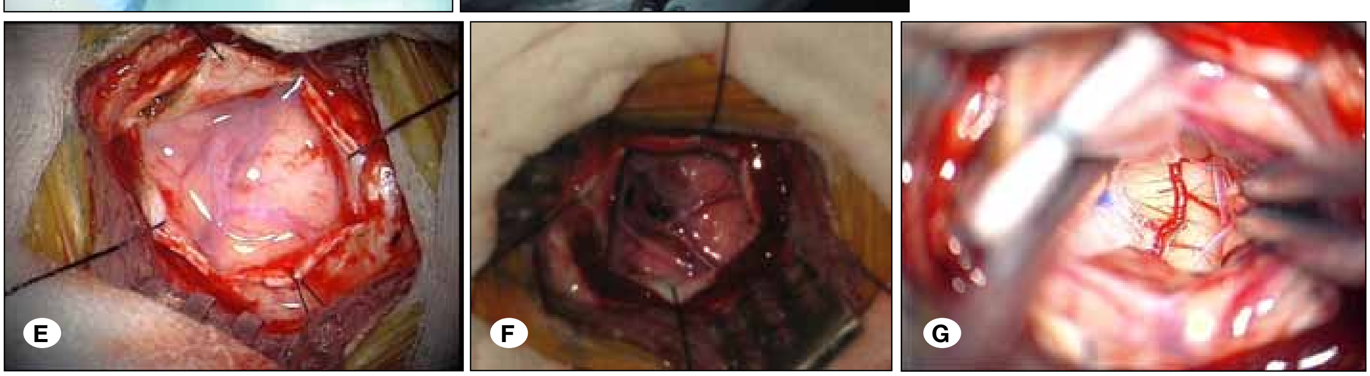


Figure 3: A) Preoperative images demonstrating an insular anaplastic astrocytoma. **B)** Post-operative images demonstrating an excellent resection via the keyhole approach. **C)** Image demonstrating patient positioning and the incision, **D)** the soft tissue exposure, **E)** exposure of the Sylvian fissure, **F)** the appearance of the fissure after arachnoidal dissection, and **G)** the exposure of the insula provided by this approach.





temporalis muscle is cut in a linear fashion with a monopolar cautery, undermined with a periosteal elevator, and retracted with a self-retaining retractor. The craniotomy is made with a single burr hole, and is about 3 cm in maximum diameter if only the insula is involved.

Intradural Work

If the image guidance-based planning is accurate, the exposure should demonstrate the superficial Sylvian venous system, which demarcates the temporal side of the fissure. Arachnoidal dissection is utilized to open the superficial arachnoid along the length provided by the craniotomy. It is important to note that, because of the greater degree of working angles subtended through a craniotomy at depth, this 3 cm superficial arachnoid opening may be utilized to access a wider length of the fissure at the depth of the lesion. Careful arachnoidal dissection is used to expose the insular vessels and insular cortex along the length of the tumor as defined by image guidance. Because this technique avoids opening the proximal fissure and the basal cisterns, the brain shift is much less than in larger Sylvian splits, and the image guidance remains relatively accurate.

Insular resection proceeds through as many perivascular windows as are provided by the Sylvian middle cerebral artery anatomy; typically no more than one or two windows are provided in this approach. Tumor resection then proceeds according to the anatomic demands of the tumor, guided by standard visual and tactile clues and image guidance. In many cases, the endoscope can be introduced to expand the extent of resection around that provided by the exposure. Angled suctions and bipolars can be helpful to work around corners in this tight space.

Patient Population

Data for all patients undergoing surgery at our center were collected prospectively, and this was used to identify cases for this study. The current study is a retrospective review based on all insular glioma cases performed using this approach at our center between 1999 and 2010. The patients included in this study underwent surgery for an infiltrating glioma principally limited to the insula using the approach described above. Patients with tumors significantly involving the frontal or temporal lobes, or the overlying opercular cortices, required some modification of this approach. Namely, they typically required a slightly larger bone flap than those patients in whom the tumor was limited to the deeper insular structures. Consequently, for simplicity of analysis, we excluded those patients from this report.

All patients underwent post-operative magnetic resonance (MR) imaging in the first 48 hours, and thereafter as needed for oncologic management. The extent of resection was determined based on the first post-operative imaging. This study was performed with the approval of local institutional guidelines for human research.

Data Collection

The goal of this study was to determine the safety and efficacy of the keyhole transsylvian approach to insular tumors. We thus limited this analysis to determinations of extent of resection, neurological, and surgical complications. Extent of resection was calculated using volumetric assessments, in which the total planimetric tumor volume on all slices was first calculated as a percentage of the total volume, to normalize values between imaging studies stored using different imaging techniques. The extent of resection for largely non-enhancing tumors was calculated by comparison of pre- and post-operative T2 imaging changes. The extent of resection for enhancing tumors was calculated by comparing pre- and post-operative volumes of enhancement. The tumor and total brain volumes for a given image were analyzed using identical scale, brightness and contrast scanning, and were calculated for analogous brain regions between imaging studies. The tumor and brain outlines were traced by a neurosurgeon using Adobe Photoshop, and the overlays of the tracings were exported. These tracings were quantitatively assessed using the ImageJ program (NIH), specifically quantifying the total area within the tracing volume using the count particles function, and expressing the tumor volume as a fraction of total hemispheric volume.

Neurologic deficits were compared to pre-operative baseline, and the worsening of a pre-existing deficit, or the presence of a new neurologic deficit, were both considered to be neurologic complications. The term ‘surgical complication’ includes any cerebrospinal fluid (CSF) leak, meningitis, wound infection or breakdown. Central pathology review was performed on the basis of the most recent World Health Organization (WHO) guidelines (8). Clinical data were collected from patient records and telephone interviews. All clinical assessments were performed by a neurosurgeon.

■ RESULTS

Patient Population

We identified 20 patients who underwent keyhole surgery for tumors localized mainly to the insula. The basic demographic characteristics are listed in Table I. This cohort included five glioblastomas (WHO grade IV), six WHO grade III astrocytomas, five WHO grade II astrocytomas, and four WHO grade II oligodendrogliomas. The median patient age at time of surgery was 36.5 years (range 26-54 years). There were 12 right-sided and 8 left-sided tumors in this series. The median skin-to-skin operative time was 215 minutes (range 100-305 minutes). Fifteen of twenty patients were discharged from the hospital on or before post-operative day three, with five patients going home the next day after surgery. Two cases are illustrated in Figures 2A-G and 3A-G.

Extent of Resection

To determine if we could achieve a similar extent of resection using a keyhole approach as through a larger craniotomy, we subjected our pre- and post-operative images to computerized volumetric analysis as described above. In one half of the cases, complete radiographic resection of all tumors was achieved. Greater than 90% of the tumor was removed in eighteen of twenty cases, with an additional case achieving 89.5% resection. In no cases was the residual tumor volume greater than 3 cm^3.

Neurological Morbidity

To address the potential concern that working in a smaller space could compromise our ability to work safely around the insular vasculature and to navigate in the deeper cortical and subcortical structures, we analyzed our rates of radiographic and neurologic morbidity in this patient population. There were no major vascular injuries or cortical infarction; a single patient had an asymptomatic subcortical infarct in the genu of the internal capsule, and went home on post-operative day two.

The pre-operative and discharge Karnofsky performance status (KPS) scores are provided for the patients in Table I. Six patients experienced some improvement in performance status immediately post-operatively, eight patients retained the same performance status, and six patients experienced at least a slight decline in performance status. Most of these declines were slight (i.e. a 10 point change) and could probably be attributed to post-surgical recovery, improving to baseline or better by their first clinic visit. Two patients experienced performance status decline of more than 10 points.

Thirteen of 20 patients (65%) in this series were neurologically normal immediately after surgery. Temporary limb weakness or hemiplegia (defined as objective or subjective weakness which completely resolved to baseline by the first post-operative clinic visit) occurred in 5 patients. Permanent weakness occurred in the 2 patients mentioned above who suffered a decline in performance status. One patient had arm weakness that partially improved in follow-up, and another had hemiparesis that mostly improved in follow-up. Despite a significant number of left-sided tumors in this series, temporary dysphasia occurred in only 1 patient, which had largely resolved by discharge on post-operative day 5. Her speech was objectively normal by the first post-operative clinic visit.

Surgical Complications

There were no wound infections, episodes of wound breakdown, pseudomeningocele, or CSF leak in this series. No patients required CSF diversion of any kind. There were no symptomatic or asymptomatic epidural or subdural hematomas noted on post-operative imaging. No patients complained of temporalis atrophy or wound-associated alopecia, and we did not objectively observe any of these issues in these patients.

■ DISCUSSION

Insular lesions can be safely resected via either a transfrontal, transopercular or a transinsular approach. While removal of opercular cortex after functional mapping certainly simplifies access to the subinsular region, there is some evidence that removal of even nominally "non-eloquent" brain has demonstrable cognitive consequences, and is probably best avoided whenever technically feasible (1, 13, 22). Thus, while

Table I: Patient Demographics and Outcomes

Patient number	Age	Sex	Side	Post-op stay, days	Op time	Endoscopy	Pathology of tumor with grade	% Resection	Pre-op KPS	Post-op KPS
1	32	M	R	3	270	N	Astrocytoma (Grade II)	100%	70	80
2	49	F	R	7	235	N	An. Astrocytoma (Grade III)	100%	80	50
3	31	M	R	2	203	Y	An. Astrocytoma (Grade III)	100%	80	80
4	39	F	L	2	225	Y	Oligodendroglioma (Grade II)	100%	90	50
5	36	M	L	3	175	Y	Astrocytoma (Grade II)	100%	80	90
6	26	M	L	1	263	N	Astrocytoma (Grade II)	100%	100	80
7	50	M	R	3	217	N	Oligodendroglioma (Grade II)	100%	80	80
8	36	M	R	3	255	N	Oligodendroglioma (Grade II)	100%	80	80
9	46	M	L	2	195	N	GBM (Grade IV)	100%	70	80
10	46	M	R	7	325	Y	An. Astrocytoma (Grade III)	100%	80	80
11	30	M	R	3	245	N	An. Astrocytoma (Grade III)	99.9%	90	80
12	37	F	R	3	210	N	An. Astrocytoma (Grade III)	99.0%	70	80
13	26	M	L	5	210	N	GBM (Grade IV)	98.0%	80	70
14	26	M	R	4	285	Y	Astrocytoma (Grade II)	95.5%	70	60
15	54	F	R	10	100	N	GBM (Grade IV)	95.0%	80	80
16	54	F	R	3	170	N	GBM (Grade IV)	92.0%	70	60
17	29	M	L	3	311	Y	GBM (Grade IV)	91.1%	60	50
18	35	M	R	2	250	N	An. Astrocytoma (Grade III)	90.1%	70	90
19	45	F	L	3	185	N	Astrocytoma (Grade II)	89.5%	80	90
20	43	M	L	2	205	Y	Oligodendroglioma (Grade II)	66.7%	80	90

***M:** Male, **F:** Female, **L:** Left, **R:** Right, **An.:** Anaplastic, **GBM:** Glioblastoma multiforme, **Y:** Yes, **N:** No.*

we would not hesitate to remove the superior temporal gyrus if involved with tumor, for tumors contained within the insula, a resection that achieves equal anatomic results without removing normal brain is inherently preferable.

In this study, we have demonstrated that surgery for infiltrative lesions localized to the insula can be performed using small incisions, keyhole craniotomies, and minimal disruption of the overlying opercular cortex. We achieved very acceptable resections of these localized tumors using keyhole surgical techniques, with extent of resection comparable to published surgical series by very experienced glioma surgeons operating through significantly larger openings, with large U-shaped incisions, elevation of the entire temporalis muscle, and large holo-frontotemporal craniotomies (4, 9, 12, 14, 21). Our results are compared to other large published series in Table II.

Through avoidance of exposure and manipulation of normal opercular cortices through the use of the transsylvian route yielded minimal speech morbidity, despite not performing awake speech or motor mapping in any of our left-sided cases. Thus, we conclude that it is possible to remove insular gliomas through a keyhole frontotemporal transsylvian route with results similar to those achieved by expert surgeons operating through conventional approaches. In other words, efficacy is not sacrificed by removing these lesions through a smaller opening, if the craniotomy is planned and performed correctly.

It is important to mention that excellent functional results have been obtained in resecting insular tumors using cortical-subcortical stimulation mapping, with permanent deficit rates of 4-6% reported in recent years (3, 12, 15). While there is certainly a role for mapping in transopercular approaches, this is debatable for transsylvian approaches to the insula proper, which infrequently harbors eloquent brain. Nonetheless, the purpose of the present report is not to argue that subcortical mapping is unnecessary or unwise, and it is an important adjunct for many neurosurgeons. Rather, we are reporting our keyhole approach through the sylvian fissure to resect these tumors. Our rate of permanent motor weakness of 10% is slightly higher than the rates reported in recent series. However, the 95% confidence interval for this proportion has a wide range, 0% to 23%, due to the modest sample size. Of course, with a larger sample it is possible that a difference in morbidity would be seen. This would almost certainly reflect our aggressive philosophy in resecting gliomas rather than specific aspects of the minimally invasive approach.

A few technical points relevant to all keyhole surgery should be re-emphasized, as they are critical to achieving success with a keyhole opening (16, 17). While positioning and pre-operative planning are important to nearly all brain tumor surgeries, they are absolutely essential in keyhole surgery (16). Due to the small openings, keyhole surgery is unforgiving to errors in positioning and planning, and while incisions and bone flaps can be extended if necessary, the approach may not be ideal if one starts in the wrong spot (16). Specific to insular gliomas, the bone flap must be turned directly over the Sylvian fissure, and the head should be repositioned so that the trajectory over the fissure lies directly vertically. We recommend preserving all venous and arterial vessels until they have been followed and found to be insular in destination and not *en passant*. The microscope is an essential tool in the initial stages of keyhole surgery, providing high magnification at the depths of the insula to differentiate tumor from basal ganglia, specifically the caudate nucleus which has the typical appearance of cut nutmeg (Figure 4A,B).

In these cases, as in many other minimally invasive surgeries, the endoscope is a valuable tool for visualizing around corners in small spaces (17, 18). It is especially helpful in these cases as this approach avoids a traditional Yasargil-style separation of the entire Sylvian fissure down to the basal cisterns (20), and instead works through small perivascular windows. Generous use of endoscope-assisted surgery helps maximize the degree of resection at the peripheral margins of the insula, and at the same time minimizes retraction and contusion of opercula. We feel that in a keyhole approach, extensive insular tumors benefit greatly from the improved visualization provided by endoscopic assistance, and obviates the need to retract or manipulate the opercular cortices; we never used fixed blade brain retractors in any of these cases (5, 7).

It is important to note that this approach is not the panacea for all insular-involving gliomas. While tumors with some involvement of the overlying operculum can easily be accommodated with careful planning and a slightly larger opening, other tumors are better removed with a different approach. Considerations include the keyhole subtemporal and the supraorbital eyebrow approach, among others.

Finally, while of secondary concern, keyhole approaches are inherently faster and easier than traditional surgery, once pre-incision planning is complete. In many cases, our operative times are short, in part because we do not need to spend as much time opening and closing a large opening in layers,

Table II: Results of Select Series of Insular Gliomas

	N	Speech Deficit	Motor Deficit	>90% resection
Skrap et al., 2012	66	3%	3%	33%
Sanai et al., 2010	104	1%	5%	23%
Duffau et al., 2009	51	0%	4%	NS[1]
Simon et al., 2009	94	13%	13%	42%
Moshel et al., 2008	38	5%	13%	74%
Present Study	20	0%	10%	90%

[1]***Complete resection:*** *16%, <10 cm^3 residual disease in an additional 61%.* ***NS:*** *not stated.*

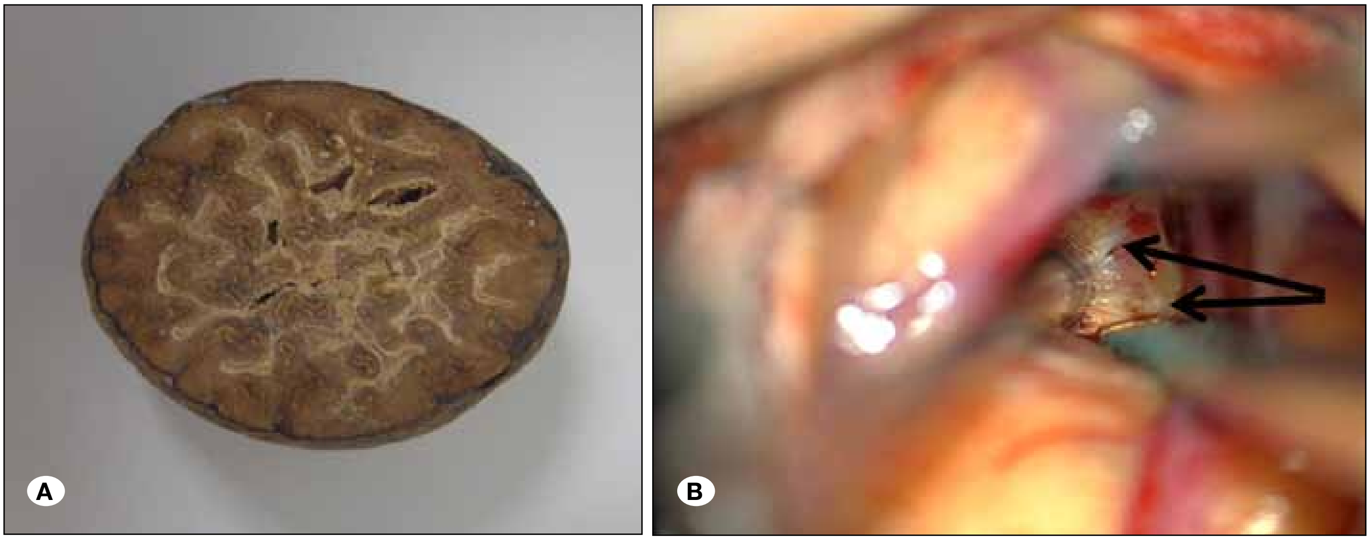


Figure 4: (A) A section of cut nutmeg which is similar in appearance to the caudate nucleus when encountered during insular surgery. It is important to recognize the appearance of the caudate when resecting insular gliomas, as it looks and acts like glioma tissue intraoperatively and is often only differentiated by its nutmeg-like appearance. **(B)** Intraoperative image demonstrating the white spots against a grey/red background, indicating that the edge of the caudate nucleus has been reached, signifying the limit of depth of the resection.

Supplemental Video: A narrated step-by-step video demonstrating the keyhole method for removal of insular gliomas.

drilling the pterion, obtaining hemostasis from a large surface area of bleeding sites, or performing other time consuming activities involved with opening a large bone flap. Most of these cases take about 7-10 minutes to open and similar time to close, without cutting any necessary corners which could cause surgical morbidity or wound complications. Because the risk of epidural hematoma is minimal, subgaleal drains are unnecessary. In addition to improving the cost-effectiveness of surgery by minimizing anesthetic times, patients recover quickly and often go home quickly. We are frequently able to stop the steroids on post-operative day one without issue. Thus, we argue that, by learning to work within a keyhole opening, one inherently becomes a more efficient and cost-effective surgeon as a result. In our opinion, given that results similar to those achieved by others can be obtained with shorter recovery times, this argues that the effort to learn to perform these surgeries through a keyhole is worthwhile.

■ CONCLUSION

In short, we demonstrate that gliomas localized to the insula can be effectively removed aggressively using a minimally invasive approach without increasing neurological morbidity. This technique minimizes manipulation of uninvolved, potentially eloquent cortices, and at the same time minimizes damage to the overlying soft tissue. In our experience, hospital stays are short, overall pain is less (in our experience most of these patients do not require oral narcotics at discharge), and wound complications are uncommon with smaller openings and short linear incisions, making efforts to reduce approach-related impact worthwhile in this patient population.

■ FINANCIAL DISCLOSURE/FUNDING STATEMENT

Dr. Teo is a consultant for Aesculap, however this work does not directly relate to the content of this report. The authors declare that they are not involved in any other relationships with companies that make products related to this study.

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