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Original Article

Minimally invasive image-guided keyhole aspiration of cerebral abscesses

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Abstract: Despite the low incidence of brain abscesses in Western nations (1-2%), the incidence in developing countries is as high as 8%. We evaluate a minimally invasive image-guided keyhole aspiration of cerebral abscesses and compare it with a series of cases treated with surgical excision. 23 patients (20 male and 3 female, aged 7-67 years) underwent image-guided burr hole aspiration of single or multiple cerebral abscesses. Patient characteristics, perioperative, and postoperative data were analyzed and compared with a second group of 22 patients (14 male and 8 female, aged 12-72) treated for cerebral abscesses with open surgical excision. In all cases, the surgical procedure was performed successfully without complication. 8 of the 23 aspiration cases were performed with the aid of iMRI. A comparison of patient demographics, duration of hospital stay, duration of antibiotic therapy, postoperative neurological recovery time, intraoperative blood loss, operative duration, length of incision, postoperative fever, repeat surgery, and mortality was performed between the aspiration and excision groups. Intraoperative blood loss, operative duration, length of incision, and postoperative fever were all significantly reduced in the aspiration group. Though, duration of hospital stay and antibiotic therapy and postoperative neurological recovery time were all increased in the aspiration group, and statistical significance was observed in all except the duration of hospital stay. This technique is a feasible and comparable minimally invasive alternative to open surgical excision and may provide reduced intraoperative blood loss, shortened operative duration, improved cosmetic outcomes, and a lessened incidence of postoperative fever.

Keywords: Brain abscess, burr hole, neuronavigation, drainage, aspiration, minimally invasive

Introduction

Brain abscesses are focal collections of pus within the brain parenchyma that are the result of bacterial or fungal infections [1]. Intracranial abscesses are rare and can cause severe inflammation and neurological deficits. Recent advances in neurosurgical techniques have improved management of intracranial abscesses with the development of new antibiotics, more efficient culturing and identification methods, and novel non-invasive imaging including computed tomography (CT) with software algorithms to quickly process imaging data and provide accurate intraoperative localization of intracranial lesions.

Despite the low incidence of brain abscesses in Western nations of 1-2%, the incidence in developing countries is approximately 8%. In recent years, minimally invasive neurosurgery has become more common due to improvements in neurosurgical technique and equipment. The treatment of brain abscesses is challenging due to the various causative pathogens and etiologies. However, in addition to antibiotic therapy, early surgical intervention can improve clinical symptoms. Commonly, after performing an initial craniotomy, the contents of the abscess is drained or aspirated. However, inadequate aspiration or drainage is a common failure for deep-seated brain abscesses. We evaluate a minimally invasive image-guided keyhole aspiration of cerebral abscesses performed on 23 patients at our institution from April 2009 to March 2013 and compare the results with those of 22 patients treated with classic open surgical excision treated at our institution from January 2005 to May 2009.

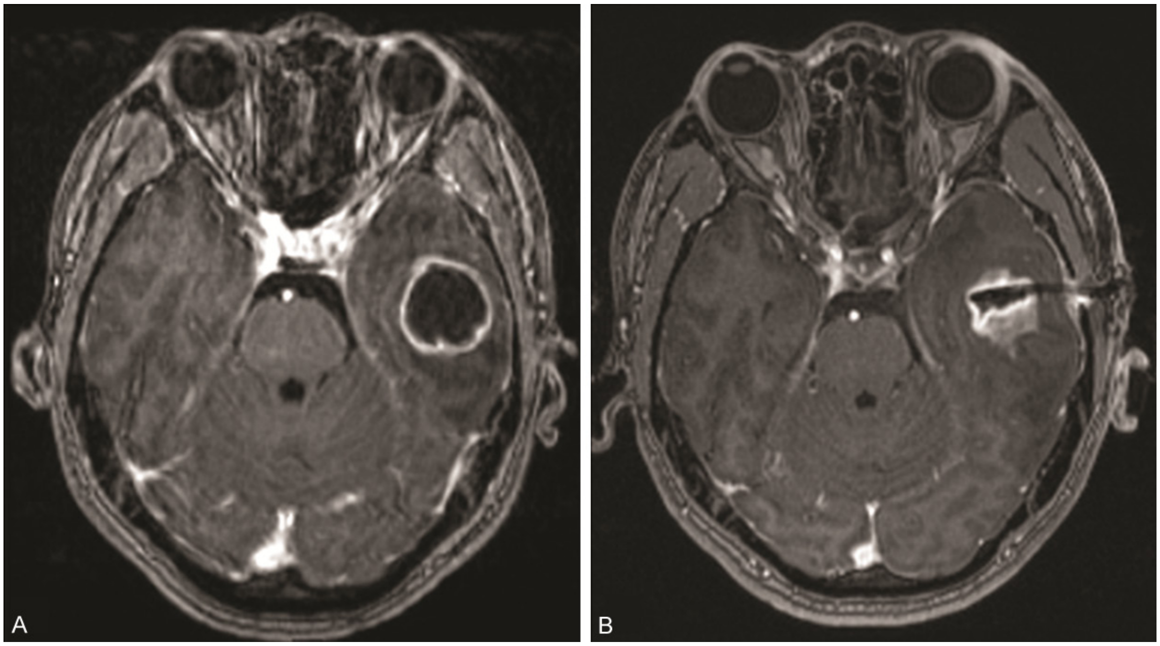

Figure 1. Intraoperative MRI of Case 1 demonstrating a non-collapsed abscess cavity (A) and proper drainage tube positioning (B).

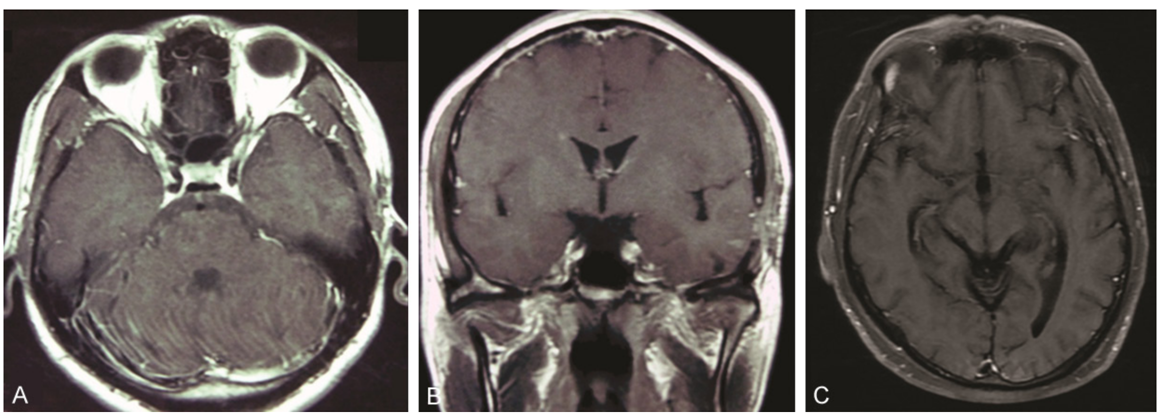

Figure 2. Axial (A, C) and coronal (B) CT's of Case 1 at 6 month follow-up showing complete resolution of the abscess.

Materials and methods

23 consecutive cerebral abscesses were treated with image-guided keyhole aspiration at our institution between April 2009 and September 2013. Patient data was reviewed for demographic and imaging data, clinical presentation, neurological status at admission, length of hospital stay, lesion location, lesion size/number, etiology, complications (based on the longest period of follow up), and outcome. These collected parameters were compared to a second group of 22 patients treated at our institution from January 2007 to September 2013 with classical craniotomy and excision.

Image acquisition and preoperative planning

Each patient in the keyhole aspiration group underwent preoperative magnetic resonance imaging (MRI), including T1-weighted 3D magnetization-prepared rapid-acquisition gradient echo (MP-RAGE), T2-weighted, T2 FLAIR, diffusion tensor image, and post-contrast 3D T1-weighted MP-RAGE sequences obtained using a dual-room iMRI with a scanner and movable 1.5-T magnet (MAGNETOM Espree; Siemens Ltd.; Beijing, China) (**Figures 1**, **2**) [2, 3].

Neuronavigation planning software (iPlan 2.6, Brainlab AG; Feldkirchen, Germany) was uti-

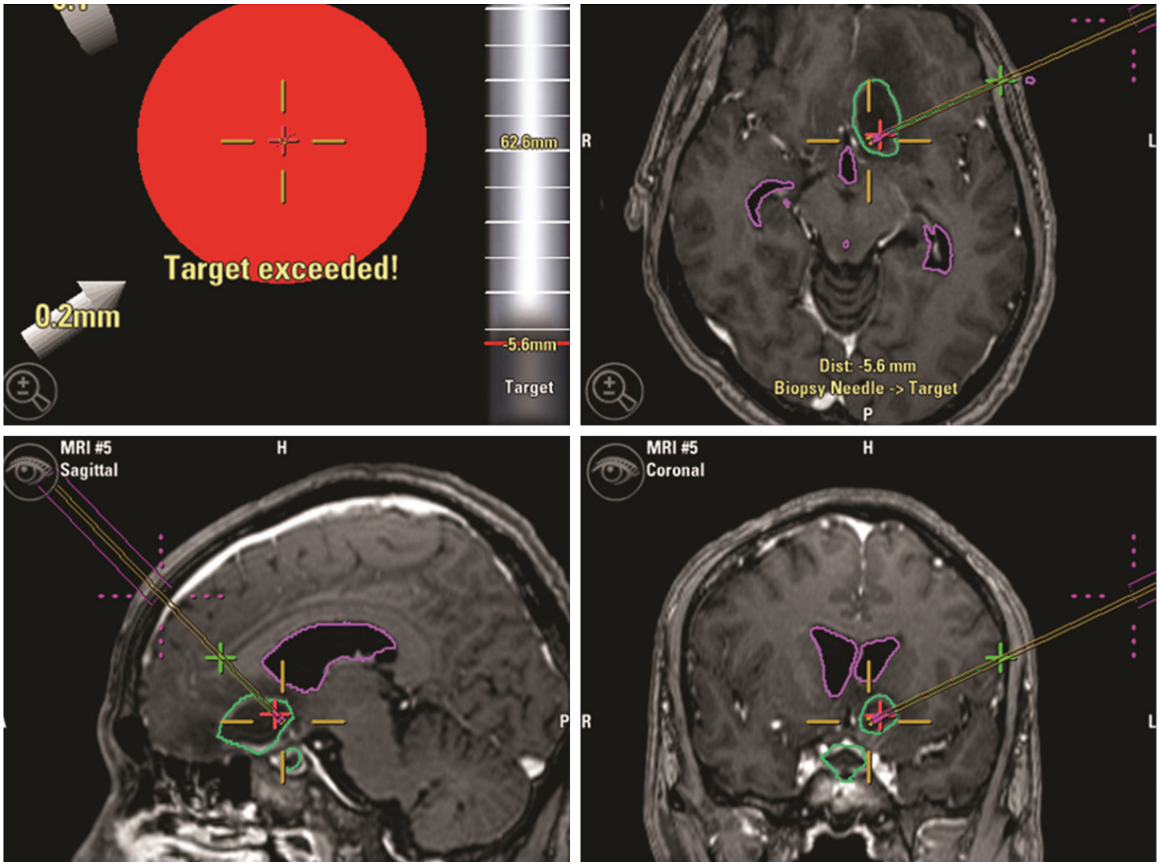

Figure 3. Case 2. Neuronavigation screenshot showing preoperative fMRI of a 51 years old male with a deep frontal lobe abscess. The operative trajectory, designed to avoid the ventricle puncture tract, is also visible.

lized to perform 3D reconstruction of the images (**Figure 3**) [4]. 3D Reconstruction of the abscess was performed using high-resolution post-contrast sequences and, as all abscesses displayed clear ring enhancement, the outermost rim of enhancement was considered to be the border of the abscess. The abscess was out-lined on all applicable slices, reconstructed into a 3D object, and its volume was calculated using the planning software. The fiber tracking module of iPlan 2.6, based on a tensor deflection algorithm, was utilized to reconstruct the pyramidal tract and, in select cases, the arcuate fasciculus. This data was then transferred to the neuronavigation unit and utilized for intraoperative image-guide navigation [3-5].

Surgical technique

Six-point fixation was achieved using a Sugita® Head Frame (Mizuho Medical Inc.; Tokyo, Japan) and the patient was registered with the neuronavigation system. The trajectory planning feature of the neuronavigation system was used to plan a safe route to the abscess that avoided critical neurovascular structures (**Figure 3**). A straight or curved ~2-4 cm skin incision was fashioned based on the preplanned trajectory. A self-retraining Adson Retractor was used to retract the scalp bilaterally, the bone was exposed, and a single 1 cm diameter burr hole was placed. The dura was incised and a soft plastic catheter with a straight guidewire was directly inserted into the abscess cavity (**Figure 4**). Aspiration of the abscess was performed using the catheter and care was taken to avoid the eloquent areas and conduction tracts (**Figure 5**). Eloquent areas were considered to be the motor and sensory strip, the speech and visual centers, and the hypothalamus and basal ganglia.

After drainage was completed, a syringe was used to aspirate any remaining pus. Following evacuation of the abscess, saline was used to copiously irrigate the abscess cavity until no

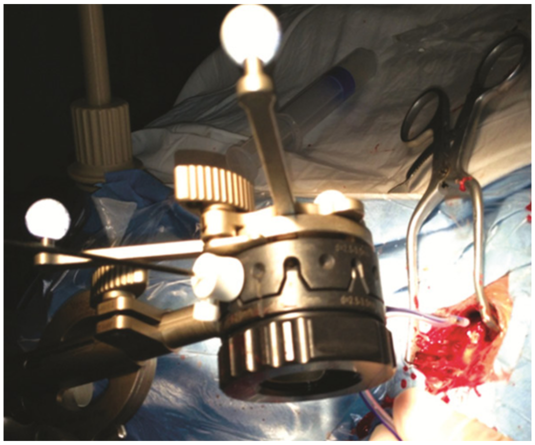

Figure 4. Using the image-guided neuronavigation system, a biopsy needle was advanced into the surgical opening to with a drainage tube.

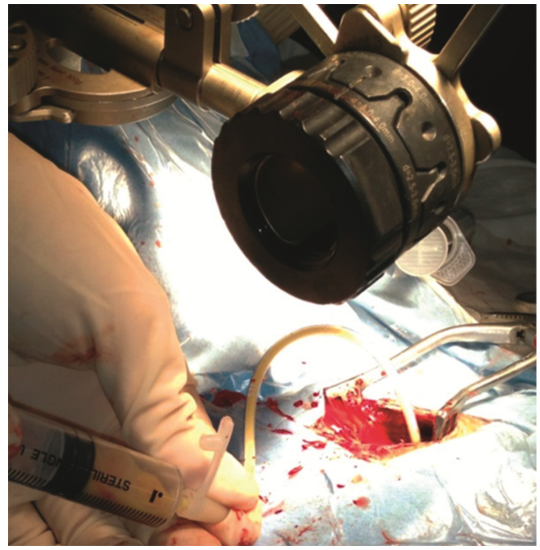

Figure 5. Aspiration of pus. The abscess cavity was repeatedly washed with saline and the cavity was filled with antibiotics.

further residual pus could be observed. A soft catheter was left in situ to serve as an external drainage tube. External drainage was removed after cessation of drainage was observed.

Statistical analysis

Statistical analysis was performed using SPSS software (Version 13.0.0, IBM Corporation; Armonk, NY). Estimated blood loss, postoperative complications, duration of hospital stay, postoperative neurological improvement time, postoperative fever, mortality, reoperation, and duration of antibiotic therapy as well as patient demographics were compared and analyzed in both the aspiration and excision groups. Categorical variables were compared using the chi-square test and a comparison of the mean values was performed using a paired t-test. P values of < 0.05 were considered to be significant.

Results

Patient demographics

20 males (87%) and 3 females (13%) with a mean age of 40.17 years were successfully treated with image-guided keyhole aspiration using functional neuronavigation and were seen for follow up for 3 months to 3 years. All patients recovered postoperatively with the exception of 1 patient who required a second drainage 10 days following the initial aspiration.

All the lesions appeared hyperintense on T2-weighted images and hypointense on T1-weighted images with perifocal edema and rim enhancement on post-contrast T1-weighted images (**Figures 1**, **2**). Diffusion-weighted imaging, performed in 21 cases, showed hyperintense lesions. The diameters of the abscesses ranged from 2.5 cm to 6.1 cm with a mean diameter of 4.1 cm. Contrast CT scans were performed in 18 cases wherein ring enhancement was clearly represented.

Lesions were located in the frontal (30.3%), frontoparietal (12.9%), parietal (13%), tempoparietal (8.6%), temporal (12.9%), frontotemporal (4.3%), occipital (4.3%), parieto-occipital (4.3%) thalamic (4.3%), and cerebellar (4.3%) regions (**Table 1**). Abscesses were identified in eloquent areas-including the motor and sensory strip, speech and visual centers, and hypothalamus and basal ganglia-or deep cortical regions in 10 cases (44%), adjacent to the eloquent areas in 9 cases (39%), and in non-eloquent areas in 4 cases (17%).

Clinical presentations included increased intracranial pressure (83%), focal neurologic deficits (44%), fever (17%), visual field deficits (17%), seizures (13%), aphasia (9%), and cognitive impairment (4%).

Causes of infection included contiguous spread from otitis media and nasosinusitis in 5 cases (22%), hematogenous infection in 3 cases (13%), post-neurosurgical infection in 2 cases (8.6%), and an open head injury in 1 case

Table 1. Location of cerebral abscesses

Location	No. of cases (%)
Single	19 (82.7)
Frontal	6 (26.0)
Frontoparietal	2 (08.6)
Frontotemporal	1 (04.3)
Temporal	2 (08.6)
Tempoparietal	2 (08.6)
Parietal	3 (13.0)
Occipital	1 (04.3)
Thalamic/Basal ganglia	1 (04.3)
Cerebellar	1 (04.3)
Multiple	4 (17.3)
Frontal†	1 (04.3)
Temporal*	1 (04.3)
Frontoparietal*	1 (04.3)
Parieto-occipital*	1 (04.3)
Total	23 (100.0)

*Two lesions; †three lesions.

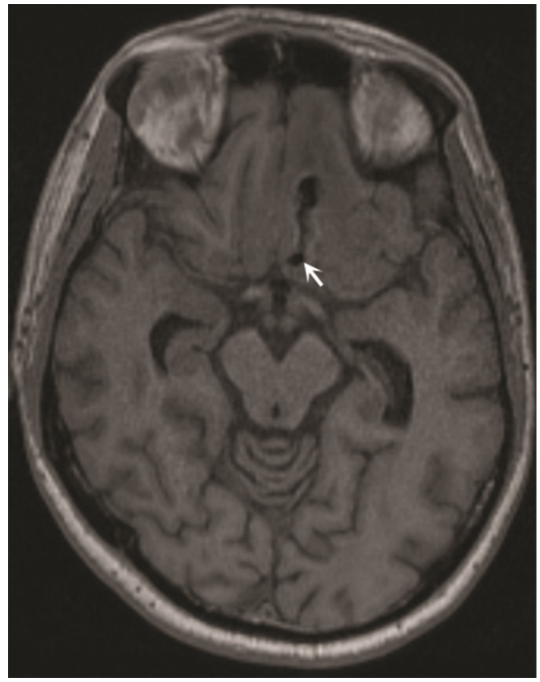

Figure 6. Intraoperative MRI scan of Case 2 showing satisfactory drainage of pus and collapse of the wall of the abscess. The white arrow indicated the tip of the drainage tube.

(4.3%). Idiopathic infections were observed in 12 cases (52%). Of the 23 patients, 17 received preoperative antibiotics before being referred to our department.

Surgical procedure

In all cases, the surgical procedure was performed successfully without complication. In the 4 patients with multiple abscesses, 3 underwent multiple aspirations during a single surgery. 8 of the 23 cases were performed in the iMRI suite and iMRI was used to confirm the complete evacuation of the abscess cavity (**Figure 6**).

Postoperative course

Bacterial and fungal cultures were performed regularly during the postoperative course. 11 patients (48%) had positive cultures including escherichia coli in 2 cases (8.7%), viridans streptococci in 2 cases (8.7%), streptococcus constellatus in 2 cases (8.7%), staphylococcus epidermidis in 2 cases (8.7%), staphylococcus coagulase in 1 case (4.3%), Acinetobacter baumannii in 1 case (4.3%), and Enterococcus hirae in 1 case (4.3%). Preoperative antibiotic therapy correlated strongly with sterile cultures and is likely the reason for obtaining only 11 positive cultures in this series.

Sixteen patients (70%) showed improvement of symptoms and neurological status within the first day following surgery, and an additional 3 patients (13%) showed improvement by the second postoperative day. Moreover, one patient with hemiplegia showed improvement after 10 days and another patient showed temporary postoperative deterioration with eventual recovery after 15 days. The average time observed for symptom improvement was 2.73 ± 3.49 days.

Full radiologic disappearance of the abscess, with complete absorption of its wall, occurred within 3 months to 1 year following surgery (**Figure 7**). Due to limited bed capacity in our department, patients were discharged after their incision healed and once they were in stable condition. Because of this limitation, some patients were readmitted to local hospitals to continue antibiotic treatment.

Comparison with classical excision

A comparison of patient demographics, duration of hospital stay, duration of antibiotic therapy, postoperative neurological recovery time, intraoperative blood loss, operative duration, length of incision, postoperative fever, repeat surgery, and mortality was performed between the aspiration and excision groups (**Table 2**).

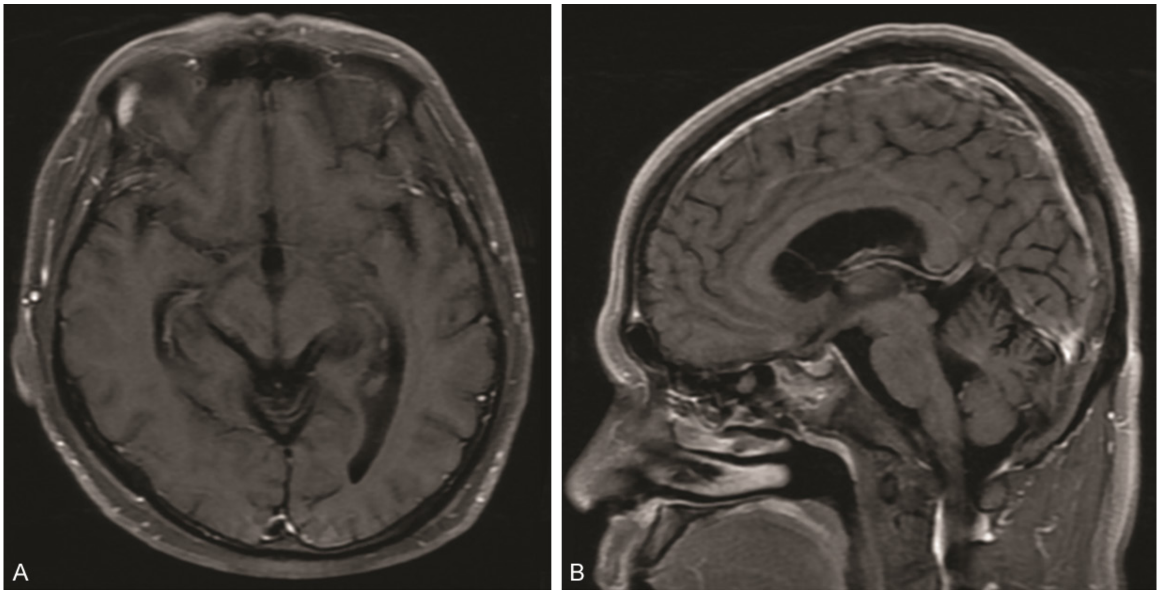

Figure 7. Case 2 at three month follow-up. The axial (A) and sagittal (B) slices show complete resolution of the abscess.

The excision group consisted of 22 patients, 14 males (64%) and 8 females (36%), aged 12-72 (mean 45.00 ± 16.86). Intraoperative blood loss, operative duration, length of incision, and postoperative fever were all significantly reduced in the aspiration group. However, duration of hospital stay and antibiotic therapy and postoperative neurological recovery time were all increased in the aspiration group, and statistical significance was observed in all parameters except the duration of hospital stay.

Discussion

The main goal of surgical management of brain abscesses is to reduce both the space-occupying activity and the intracranial pressure, as well as to eradicate the pathogenic microorganisms [6]. The anatomical location, number, and size of the abscesses as well as the stage of abscess formation, and age and neurological status of the patient can all influence the selection of a treatment methodology [6]. Regardless of methodology, early diagnosis, prompt surgical drainage of pus, simultaneous eradication of the primary source, and high-dose intravenous antibiotics are all important factors for achieving a good patient outcome.

Abscesses larger than 2.5 cm in diameter that cause mass effect commonly require surgical excision or aspiration as the results of conservative treatment have been shown to be poor [6, 7]. With the development of new technologies and equipment, a number of new treatment modalities have been proposed for managing these larger lesions, including craniotomy and evacuation, frameless and framed stereotactic keyhole aspiration, as well as endoscopic, ultrasound-guided, fluoroscopy-guided, and open MRI-guided evacuation [8-11]. The efficacy of these different methods and selection of one over another is still debated heavily in the literature; specifically the choice of one procedure over another has been the subject of much debate. Several studies have advocated for excision as the procedure of choice since it is often followed by a lower incidence of recurrence and a shorter duration of hospitalization [12, 13]. However, recently proposed minimally invasive methods of surgical excision have been advocated due to the increased risks of damaging surrounding neural tissue and resulting in permanent neurological deficit observed in traditional open excision.

Definitive diagnosis of an intracranial abscess is critical selecting the most appropriate treatment. In cystic lesions, low density areas are not always indicative of liquids, and repeated blind aspiration may increase the risk of bleeding. The diagnosis of an intracranial abscess can be nearly confirmed via reviewing the history of the infection, assessing the presence of

Table 2. Comparison of perioperative characteristics between drainage and excision

	Surgical approach		*P*
	Aspiration (n = 23)	Excision (n = 22)	
Gender (n)			
Male	20	14	
Female	3	8	
Age (years)			
Mean ± SD	40.17 ± 9.16	45.00 ± 16.86	
Range	7-67	12-72	
Postoperative hospital stay (days)			
Mean ± SD	15.30 ± 9.16	14.10 ± 8.28	0.937
Range	8-42	7-36	
Postoperative antibiotic duration (days)			
Mean ± SD	22.74 ± 5.80	18.68 ± 5.58	0.021
Range	18-42	14-36	
Postoperative neurological recovery time (days)			
Mean ± SD	2.63 ± 3.50	2.00 ± 1.88	0.436
Range	1-15	1-6	
Intraoperative blood loss (mL)			
Mean ± SD	22.26 ± 20.66	265.45 ± 221.18	0.000
Range	5-100	100-1200	
Operative duration (minutes)			
Mean ± SD	43.17 ± 10.24	175.64 ± 30.23	0.000
Range	30-60	125-234	
Length of incision (cm)			
Mean ± SD	2.91 ± 0.67	18.41 ± 5.70	0.000
Range	2-4	8-23	
Postoperative fever (n)	3	8	0.069
Repeat surgery (n)	1	0	
Mortality (n)	0	0	

P-value of < 0.05 was considered to be significant.

fever, and interpreting the MRI results. However, some patients do not present with a history of infection and have ambiguous MRI findings. In order to differentiate cystic lesions, imaging techniques such as position emission tomography (PET), diffusion-weighted imaging (DWI), apparent diffusion coefficient (ADC), perfusion-weighted imaging (PWI), and proton magnetic resonance spectroscopy (PMRS) can been applied. In addition, diffusion-weighted imaging has been found to be useful in distinguishing abscesses from necrotic or cystic lesions. Cystic intraparenchymal ring-enhancing lesions with hyperintensity on DWI are generally consistent with the presence of an abscess [14, 15]. If the lesion appears hypointense on DWI, Magnetic Resonance Spectroscopy (MRS) may be necessary to distinguish an abscess from other lesions [16, 17].

Keyhole aspiration of intracranial abscesses has been performed using framed-based and frameless stereotactic techniques. The advent of frameless neuronavigation, specifically the application of multimodal functional neuronavigation, has greatly improved the accuracy and safety of this procedure while reducing its complexity. However, a definitive preoperative diagnosis, accurate intraoperative positioning, complete evacuation of pus, comprehensive postoperative therapy, and are essential for successful keyhole aspiration.

When performing keyhole aspiration, the puncture point and direction should be chosen in order to avoid functional areas, blood vessels, and ventricles. Neuronavigation should be used to determine the optimal puncture site and angle of the puncture. To ensure the accuracy of the aspiration, we chose puncture sites that were located at most easily accessible level of the abscess with shortest distance to the cortical surface. We measured the distance from the posterior wall of the abscess to the puncture point in order to know the depth of tube required without inadvertently penetrating the opposite wall of the abscess which could cause parenchymal damage. This also facilitated aspiration of pus by allowing the drainage tube to fully reach the opposite wall of the abscess. In cases where the abscess is situated deep within the cortex, a neuronavigation integrated biopsy needle (VarioGuide™, Brainlab) can be used for drainage.

Using multimodal image reconstruction, the abscess was observed around the puncture trajectory and any surrounding vascular structures were identified. As such, the rate of intracranial hemorrhage was minimized increasing operative safety. A total of 8 of the described procedures were performed in an iMRI suite. Following intraoperative MRI, residual pus was found in only 1 case in which subsequent aspiration was performed by adjusting the location of the drainage tube. A second scan showed complete evacuation of pus. Through intraoperative imaging, we were able to observe the degree of collapse of the abscess cavity, the location of the drainage tube, and any residual pus. These observations helped reduce the rate of reoccurrence and also provided imaging that facilitated complete surgical aspiration. In order to fully remove any residual pus at the conclusion of the procedure the remaining cavity was flushed with saline. Repeat drainage was performed on abscesses with residual pus that did not completely collapse after flashing. Residual pus and exudate was discharged via external drainage for 2-3 days postoperatively allowing for a faster recovery time and a reduced possibility of recurrence. In this group, 23 patients who underwent keyhole aspiration and drainage guided by functional neuronavigation had positive outcomes.

All patients in this study were administered postoperative antibiotics, including third-generation cephalosporins, which penetrate well into the CNS, and a combination of vancomycin and ceftriaxone in cases with otitis, mastoiditis, sinusitis and post-neurosurgical trauma. Following culture and identification of the causative bacterial agent, pathogen-specific antibiotics were administered. The duration of antibiotic therapy varied depending on the results of the bacterial cultures as well as the specific course of the patient's recovery. The mean duration of antibiotic therapy in the aspiration group was 22.74 ± 5.8 days compared to 18.68 ± 5.58 in the excision group (P = 0.021). The presence of more aggressive pathogens in the burr hole aspiration group, or incomplete evacuation of the abscess, could possibly explain this finding though there no evidence was found to support either hypothesis. Postoperatively, patients with temperatures greater than 38°C for at least 2 days were considered to have intracranial infection. In such cases, lumbar drainage was performed to release CSF and was repeated until CSF values returned to normal.

When comparing intraoperative blood loss, operative duration, and length of incision between the aspiration and excision groups, we found these values to be significantly reduced in the aspiration group ($P < 0.05$). However, statistical significance was not observed between the two groups when comparing duration of postoperative hospital stay, postoperative neurological improvement time, postoperative fever, repeat surgery, and mortality ($P > 0.05$). Due to limited bed capacity in our department, patient were discharged after their incision healed and once they were in stable condition. Thus, the interpretation of duration of hospital stay may not fully reflect the true duration of necessary hospitalization especially since some patients were readmitted to local hospitals to continue antibiotic treatment. The postoperative neurological recovery time was nearly identical in both groups and, importantly, the duration of antibiotic therapy was significantly longer in the drainage group. This increased duration may be indicative of an increased complete bacterial clearance time in this procedure and warrants further study to fully understand.

We believe that keyhole aspiration represents a valid option for the surgical management of intracranial abscesses but should be ruled out in patients who have not responded to repeated punctures with only a single intracranial abscess site. Surgical excision should remain the primary option in patients with large abscesses with edema and herniation, where keyhole aspiration failed to reduce intracranial pressure, or where the preoperative diagnosis of brain abscess is not certain. Traumatic brain abscess containing foreign bodies and/or bone fragments also necessitate craniotomy.

Conclusion

Image-guided keyhole aspiration of cerebral abscesses is a feasible and comparable minimally invasive alternative to open surgical excision and may provide reduced intraoperative blood loss, shortened operative duration, improved cosmetic outcomes, and a lessened incidence of postoperative fever. We believe that this technique may provide the same clinical efficacy and outcomes as open surgery.

Disclosure of conflict of interest

None.

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