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Original Article

Computed tomography-guided stereotactic surgery in the management of brain lesions: A single-center experience

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ABSTRACT

Background: The present study presents our experience with computed tomography (CT)-guided stereotactic surgery in managing deep-seated brain lesions and provides a background in the expanding fields of morphological stereotactic neurosurgery.

Methods: We conducted this retrospective cohort study on 80 patients managed at the Department of Neurosurgery, Zagazig University Hospitals, Zagazig, Egypt, between January 2019 to January 2021. We targeted patients with morphological stereotactic surgeries performed as the primary management modality of their treatment.

Results: A total of 80 patients, with a mean age of 44.3 years, were included in the study. The stereotactic targets were supratentorial in 71 patients (88.75%), infratentorial in seven patients (8.75%), and both supra- and infratentorial in two patients (2.5%). The lesions showed enhancements with IV contrast in 55 patients (68.75%). Stereotactic procedures were performed under local anesthesia in 64 patients and general anesthesia in 16 patients. Of the 80 stereotactic procedures, 52 were biopsies (65%). We observed a significant improvement in the postoperative Karnofsky performance score compared to the postoperative score (63.4 ± 19.8 vs. 56.7 ± 15.4, $P = 0.001$). The level of agreement between clinical, radiological, and final pathological diagnosis was assessed; it was complete in 47.5% of the patients. The postprocedural CT scan demonstrated intracranial hemorrhage in five patients (6.25%); four (5%) were silent with no neurological complications.

Conclusion: This study provided evidence that the stereotactic procedure is easy to perform, accurate in targeting the lesion, and spares patients from undergoing major surgical procedures. Stereotactic applications of spontaneous intracerebral hemorrhage, deep-seated abscesses, encysted tumors, or medically refractory benign intracranial hypertension can improve the outcome even in medically high-risk patients.

Keywords: Deep-seated brain lesions, Neurosurgery, Histopathology, Stereotactic surgery

INTRODUCTION

The importance of stereotactic localization tools in modern neurosurgery is equal to that of other valuable standard devices, such as the ultrasonic aspirator, the laser, and the operating microscope in microsurgery.[23] The stereotactic technique has been used for 30% or more of the patients with intracranial mass lesions. The number of patients harboring small, deep, multiple, or critically located intracranial lesions gradually increases. Such lesions are disclosed shortly in the disease course by noninvasive imaging modalities. Histopathological diagnosis has remained mandatory for further management of such lesions despite the marked advances in neuroimaging.[1,2,47]

For patients with minimal brain metastases and good performance status, stereotactic radiation is the standard treatment.[12,32,45] Radiation necrosis (RN) is one of the most serious late consequences of stereotactic radiosurgery (SRS), and it can have a considerable impact on neurological function and quality of life.[12] The incidence of SRS-induced RN differs depending on whether RN is regarded as reversible, irreversible, or both harm to the brain's white matter.

The majority of brain lesions can be biopsied and classified according to their pathological nature using a standard stereotactic brain biopsy technique with a high diagnostic yield.[8,9,26] Beyond lesion diagnosis, histopathological characterization may help guide surgical planning for resection surgery.[48,49] For infectious pathologies, antibiotic sensitivities can be assayed using the biopsy tissue or aspirated fluid sample to optimize medical management.[3,22,27] The development of computed tomography (CT) and magnetic resonance imaging (MRI) revived interest in stereotaxy and greatly expanded indications for stereotactic approaches since deeper parts of the brain could be addressed with high precision.[20,23,35]

During the postradiosurgery follow-up, magnetic resonance perfusion imaging, particularly dynamic contrast-enhanced (DCE), aids in the differential detection of tumor recurrence and RN. Some instances of RN cannot be reliably distinguished from tumors using CT or MRI (especially astrocytoma; RN occasionally resembles glioblastoma). To identify RN from tumor recurrence, MRI perfusion-based techniques such as DCE dynamic susceptibility-weighted imaging and magnetic resonance spectroscopy (MRS) have been utilized.[5,7,44] MRI, comprising diffusion and perfusion measures, has shown potential as an imaging biomarker for characterizing structural alterations observed following SRS.[13,42]

Nonetheless, susceptibility artifacts and the small lesion size were most likely responsible for the equivocal perfusion-weighted imagingMRI and MRS results. The preferred approach for monitoring brain metastases following SRS therapy is contrast-enhanced structural MRI. Nevertheless, in many cases, utilizing contrast-enhanced MRI to differentiate local recurrent brain metastasis from radiation-induced alterations following SRS is problematic.[17] Alternative diagnostic approaches are required to follow-up and care for individuals with recurring brain metastases. PET, single-photon emission CT, MRS, and PWI have all been utilized to distinguish local tumor recurrence from radiation-induced alterations.

Although stereotactic surgery is minimally invasive, the procedure has definite risks that must be contemplated for each patient against the benefits. The incidence of morbidity due to stereotactic biopsy ranges from 1% to 6.5%, and mortality rates range from 0% to 1.7% in referenced large studies.[8,21,30,36,39] The present study presents our experience with CT-guided stereotactic surgery in managing deep-seated brain lesions and provides a background in the expanding fields of morphological stereotactic neurosurgery.

MATERIALS AND METHODS

We conducted this retrospective cohort study on 80 patients managed at the Department of Neurosurgery, Zagazig University Hospitals, Zagazig, Egypt, between January 2019 and January 2021. We targeted patients with morphological stereotactic surgeries performed as the main management modality of their treatment. Our study protocol was approved by the Hospital Research and Ethics Committee at the Faculty of Medicine, Zagazig University (#10162). Routinely, after understanding the procedure's purpose, benefits, and potential adverse events, each patient voluntarily provided written informed permission.

Eligibility criteria

Inclusion criteria

The inclusion criteria that were employed to ensure that the patients are suitable for such a technique of surgery included in the study:

1. Lesions in functionally critical areas, such as motor, sensory cortex, or basal ganglia
2. Invasive neoplastic lesions without mass effect or significant neurological signs
3. Poorly defined lesions on CT or MRI
4. Small lesions and deep-seated lesions, as in the brain stem or midline region
5. Multiple lesions, where a distinction between metastasis and inflammatory lesions is required
6. Patients with poor medical conditions or advanced age who cannot tolerate prolonged craniotomy
7. Lesions in which differentiation between tumors recurrence and radio necrosis is required
8. Deep-seated subcortical brain infections
9. Medically refractory benign intracranial hypertension (BIH) patients with slit-like lateral ventricles for insertion of ventricular shunt
10. Patients with cystic deep-seated neoplastic or non-neoplastic lesions, for aspiration and/or insertion of Ommaya reservoir
11. Stereotactic-guided craniotomy for different brain lesions
12. Patients with intra-axial deep-seated spontaneous hematomas without brain stem extension with clinical

onset 48 h and more than 25 mL in volume for aspiration and/or insertion of temporary drainage catheter for intracavitary injection of thrombolytic medication to evacuate residual hematoma if presented

13. Radiosensitive lesions such as germ cell tumors and lymphomas.

Exclusion criteria

We excluded patients with any of the following conditions:

1. Patients with suspected vascular lesions such as vascular malformations or cerebral aneurysms
2. Patients with extensive brain lesions with a significant mass effect require open surgery and decompression
3. Patients with lesions in close relation to large brain cisterns, especially suprasellar cistern, for a high possibility of aneurysms
4. Patients with uncorrectable coagulation disorders
5. Patients with a Glasgow coma score <8
6. Patients with signs of tentorial herniation
7. Patients who were unable to provide informed consent
8. Infants or children below 2 years of age
9. Patients with an intracranial device that interferes with trajectory pathway.

Study process

All patients underwent complete history taking followed by a general examination. The Karnofsky performance score (KPS) was used to assess the functional outcome [Appendix S1]. To document the accuracy and precision of intervention, postoperative CT is usually performed 5 h after the procedure. This enables a comparison of the intended target coordinates with the actual target coordinates of the surgical intervention and the detection of suspected complications.

Technique

Following preoperative assessment and preparation, we applied the base ring of Leksell's frame "G" generation (Elekta Instruments, Stockholm, Sweden) to the patient's head after infiltration of pins site with local anesthetic medication (xylocaine 2%, dose 5 mg/kg and adrenaline 1:100,000). A low set frame was preferable to avoid aligning the stereotactic frame pins with the target plane to avoid the metallic artifact that would obscure the image. The patients were transported to the scanner room, with an anesthesiologist and neurosurgeon in attendance. Scan orientation was parallel to the basal ring, axial images, 2 mm apart, and the scan gantry was 0. We usually administer intravenous contrast (iohexol, omnipaque 300 mg/mL at dose 100–150 mL for adults and 1–2 mL/kg for children) except for those with iodine allergy or renal dysfunction. For unenhanced lesions, we administrate an additional 50–70 mL of omnipaque 300 and repeat the scan immediately and in a delayed fashion. The contrast would delineate the enhanced lesion and show the nearby blood vessels to be avoided during trajectory planning, even if the lesion is not enhancing. Slices disturbed with metallic artifacts were neglected; we chose a clear-cut with all visible fiducials. We preferred the local anesthesia with a neuroanesthesiologist standing by. General anesthesia was indicated for patients requiring stereotactic-guided craniotomy and insertion of brain shunts and for patients with severe continuous movements, severe pain, scoliosis, vertebral pain, heavy coughing, and anxiety, or those who are uncooperative and children. Biopsies were pushed out from Sedan type needle by a saline jet and laid on a test tube with formalin 10%. We usually take 2–7 specimens except for the brain stem lesions; in such cases, we only take one bite under considerable negative pressure. We sent the specimen to an experienced neuropathologist and requested an examination of all biopsy fragments.

Statistical analysis

All analyses were performed using the Statistical Package of the Social Sciences (SPSS) version 22 (SPSS Inc., Chicago, Illinois, USA). We presented the qualitative data in frequencies and percentages. Continuous data were presented as mean ± standard deviation or median and range for parametric and non-parametric data. The paired *t*-test was used to assess the statistically significant difference between the two population means of dependent (paired) samples. The significant difference was considered when $P < 0.05$.

RESULTS

Demographics of the include patients

A total of 80 patients (47 males and 33 females), with a mean age of 44.3 years (range 5–87 years), were included in the present study. Most patients aged between 31 and 60 years (62.5%). All patients underwent preoperative brain CT scans and MRI for target localization. The stereotactic targets were supratentorial in 71 patients (88.75%), of which five cases were BIH, infratentorial in seven patients (8.75%), and both supra- and infratentorial in two patients (2.5%) [Appendix S2]. The lesions showed enhancements with IV contrast in 55 patients (68.75%). Entry techniques included twist-drill craniostomy as well as burr-hole craniostomy. The drill hole technique was performed in 63 patients (78.75%), while the burr-hole technique was utilized for stereotactically guided craniotomies, hematoma evacuation, and shunt or Ommaya insertions. Trajectories chosen for the stereotactic procedures depended on the site of the lesions and the nature of the procedure, as shown in Table 1. Stereotactic procedures were performed under local anesthesia in

Table 1: Demographic data of the included patients (*n*=80).

	Count	Percentage
Age group, *n* (%)		
0–30 years	15	18.75
31–60 years	50	62.5
61–90 years	15	18.75
Sex, *n* (%)		
Male	47	58.75
Female	33	41.25
Lesion site in relation to the tentorium cerebelli, *n* (%)		
Supratentorial	71	88.75
Infratentorial	7	8.75
Supratentorial and infratentorial	2	2.5
Lesions enhancement with intravenous contrast material, *n* (%)		
Enhanced	55	68.75
Not enhanced	25	31.25
Skull entrance, *n* (%)		
Drill hole	63	78.75
Burr hole	17	21.25
Stereotactic entry points, *n* (%)		
Right pericoronal	31	38.75
Left pericoronal	13	16.25
Right posterior parietal	9	11.25
Left posterior parietal	10	12.5
Right superior parietal lobule	2	2.5
Left superior parietal lobule	2	2.5
Right occipital	2	2.5
Left occipital	3	3.75
Right and left occipital	2	2.5
Right temporal	1	1.25
Right suboccipital	2	2.5
Left suboccipital	3	3.75
Targeting devices trajectories, *n* (%)		
Right transfrontal	31	37.5
Left transfrontal	13	17.5
Right transparietal	11	13.75
Left transparietal	12	15
Right transoccipital	2	2.5
Left transoccipital	3	3.75
Bilateral occipital	2	2.5
Right transtemporal	1	1.25
Right transcerebellar	2	2.5
Left transcerebellar	3	3.75

n: number of included patients

64 patients and general anesthesia in 16 patients. Of the 80 stereotactic procedures, 52 were biopsies (65%). The indications of stereotactic surgeries, pathological diagnosis, and morphological stereotactic procedures are presented in Table 2. We observed a significant improvement in the postoperative KPS score compared to the postoperative score (63.4 ± 19.8 vs. 56.7 ± 15.4, $P = 0.001$), as shown in Figure 1.

Further assessment dividing the patients into biopsy alone group and other procedures group showed no significant difference between the two groups in terms of preoperative

Table 2: The stereotactic procedures data and pathological diagnosis among the included patients (*n*=80).

	Count	Percentage
Indications of stereotactic surgeries		
Site of lesion		
Deep	33	41.25
Deep and eloquent	13	16.25
Deep and small (3–15 mm width in axial CT)	9	11.25
Deep and multiple	8	10
Eloquent brain	6	7.5
Slit like ventricle	5	6.25
Type of lesion		
Differentiation of tumor necrosis from recurrence	1	1.25
Patients		
Refuse craniotomy	1	1.25
Unfit for craniotomy	4	5
Pathological diagnosis		
Glial neoplasms		
Pilocytic astrocytoma 1[¶]	2	2.5
Diffuse astrocytoma 2	11	13.75
Subependymal astrocytoma 2	1	1.25
Anaplastic astrocytoma 3	10	12.5
Glioblastoma multiforme 4	18	22.5
Gliomatosis cerebri 5	1	1.25
Oligodendroglioma	3	3.75
Oligoastrocytoma	2	2.5
Ependymoma	3	3.75
Non-glial neoplasms		
Metastasis	8	10
Craniopharyngioma	3	3.75
Meningioma	1	1.25
Lymphoma	1	1.25
Non-neoplastic		
Pyogenic abscesses	5	6.25
Tubercloma	1	1.25
Amoebic infection (Naegleria fowleri)	1	1.25
Hematomas	4	5
Clear CSF (BIH)	5	6.25
Morphological stereotactic procedures		
Biopsy alone	52	65
Aspiration alone[§]	6	7.5
Aspiration and biopsy[§§]	7	8.75
Biopsy then stereotactic-guided craniotomy	1	1.25
Ommaya insertion, aspiration and cyst wall biopsy	4	5
Stereotactic-guided craniotomy and gross radical excision.	2	2.5
Shunt (Ventriculoatrial) insertion for BIH	5	6.25
Aspiration and drain insertion for intracerebral hematoma	3	3.75

[¶]includes one case with intratumoral hematoma, [§]one case of intracerebral hematoma and five abscesses, [§§]one case of intracerebral hematoma and six neoplastic cysts. CSF: Cerebrospinal fluid, BIH: Benign intracranial hypertension, CT: Computed tomography *n*: number of included patients

KPS (*P* = 0.9) and showed a significant difference between the two groups in postoperative KPS (*P* = 0.001). When the preoperative and postoperative KPS were compared, the other procedures group showed significant improvement (*P* = 0.001), but not the biopsy alone group (*P* = 0.73), [Appendix S3].

In the other procedures group, the improvement causes were abscess aspiration, hematoma aspiration, tumoral cyst aspiration, tumoral cyst aspiration with Ommaya Reservoir insertion, tumoral excision, and ventriculoatrial shunt insertion. Most patients (*n* = 49, 61.25%) stayed for 1 day, while 23.75% stayed for ≥4 days. The level of agreement between clinical, radiological, and final pathological diagnosis was assessed; it was complete in 47.5% of the patients. The postprocedural CT scan demonstrated intracranial hemorrhage in five patients (6.25%); four (5%) were silent with no neurological complications. Postoperative data are shown in Table 3.

DISCUSSION

In our study, preoperative brain CT and MRI were performed for target localization. Several methods have been offered to increase the accuracy, and diagnostic yield of the CT-guided stereotactic brain biopsy, such as targeting multiple regions of the lesion as most brain tumors harbor different pathological grading like astrocytoma, delaying the localization scan after the administration of contrast medium to improve resolution and target selection, proper tissue handling, utilizing modern histopathological techniques, and double-check of stereotactic coordinates calculation and registration to avoid technical errors.[16,36,50] Due to the small sample size of specimens, communication with the histopathologists and correlation with clinical and radiographic information was necessary to increase the diagnostic yield.[6,11,18,19,25,28,39] A pericoronal entry point was used in 44 cases (55%); it provides good access and a relatively safe transfrontal trajectory for lesions anterior to the center of the stereotactic field.

Stereotactic procedures were performed under local and general anesthesia in 64 and 16 patients, respectively. The main indications for general anesthesia were young age, uncooperative patients, and the need for shunt insertions, lesions resection, or hematoma evacuation. About 65% of the stereotactic procedures were biopsied. Stereotactic biopsy is a minimally invasive diagnostic procedure with minimal risk for patients.[34,37,39] In the present series, we utilized a unique biopsy technique that minimizes sampling error and increases the likelihood of an accurate diagnosis. Multiple sections were taken with the Sedan side-cutting needle at serial depths along the track. The utility of this approach is reflected in the accurate grading of all but two of the gliomas in our series. The same biopsy technique was utilized by Owen and Linskey.[41]

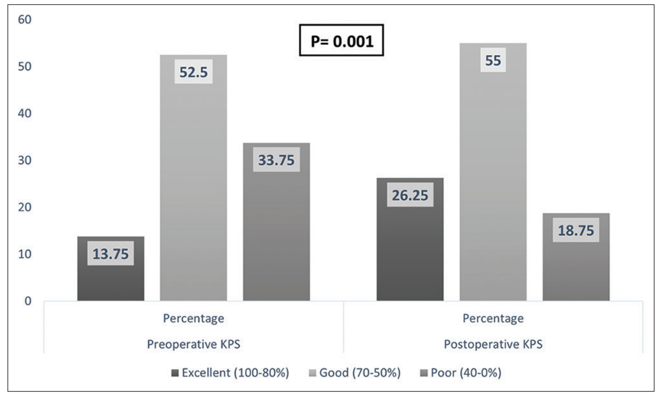

Figure 1: Preoperative and postoperative Karnofsky performance score (KPS).

Table 3: Postoperative data.

	Count	Percentage
Causality of improvement in other procedures group		
Abscess aspiration	5	18.52
Hematoma aspiration	5	18.52
Tumoral cyst aspiration	5	18.52
Tumoral cyst aspiration and Ommaya insertion	4	14.81
Tumoral excision	3	11.11
Ventriculoatrial Shunt insertion	5	18.52
The hospital stay after surgeries (in the other procedures group)		
1 day	49	61.25
2 days	6	7.5
3 days	6[+]	7.5
≥4 days	19[+]	23.75
Level of agreement between clinical, radiological diagnosis, and final pathological diagnosis		
Complete	38	47.5
Partial[+]	23	28.75
No	19	23.75
Complications		
Massive hemorrhage	1	1.25
Minimal hemorrhage radiologically evident without clinical sequel	4	5
Failed biopsy requires procedural repetition	2	2.5
Total	7	8.75

¶The majority of patients undergoing other interventions rather than stereotactic biopsies require hospitalization for more than 2 days; +Partial agreement means different pathological grading between clinical, radiological diagnosis, and final pathological diagnosis

A histopathological analysis is important when the treatment of brain lesions is planned. The stereotactic brain biopsy is indicated for the diagnosis of inaccessible deep-seated lesions, lesions in the eloquent areas of the brain, diffuse infiltrative brain lesions with minimal to moderate mass effect, multiple and cystic lesions, and for patients with poor medical conditions for a craniotomy. In these patients, stereotactic biopsy provides a small tissue sample from a target point predetermined by radiological methods with low morbidity and mortality rates.[39,40]

In our study, astrocytoma was the commonest pathology, followed by brain metastasis. We identified three levels of agreement between pre-biopsy clinical and radiological diagnosis and the final pathological diagnosis. Complete agreement was noticed in 47.5% of the included patients, partial agreement in 28.75%, and no agreement at all in 23.75%. The important role of stereotactic biopsy is confirming tissue diagnosis for patients with multiple brain lesions in a negative systemic metastatic survey setting. In our series, four out of eight patients with multiple brain lesions were primary brain tumors. A retrospective review by Arbit and Galicich found that 19% of cases that underwent stereotactic biopsy had a different diagnosis than radiographic.[4] Lunsford and Martinez also found that nearly 21% of strongly suspected preprocedural diagnoses were overturned after the biopsy to another pathology that was not considered in the pre-biopsy differential.[15] This finding is relatively similar to our observation.

Postprocedural increasing of cerebral edema was documented as the commonest finding in follow-up CT brain.[14,30,39,40,46] We usually give brain dehydrating medication 2 h before frame application and immediately after the procedure. Furthermore, we keep our patients under strict observation and monitoring for the rest of the day after the biopsy, and the patients can be discharged the next day; regardless, there is neither neurological function deterioration nor new CT brain abnormalities development. Our control CT scan was performed after a median time of 5 h after the operation. CT brain was routinely performed after the stereotactic procedure in our series, while it was performed promptly in suspected cases of bleeding during the procedure.

In our study, we successfully evacuated five intracerebral hematomas; four were thalamic without intraventricular extension, and one was frontoparietal. All of them have improved. We used the Backlund hematoma evacuator kit with drill screws in all patients. Sufficient reduction of hematoma volume without fibrinolysis is achieved in two cases. Furthermore, residual hematomas were liquefied by streptokinase infusion (6000 IU) and drained through a catheter, usually placed in a hematoma center for three patients. Our patients have no rebleeding as we keep systolic blood pressure not more than 150 mmHg in operative and postoperative times. We never aspirate the residual hematoma after fibrinolytic agent infusion to avoid negative pressure inside the hematoma cavity. We only let the hematoma drain spontaneously against 0 cm of pressure. By that time, a maximal mass effect from surrounding edema would have been anticipated, and there was no clinical deterioration from edema or mass associated with residual hematoma.

In our study, five patients with six supratentorial deep-seated abscesses underwent stereotactically guided aspiration. Antibiotics were started as soon as the procedure was finished. Antibiotic combination therapy was adjusted according to the results of cultures and sensitivity tests. Follow-up was performed with clinical evaluation and repeated CT scans for three to 6 months. All patients had normal courses, and no recurrence was observed. All patients returned to their previous activities within a median of 3 months after the operation.

Kondziolka *et al.* reported a 93% success rate in the stereotactic treatment of brain abscesses.[29] Hsieh *et al.* reported a 92% cure rate in patients with bacterial brain abscesses treated with stereotactic aspiration and intravenous antibiotics for 6 weeks.[24] Mamelak *et al.* reported that 62% of their patients required re-aspiration after initial stereotactic lavage.[33] In a unique report, Kutlay *et al.* described that using hyperbaric oxygen along with stereotactic aspiration and antibiotic therapy will significantly decrease the recurrence and improve healing.[31] The possibility of placing a catheter in the abscess cavity and leaving it *in situ* for 3 days to continue drainage and for infusion of antibiotics was reported by Broggi *et al.*[10] We did not pursue this method, with similar results.

The present study showed ten neoplastic cystic lesions (two peritumoral cysts with mural nodules and eight intratumoral cystic lesions). All patients had one CT-guided stereotactic cyst aspiration. Four patients (three craniopharyngiomas and one recurrent anaplastic astrocytoma cyst) required a catheter-reservoir system. Histopathological analysis revealed three craniopharyngiomas, two pilocytic astrocytomas, three glioblastoma multiforme, one anaplastic astrocytoma, and one metastatic adenocarcinoma. Symptomatic improvement was achieved in nine patients. A silent intracystic hemorrhage occurred in one patient after a cyst wall biopsy. All patients undergoing Ommaya reservoir insertions were symptomatically improved with significant tumor size control. No procedure-related mortality was encountered. Niranjan *et al.* reported that 38 patients with glial and metastatic brain cysts were managed with single stereotactic aspiration. Twelve patients of them required an intracavity catheter and Ommaya reservoir insertion. All patients were symptomatically improved.[38] Rogers and Barnett reported symptomatic improvements in 20 patients with intraaxial neoplastic cysts with a significant reduction in cyst size in follow-up CT brain. Asymptomatic intracystic hemorrhage occurred in two patients after biopsy and catheter placement.[43]

CONCLUSION

This study provided evidence that the stereotactic procedure is easy to perform, accurate in targeting the lesion, and spares patients from undergoing major surgical procedures. The specimen taken for biopsy was adequate for diagnosis.

Stereotactic target localization is more than 97.5% if the meticulous methodology is applied. Stereotactic applications of spontaneous ICH, deep-seated abscesses, encysted tumors, or medically refractory BIH are minimally invasive, highly effective, and accurate, which can improve the outcome even in medically high-risk patients. Overall, complications arising from stereotactic surgeries are infrequent, with minimal associated morbidity and mortality compared to other cranial surgical procedures. Given the current state of the art, frame-based surgeries are still an important technique, even in the frameless era.

Declaration of patient consent

The Institutional Review Board (IRB) permission obtained for the study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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APPENDIX

Appendix S1: Karnofsky performance status scale.[1]

Excellent: able to carry on normal activity and to work; no special care needed.	100	Normal no complaints; no evidence of disease.
	90	Able to carry on normal activity; minor signs or symptoms of disease.
	80	Normal activity with effort; some signs or symptoms of disease.
Good: unable to work; able to live at home and care for most personal needs; varying amount of assistance needed.	70	Cares for self; unable to carry on normal activity or to do active work.
	60	Requires occasional assistance, but is able to care for most of his personal needs.
	50	Requires considerable assistance and frequent medical care.
Poor: unable to care for self; requires equivalent of institutional or hospital care; disease may be progressing rapidly.	40	Disabled; requires special care and assistance.
	30	Severely disabled; hospital admission is indicated although death not imminent.
	20	Very sick; hospital admission necessary; active supportive treatment necessary.
	10	Moribund; fatal processes progressing rapidly.
	0	Dead

Appendix S2: List of lesion sites among the include patients.

Location	Count	Percentage
Right frontal	3	3.75
Left frontal	3	3.75
Right parietal	10	12.5
Left parietal	6	7.5
Right temporal	1	1.25
Left temporal	1	1.25
Right occipital	1	1.25
Left occipital	1	1.25
Right basal ganglia	2	2.5
Left basal ganglia	1	1.25
Peri sylvian, insular with basal ganglia invasion	1	1.25
Right thalamic	5	6.25
Left thalamic	4	5
3rd ventricle	3	3.75
Right lateral ventricle	2	2.5
Left lateral ventricle	3	3.75
Corpus callosum	7	8.75
Right over one lobe supratentorial	3	3.75
Left over one lobe supratentorial	6	7.5
Multiple supratentorial	3	3.75
4th ventricle	1	1.25
Brain stem	2	2.5
Pineal	1	1.25
Multiple infratentorial	3	3.75
Multiple supra and infratentorial	2	2.5
BIH	5	6.25
Total	80	100%

Appendix S3: Preoperative and postoperative KPS.

	Biopsy alone group	Other procedures group	*t*-test	*P*-value
Preoperative KPS, Mean±SD	56.6±14.53	57.03±18.14	−0.11	0.908
Postoperative KPS, Mean±SD	56.2±16.43	79.62±17.42	−5.9	0.001**
Paired *t*-test	0.34	−10.3		
P-value	0.73	0.001**		

SD: Standard deviation, **Highly significant. KPS: Karnofsky performance score

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