# Prospective Observational Study On Uses Of Intraoperative Ultrasound In Neurosurgery

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## Abstract

**Aim**: To assess the beneficial effects of intraoperative ultrasound in neurosurgery.

**Material and Methods**: The present Hospital based observational study with prospective design was conducted in the Department of Neurosurgery, Bangur Institute of Neurosciences, IPGMER and SSKM Hospital, Kolkata, after approval of the institutional ethics committee, including 50 cases admitted with CNS tumours (Brain cases –44; Spine cases – 6), after considering the inclusion and exclusion criteria. All subject/ attendants were explained about the study and were asked to sign a written consent prior to commencement of the study. The information regarding each patient was kept confidential and was not revealed at any point of time. After enrolment into the study, patient's information regarding their age, and history of present illness was taken and clinical as well as radiological examinations were done. Data was collected in a pretested and predesigned proforma. Surgery was planned and various parameters which reflect different aspects of the perceived utility of the IOUS were identified and scoring was done.

**Results**: Laminectomy was performed in 5 (10%) of cases and craniotomy was performed in 44 (88%) of cases. Mean duration of surgery in Brain cases was 204.58±31.73 min. and in Spinal cases was 132.96±19.27 min. In majority of subjects total resection was performed (78%).For lesion identification and lesion delineation IOUS was useful in all cases.The majority demonstrated usefulness of IOUS in 5 or more parameters (88%).Mortality rate was 4% on follow-up.

**Conclusion**: According to the findings of this study, it can be concluded that intraoperative ultrasound had a significant beneficial role in lesion identification and lesion delineation during surgery providing a high total resection rate of brain and spine masses in patients. As a result, it is recommended to use intraoperative ultrasound in neurosurgical procedures for the resection of brain and spine tumours as a useful imaging tool in distinguishing tumour tissues from normal tissues and maximising resection and detection of residual tumour tissues, taking into account the fact of non-availability of MRI in all hospitals, cost-effectiveness, and surgical time.

**Keywords**: Neurosurgery, Craniotomy, IOUS, MRI

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**Introduction**: The ideal intraoperative navigational modality for neurosurgeons is the one that is accurate, user-friendly, and most of all cost-efficient[1–4]. Over the last two decades, the most reliable and frequently used intraoperative navigational tools include intraoperative computed tomography (iCT) and intraoperative magnetic resonance imaging (iMRI), with the latter being deemed the "golden standard"[5–7]. Despite the

effectiveness of the aforesaid intraoperative tools, neurosurgeons still face challenges in the acquisition and use of iCT and iMRI. These challenges include the following: (1) Enormous costs in the acquisition of these tools, especially in low-budget neurosurgical centres and developing countries; (2) Heavy dependence on acquired pre-operative images; (3) At every stage of the procedure; post craniotomy, dural opening, tumour debulking, and resection, the element of brain shift results in varying degrees of loss of accuracy; (4) Inherent lack of soft-tissue resolution and the associated radiation exposure like in the case of iCT[8].

To circumvent these hurdles, more innovative, convenient, and novel generation modes of Intraoperative sonography or ultrasound (IOUS) systems have been developed. The IOUS is comparatively inexpensive, easy to use, and requires less intraoperative preparation. The two-dimensional (2D) greyscale and three-dimensional (3D) IOUS provide real-time, clear, and well-correlated images, which are easily interpreted by the neurosurgeon. Additionally, the ease and flexibility it provides the user make it possible to counter-check the location of the lesion at any stage of the surgery without prolonged workflow stoppages[8]. This, therefore, solves the element of brain shift. The IOUS does not require pre-existing images before surgery. However, there is a necessity to save the initial image scanned to serve as a baseline check during the surgery.

With regards to advanced US techniques, anatomical information provided by standard B-mode US may be extended by the use of different other techniques. In particular, Doppler IOUS differs from standard B-mode, since it does not provide an anatomical imaging but rather functional information about blood flow. The visualization of Doppler IOUS can be enhanced by the colour techniques (colour Doppler and power Doppler) in order to enrich B-Mode anatomical images with functional information about vascularization[9].

In relation to vascularization, intraoperative contrast-enhanced ultrasound (CEUS) is an advanced technique that adopts an intravenous ultrasound contrast agent made of gas-filled microbubbles in order to provide functional information about tumour biological characteristics through a direct visualization of its pattern of vascularization[10–13].

Even though, ultrasound (US) is an affordable, safe, repeatable imaging technique; it is difficult to standardise, highly operator-dependent, and deemed a technique with poor image quality compared with CT and MRI. This has prevented the universal use of intraoperative US. In the meantime, US technology has dramatically advanced, making images clearer and easier to understand. Also, the development of contrast enhanced US, 3D US and elastography, provide additional information which was earlier not possible.In the above context the purpose of the study was to assess the beneficial effects of intraoperative ultrasound in neurosurgery.

**Materials And Methods**: The present prospective study was carried out for total of 18 months (July 2022-December 2023)in the Indoor Male and Female Ward, Department of Neurosurgery, Bangur Institute of Neurosciences, IPGMER and SSKM Hospital, Kolkata. The ethical clearance for study was taken from the Institutional Review Board for Ethical Clearance ofBangur Institute of Neurosciences, IPGMER and SSKM Hospital, Kolkata. All subjects/attendants were explained about the procedure involved and purpose of the study. All consenting patients /attendants were asked to sign a written informed consent form (in the language best understood by them). 50 patients (Brain cases – 44; Spine cases – 6), admitted with CNS tumours planned for intraoperative ultrasound assisted resection were recruited in the present study using purposive sampling.

Inclusion Criteria: All elective patients of CNS tumours planned for IOUS guided resection.

Exclusion Criteria:

1) Patients for emergency decompression of CNS tumours.

2) Patients with bleeding diathesis.

3) Patients unfit for anaesthesia.
4) Patients not willing to participate in study.
5) Recurrent cases.

**Study Procedure**: Data was collected in a pretested and predesigned proforma.Surgery was planned as is routinely done in our department reviewing the images to decide the routeof approach. IOUS was utilized whenever the need forintraoperative imaging was deemed desirable by theoperating surgeon. A portable US scanner was used (SonoSite M-Turbo; SonoSite Inc., Bothell, WA, USA). In each of thesecases, the insonation was performed both before and afterdural opening. The selected probe was draped in a sterilecover filled with sterile jelly and all air bubbles wereeliminated. Sterile irrigation with saline was employedduring the procedure to ensure optimal coupling.The probe frequency was adjusted (with the variable frequency probe) to suitably insonate both superficialand deep structures as required.

**Utility scoring system:** We identified various parameters which reflect differentaspects of the perceived utility of the IOUS. These wereassessed and documented in the surgical notes. A scoringsystem was devised based on these parameters. Eachparameter was given a score of 0 (no utility) or 1 (useful)[Table 1]. These individual scores were totalled to obtainan overall "utility score" (maximum 7 and minimum0). Our scoring system assessed the utility of the IOUS i.e., to answer the question "was the ultrasound usefulin guiding/modifying a particular stage of the surgicalprocedure?"

**Table 1: Scoring system for assessing the utility of intraoperative ultrasound (IOUS)**

| Parameter | Interpretation | Score |
|---|---|---|
| Lesion identification | Lesion discernable | 1 |
| | Not discernable on IOUS | 0 |
| Lesion delineation | Well defined margins | 1 |
| | Poorly defined margins but discernably distinct from normal brain | 1 |
| | Imperceptibly diffuse. no use of IOUS | 0 |
| Utility in craniotomy/ laminectomy modification | IOUS prompted a modification/ extension in the craniotomy/ laminectomy | 1 |
| | No modification of bone removal needed | 0 |
| Use in durotomy planning | Useful/helped optimize the durotomy site and extent | 1 |
| | Not needed/useful | 0 |
| Use in corticectomy/ myelotomy planning | Useful to plan the entry site | 1 |
| | Not needed/useful | 0 |
| Use for assessment of extent of resection | Used for assessing extent of resection/residue | 1 |
| | Not needed/useful | 0 |
| Visualization of adjacent structures | Useful and needed | 1 |
| | Not needed/useful | 0 |

After the surgery, patients were followed up in the immediate post-operative period till their discharge and also at 1 month from the date of discharge in the form of clinical, neurological and radiological examinations. This was useful to know the EOR, complications and outcomes of the patients.

**Statistical Analysis**: Data so collected was tabulated in an excel sheet, under the guidance of statistician. The means and standard deviations of the measurements per group were used for statistical analysis (SPSS 22.00 for windows; SPSS Inc., Chicago, USA). For each assessment point, data were statistically analysed using one way ANOVA. The level of significance was set at $p<0.05$.

Figure 1: Insonation by IOUS

Figure 2: IOUS showing lesion with central necrosis

**Results**: Majority of study subjects were males (n=32, 64%) and remaining 18 (36%) were females.Maximum number of subjects were >50 years of age (n=19, 38%), followed by 12 (24%) subjects within 41-50 years of age. Various co-morbidities were present among patients, including hypertension (n=17, 34%), diabetes mellitus (n=12, 24%) and thyroid disorder (n=4, 8%) as shown in table 2.

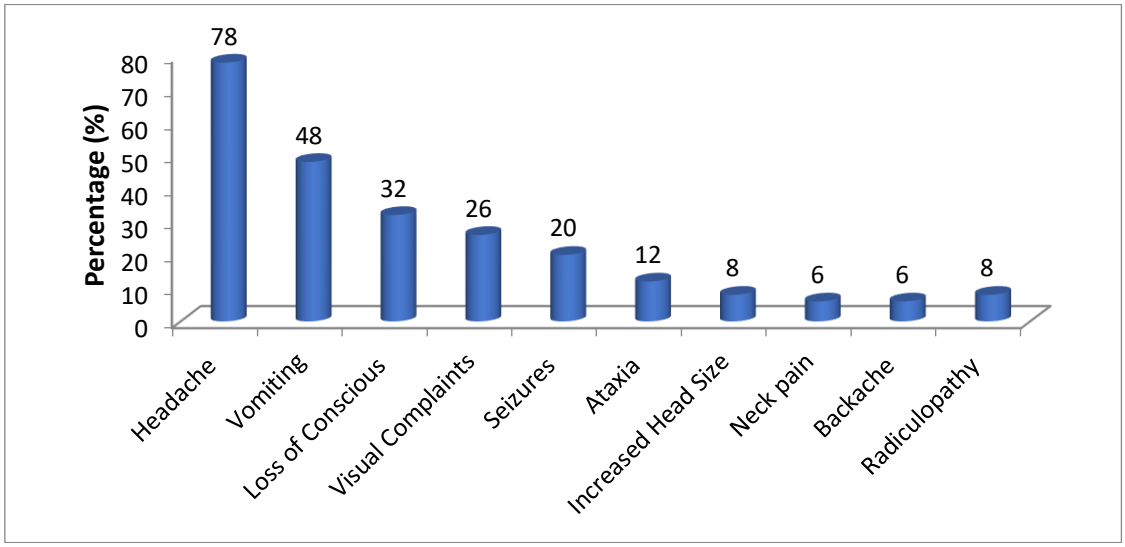
Table 2: Gender distribution among the study subjects

| **Gender** | **N=50** | **%** |
|---|---|---|
| Male | 32 | 64 |
| Female | 18 | 36 |
| **Age Group (in years)** | | |
| ≤ 20 | 9 | 18 |
| 21-30 | 3 | 6 |

| | | |
|---|---|---|
| 31-40 | 7 | 14 |
| 41-50 | 12 | 24 |
| >50 | 19 | 38 |
| **Co-morbidities** | | |
| Hypertension | 17 | 34 |
| Diabetes Mellitus | 12 | 24 |
| Thyroid Disorder | 4 | 8 |

As depicted in graph 1, subjects presented with various complaints including headache (n=39, 78%), vomiting (n=24, 48%), loss of consciousness (n=16, 32%), visual complaints (n=13, 26%), seizures (n=10, 20%), ataxia (n=6, 12%), increased head size (n=4, 8%), neck pain (n=3, 6%), backache (n=3, 6%) and radiculopathy (n=4, 8%).





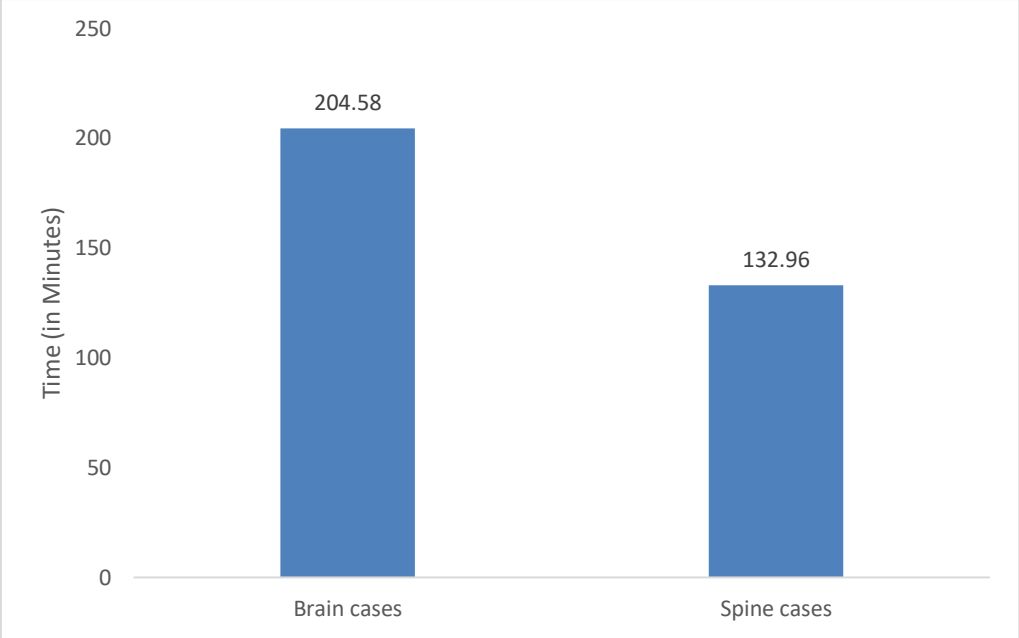

Graph 1: Complaints among the study subjects

As depicted in table 3, maximum number of subjects were having tumours i.e. 48 (96%) followed by 2 (4%) cases having vascular lesions. According to location, 39 (78%) were supratentorial cranial lesions, 6 (12%) were spinal lesions and 5 (10%) were posterior fossa lesions.Laminectomy was performed in 5 (10%) of cases, Craniotomy was performed in 44 (88%) of cases and in 1 (2%) subject other procedure was performed.

Table 3: Types of lesions and surgery

| **Lesions** | **N=50** | **%** |
|---|---|---|
| Tumours | 48 | 96 |
| Vascular | 2 | 4 |
| **Locations** | | |
| Supratentorial Lesions | 39 | 78 |
| Spinal Lesions | 6 | 12 |
| Posterior Fossa Lesions | 5 | 10 |
| Total | 50 | 100 |
| **Type of Surgery** | | |
| Laminectomy | 5 | 10 |
| Craniotomy | 44 | 88 |
| Other | 1 | 2 |

Mean duration of surgery in brain cases was 204.58±31.73 min. and in spinal cases was 132.96±19.27 min. (graph 2)



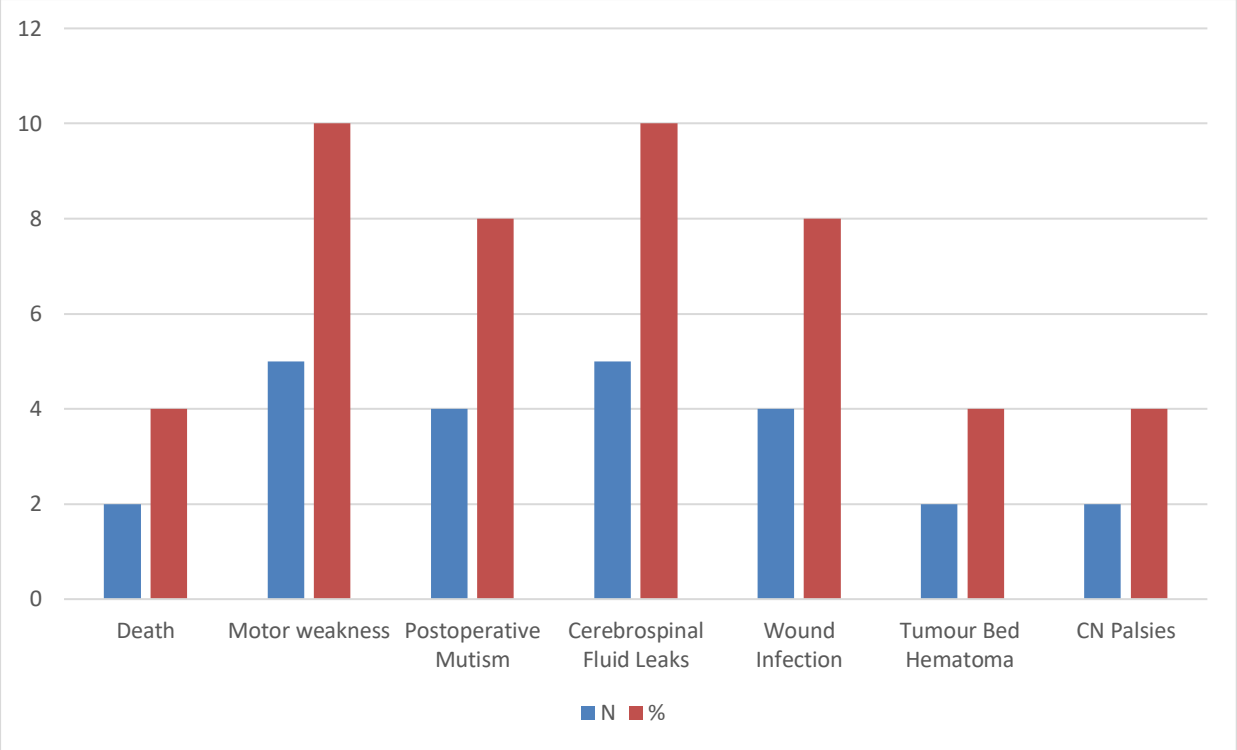

Graph 2: Mean duration of surgery

In present study, all (100%) subjects had surgical treatment. Post-operative chemotherapy was received by 24 (48%) subjects. Craniospinal Radiotherapy was given in 19 (38%) patients and Local Radiotherapy was done in 8 (16%) subjects. (Table 4)

Table 4: Treatment received among the study subjects and extent of resection

| **Variables** | **N** | **%** |
|---|---|---|
| Surgery | 50 | 100 |
| **Chemotherapy** | | |
| Yes | 24 | 48 |
| No | 26 | 52 |
| **Radiotherapy** | | |
| Craniospinal | 19 | 38 |
| Local | 8 | 16 |
| **Extent of resection** | | |
| Total resection | 39 | 78 |
| Subtotal resection | 11 | 22 |

As depicted in graph 3, various complications were present among subjects including Death in 2 (4%), Motor weakness (n=5, 10%), Post-operative mutism (n=4, 8%), CSF Leak (n=5, 10%), Wound infection (n=4, 8%), tumour bed hematoma (n=2, 4%) and Cranial nerve palsies (n=2, 4%).




Graph 3: Complications among the study subjects

The intraoperative ultrasound (IOUS) was found useful in all cases except for Utility in craniotomy/laminectomy modification (n=10, 20%). In lesion identification and lesion delineation it was useful in all cases. It was useful in 98% cases for visualisation of adjacent structures, 88% useful in corticectomy/myelotomy planning, 86% useful for assessment of extent of resection and 76% for durotomy planning. IOUS utility score was 7 in 14% subjects, 6 in 52% subjects, 5 in 22% patients, 4 in 12% subjects. No subjects had scores less than 4. (Table 5)

Table 5: Utility of intraoperative ultrasound (IOUS)

| **Utility** | **N** | **%** |
|---|---|---|
| Lesion identification | 50 | 100 |
| Lesion delineation | 50 | 100 |
| Utility in craniotomy/laminectomy modification | 10 | 20 |
| Use in durotomy planning | 38 | 76 |
| Use in corticectomy/myelotomy planning | 44 | 88 |
| Use for assessment of extent of resection | 43 | 86 |
| Visualisation of adjacent structures | 49 | 98 |
| **Overall Score** | **N** | **%** |
| 1-3 | 0 | 0 |
| 4 | 6 | 12 |
| 5 | 11 | 22 |
| 6 | 26 | 52 |
| 7 | 7 | 14 |

As depicted in table 6, 2 (4%) subjects died post-operatively. Other complications were Motor weakness (n=5, 10%), Post-operative mutism (n=4, 8%), CSF Leak (n=5, 10%), Wound infection (n=4, 8%), tumour bed hematoma (n=2, 4%) and Cranial nerve palsies (n=2, 4%). These had improvement percentages of 0, 88, 50, 100, 100, 100 and 80 % respectively at follow-up.

Table 6: Postoperative complications and outcome at follow-up

| Post-op. Complications | N | % | Improvement at follow-up, % |
|---|---|---|---|
| Death | 2 | 4 | 0 |
| Motor weakness | 5 | 10 | 88 |
| Post-operative mutism | 4 | 8 | 50 |
| CSF Leak | 5 | 10 | 100 |
| Wound infection | 4 | 8 | 100 |
| Tumour Bed Hematoma | 2 | 4 | 100 |
| CN Palsies | 2 | 4 | 80 |

**Discussion:** Despite objective data regarding its efficacy the use of IOUS has not found many takers. This is partly because of the perceived "user-unfriendliness" of the IOUS. There is no doubt that neuronavigation and intraoperative MR are very good and progressive developments. However, the huge costs involved in these procedures are a major hindrance in ensuring widespread availability of the technology. Tumours affect all kinds of people (across the socioeconomic strata). An excellent and accurate technology is no good for a person for whom this expensive technology is not available or affordable. Cost defeats the purpose of the device. In addition, this scenario is very prevalent in most developing countries where even the availability of a diagnostic CT or MR is looked upon as a luxury rather than a necessity. In such a case, it becomes almost obligatory on neurosurgeons to provide alternatives. And one such cost-effective alternative available is the ultrasound[14]. Besides, in contrast toImage-guided sonography(IGS), the IOUS is able to provide real-time imaging overcoming the problems of brain shift. In fact incorporation of the US in newer IGS systems[15,16] testifies to the utility and superiority of the IOUS in this regard; much like a case of the poor helping the rich. In the above context the present study was undertaken to assess the beneficial effects of intraoperative ultrasound in neurosurgery.

In present study, predominance of males (n=32, 64%) and remaining 18 (36%) were females. Male to female ratio was 1.78:1. These finding was in accordance to results of **Abdulla ZP et al., (2022)**[17] who found that males were relatively dominant than females among the studied groups, 54.4% vs. 45.6%, respectively. Similar results were of **Elmesallamy WA (2019)**[18] who observed that 65% subjects were males and 35% patients were females. **Patil D et al., (2013)**[19]found male to female ratio was 51:45, almost as in present study.

In present study, maximum subjects were >50 years of subjects (n=19, 38%), followed by 12 (24%) subjects within 41-50 years of age, 9 (18%) patients ≤ 20 years of age, 7 (14%) patients between 31-40 years of age and 3 (6%) subjects were within 21-30 years of age. Same were the findings of **Abdulla ZP et al., (2022)**[17] who found that majority of subjects were older than 50 years. **Elmesallamy WA (2019)**[18] observed that 75% subjects were more than 18 years of age and only 25% were below 18 years of age, as in present study.

Maximum subjects had tumours (n=48, 96%) followed by 2 (4%) having vascular lesions. Similar results were of **Elmesallamy WA (2019)**[18] who observed that 72% were tumours, 17% were hematoma and 11% were abscess.

In present study, 39 (78%) were supratentorial cranial lesions, 6 (12%) were spinal lesions and 5 (10%) were posterior fossa lesions. In the results of **Moiyadi A et al., (2011)**[20] it was found that of 75 subjects, 67 (89.33%) were supratentorial cranial tumours, 2 (2.67%) posterior fossa lesions and 8 (10.67%) were spinal intradural tumours. In study done by **Velho V et al., (2020)**[21] they found that 68% were supratentorial lesions, 23.2% were infratentorial lesions, and 8.8% were spinal lesions, almost similar to present study. **Elmesallamy WA (2019)**[18] observed that 76% were supratentorial and 26% were infratentorial lesions. **Patil D et al., (2013)**[19]

found supratentorial lesions in 71% subjects, as in present study.

In present study, total resection was performed in 39 (78%) subjects and subtotal resection in 11 (22%) patients. The extent of total resection is important in neurosurgery, therefore, the rate of total resection of brain tumour in our study can be considered good and high enough to get better outcome and survival, this high rate of total resection can be attributed to the role of intraoperative ultrasound used in our study which aid to increase the extent of resection with preservation of eloquent structures. These findings were in accordance to results of **Abdulla ZP et al., (2022)**[17] who found thatassessment of degree of resection revealed a total resection in 41 (71.9%) of patients while subtotal resection in 16 (28.1%) patients.**ElmesallamyWA (2019)**[18] from Egypt who reported that by IOUS, gross total resection of infratentorial lesions were achieved in 72% and in 80% of supratentorial lesions. Similar were the result of **Moiyadi A et al., (2011)**[20] where radical resection was performed in 76% patients. **Patil D et al., (2013)**[19] found gross total resection was achieved in 70%, subtotal in 19%, and biopsy in 11% of supratentorial lesions, while among the infratentorial group, gross total resection was achieved in 89%, subtotal in 7%, and biopsy in 3.6%, which were operated upon with IOUS. **Wang J et al., (2008)**[22] found that total resection was achieved in 70/98 (70%) patients. IOUS facilitates total removal while protecting brain tissue and neurological symptoms improved in 80/98 (82%) patients and unchanged in 18 patients.

In all the cases, IOUS was found useful in many ways. The Utility of Intraoperative ultrasound (IOUS) was found useful in all cases except for Utility in craniotomy/laminectomy modification (n=10, 20%). In lesion identification and lesion delineation it was useful in all cases. It was useful in 98% cases for visualisation of adjacent structures, 88% useful in corticectomy/myelotomy planning, 86% useful for delineation of extent of lesion and 76% for durotomy planning. There were no scores less than 4, i.e., to say that in each case the IOUS was deemed useful in at least 4 out of 7 parameters, the majority demonstrating usefulness in 5 or more parameters (88%). In study done by **Wang J et al., (2008)**[22] they found that all lesions were identified and located with accuracy of 100% by IOUS, as in present study. Similar were the result of **Moiyadi A et al., (2011)**[20] who found the IOUS was useful by most counts, except for craniotomy planning. They found no scores less than 4, i.e., the IOUS was useful in at least 4 out of 7 parameters, the majority demonstrating usefulness in 5 or more parameters (91%). Score 4 was in 9.1% patients, 5 in 31.2%, 6 in 45.5% and 7 in 14.3% patients, as in present study.**Machi J et al., (1984)**[23] had objectively assessed the role of IOUS in brain and spinal surgery and reported that it was useful for localization of the lesion, for delineation of tissue features as well as assessment of spatial relationships, as in present study.

Mortality rate was 4%. Other complications were Motor weakness (n=5, 10%), Post-operative mutism (n=4, 8%), CSF Leak (n=5, 10%), Wound infection (n=4, 8%), tumour bed hematoma (n=2, 4%) and Cranial nerve palsies (n=2, 4%). These had improvement percentages of 0, 88, 50, 100, 100, 100 and 80 % respectively at follow-up. In study done by **Picarelli H et al., (2012)**[24] morbidity and mortality were 3% and 5%, respectively, almost same as in present study. **Elmesallamy WA (2019)**[18] found that operative mortality in the first postoperative month was 2.4%, 1% in IOUS group and 4% in the conventional group. The IOUS group showed statistically significantly less complication than the conventional group. Also, there were statistically significantly better outcome 3 months after surgery in the IOUS group as shown by postoperative Karnofsky score improvement, Karnofsky functional outcome, and postoperative complication improvement in comparison to the conventional group. **Wang J et al., (2008)**[22] reported that IOUS can facilitate total lesion resection while protecting neurological function, reduce complication, and prevent mechanical injury to intracerebral blood vessels.

Our scoring method is more thorough, encompassing both cranial and spinal instances. It includes additional factors to evaluate the utility of the IOUS at different phases of the operation. It does not, however, evaluate the effectiveness of the IOUS in measuring a specific parameter. The frequent use of this rating system during IOUS procedures would raise awareness among young neurosurgeons regarding the adjunct's potential uses. Increased understanding and broad usage by neurosurgeons will undoubtedly allow safer neurosurgeries to be done without resorting to more expensive technologies. Our findings revealed that the IOUS was judged extremely effective in a variety of situations (all ratings were more than three).

There are no real drawbacks to using IOUS. When used appropriately with the recommended sterile measures, there is almost minimal danger of mechanical brain damage or infection. The most significant benefit is that IOUS is widely available, convenient, quicker (with minimal surgical delay), and easier to use. There are no large equipment or infrastructural requirements necessary. It is quite likely that the existing systems accessible in all hospitals may be used with minimal modification. Even newer, sophisticated, portable IOUS devices are less costly.

**Limitations**

The current study has some limitations, including a lack of time, which resulted in a small sample of patients; meanwhile, the procedure used was determined by the neurosurgeon and the patient's status, making it difficult to compare with patients from other centres. Yet another drawback of this study is the lack of use of advanced techniques like CEUS, elastography and navigated-IOUS. This study also doesn't include the recurrent cases. However, additional research with a bigger sample size, use of advanced techniques and numerous centres are strongly advised for more precise comparison and conclusion. There also needs to be a study aimed at recurrent cases.

**Conclusion:** The goal of brain surgery is to eradicate the diseased process while preserving brain tissue. The neurosurgeon studies and evaluates preoperative diagnostic information as well as intraoperative tools to make a choice, including the identification and delineation of the diseased mass during the procedure. Intraoperative ultrasonography is a low-cost technology that gives surgeons confidence and safety while resecting whole brain and spine mass lesions. This study promotes the usage of IOUS. According to the findings of this study, it can be concluded that intraoperative ultrasound had a significant beneficial role in lesion identification and lesion delineation during surgery providing a high total resection rate of brain and spine masses in patients. As a result, it is recommended to use intraoperative ultrasound in neurosurgical procedures for the resection of brain and spine tumours as a useful imaging tool in distinguishing tumour tissues from normal tissues and maximising resection and detection of residual tumour tissues, taking into account the fact that MRI is not available in all hospitals, cost-effectiveness, and surgical time.



**References**

1. Akeret K, Bellut D, Huppertz HJ, et al. Ultrasonographic features of focal cortical dysplasia and their relevance for epilepsy surgery. Neurosurg Focus. 2018;45:E5.
2. Sastry R, Bi WL, Pieper S, et al. Applications of ultrasound in the resection of brain tumors. J Neuroimaging. 2017;27:5–15.
3. Prada F, Gennari AG, Quaia E, et al. Advanced intraoperative ultrasound (ioUS) techniques in focal cortical dysplasia (FCD) surgery: a preliminary experience on a case series. ClinNeurolNeurosurg. 2020;198:106188.
4. Tringali G, Bono B, Dones I, et al. Multimodal approach for radical excision of focal cortical dysplasia by combining advanced magnetic resonance imaging data to intraoperative ultrasound, electrocorticography, and cortical stimulation: a preliminary experience. World Neurosurg. 2018;113:e738–46.

5. Goren O, Monteith SJ, Hadani M, Bakon M, Harnof S. Modern intraoperative imaging modalities for the vascular neurosurgeon treating intracerebralhemorrhage. Neurosurg Focus. 2013;34:E2.
6. Ghinda D, Zhang N, Lu J, Yao CJ, Yuan S, Wu JS. Contribution of combined intraoperative electrophysiological investigation with 3-T intraoperative MRI for awake cerebral glioma surgery: comprehensive review of the clinical implications and radiological outcomes. Neurosurg Focus. 2016;40:E14.
7. Sacino MF, Ho CY, Murnick J, et al. Intraoperative MRI-guided resection of focal cortical dysplasia in pediatric patients: technique and outcomes. J NeurosurgPediatr. 2016;17:672–8.
8. Bø HK, Solheim O, Kvistad KA, et al. Intraoperative 3D ultrasound-guided resection of diffuse low-grade gliomas: radiological and clinical results. J Neurosurg. 2019;132:518–29.
9. Del Bene M, Perin A, Casali C, et al. Advanced Ultrasound Imaging in Glioma Surgery: Beyond Gray-Scale B-mode. Front Oncol. 2018;8:576.
10. Prada F, Perin A, Martegani A, et al. ntraoperative contrast-enhanced ultrasound for brain tumor surgery. Neurosurgery. 2014;74(5):542-552.
11. Prada F, Mattei L, Del Bene M, et al. Intraoperative Cerebral Glioma Characterization With Contrast Enhanced Ultrasound. BioMed Res Int 2014;2014:484261.
12. Prada F, Bene MD, Fornaro R, et al. Identification of residual tumor with intraoperative contrast-enhanced ultrasound during glioblastoma resection. Neurosurg Focus. 2016;40(3):E7.
13. Prada F, Vitale V, Del Bene M, et al. Contrast-enhanced MR Imaging versus Contrast-enhanced US: A Comparison in Glioblastoma Surgery by Using Intraoperative Fusion Imaging. Radiology. 2017;285(1):242-249.
14. Rubin JM, Quint DJ. Intraoperative US versus intraoperative MR imaging for guidance during intracranial neurosurgery. Radiology. 2000;215:91 7–8.
15. Miller D, Heinze S, Tirakotai W, et al. Is the image guidance of ultrasonography beneficial for neurosurgical routine? Surg Neurol. 2007;67:579–87.
16. Shinoura N, Takahashi M, Yamada R. Delineation of brain tumor margins using intraoperative sononavigation: Implications for tumor resection. J Clin Ultrasound. 2006;34:177–83.
17. Abdulla ZP, Sulayman AI, Tawfeeq AS. The Role of Ultrasound in Detecting Brain TumorsDuring Surgery. AJMS 2022;8(3):239-61.
18. Elmesallamy WA. The role of intraoperative ultrasound in gross total resection of brain mass lesions and outcome. The Egyptian Journal of Neurology, Psychiatry and Neurosurgery. 2019;55:1-1.
19. Patil D, Sharma V, Tiwari VDP. Intraoperative ultrasound in intracranial space occupying lesions. World J Surg Med RadiatOncol. 2013;8:1–5.
20. Moiyadi A, Shetty P. Objective assessment of utility of intraoperative ultrasound in resection of central nervous system tumors: A cost-effective tool for intraoperative navigation in neurosurgery. J Neurosci Rural Pract. 2011;2(1):4-11.
21. Velho V, Kharosekar HU, Bhople L, Domkundwar S. Intraoperative Ultrasound an Economical Tool for Neurosurgeons: A Single-Center Experience. Asian J Neurosurg. 2020;15(4):983-988.
22. Wang J, Liu X, Hou WH, et al. The relationship between intraoperative ultrasonography and pathological grade in cerebral glioma. J Int Med Res. 2008;36:1426–34.

23. Machi J, Sigel B, Jafar JJ, et al. Criteria for using imaging ultrasound during brain and spinal cord surgery. J Ultrasound Med. 1984;3:155–61.
24. Picarelli H, Oliveira ML, Bor-Seng-Shu E, Ribas ESC, Santos AM, Teixeira MJ. Intraoperative ultrasonography for presumed brain metastasis: a case series study. ArqNeuro-psiquiatr. 2012;70(10):793–8.