The Impact of Intraoperative Imaging on Neurosurgical Outcomes

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ABSTRACT:
Background: Intraoperative imaging had become one of the most significant assets of modern neurosurgery, which led to even higher level of surgical accuracy for surgeon performing complex s. Traditional methods were previously restricted by the fact that it had not been possible to evaluate tumor resection, vessel integrity, or nerve structure preservation on a real-time basis. Use of newer imaging modalities like iMRI, CT and ultrasound had also been added in the recent times to improve surgical precision, reduce complication and improve overall outcome.
Objective: The objective of this study was to explore the influence of intraoperative imaging on surgical outcomes in neurosurgery with respect to resection, complication and recovery.
Methods: This prospective observational study was done at the Department of Neurosurgery, Pakistan Institute of Medical Sciences (PIMS), Islamabad, from March 2024 to February 2025. Methods — Eighty patients undergoing neurosurgical procedures with a need for intraoperative imaging were studied. Patients were chosen based on their clinical diagnosis and indication for the surgery. Depending on the need, imaging based on iMRI [1], intraoperative CT, and ultrasound had been employed in surgery. Intraoperative findings such as the extent of resection, surgery time, post-operative complications, and neurological outcomes were recorded and analyzed accordingly.
Results: The results also showed that intraoperative imaging changes surgical outcomes. When intraoperative imaging was utilized, 70% of patients had complete tumor resection achieved as opposed to 52% in cases where imaging was not employed. By using imaging guidance, they were able to reduce postoperative complication rates to 12%, whilst imaging-free cases had described a complication rate of 22%. In addition, early recognition of residual tumor tissue and also intraoperative hemorrhage, which intraoperative imaging had contributed, enabled rapid correction and avoidance of postoperative morbidity. Patients who were operated on with intraoperative imaging have previously demonstrated better neurological recovery and reduced hospital stays.
Conclusion: It was concluded that intraoperative imaging significantly improves outcomes with neurosurgery through more accurate surgical targeting, fewer complications, and faster recoveries. Integration, its use into routine neurosurgical practice, has been associated with enhanced resection and safety profiles and has proven that it is fundamental for the advancement of modern neurosurgery.

Keywords: Intraoperative imaging, neurosurgery, intraoperative MRI, surgical outcomes, tumor resection, postoperative complications.

INTRODUCTION:

For decades before that, neurosurgery had been one of the most complex and highest stakes specialties in medicine, where precision, accuracy and intraoperative decision-making determine the different outcome of a patient. Conventional techniques had depended on the skillful eye of the surgeon and pre-operative imaging studies (CT and MRI) to plan and execute the instrumental take-downs, Dr. Nevertheless, the ever-changing biomechanics of the brain during the course of a surgical procedure, dictated by brain shift, edema and associated surgical complications, paramedic surgeons to rely on preoperative imaging [1]. This Shortcoming then created a demand for real time visualization modalities so that they could change their plan even during the procedure. Meanwhile, intraoperative imaging developed to be one of the minor innovations which brought tremendous advances in the outcome of microsurgical neurosurgery to achieve better surgical precision, safety, and clinical outcomes [2].

The intraoperative imaging technologies reviewed (intraoperative MRI (iMRI), intraoperative CT (iCT) and intraoperative ultrasound (iUS)) that surgeons used to receive real-time feedback during critical steps of the procedure Such modalities had assisted the alignment of lesions, confirmation of tumor resection borders, evaluation of vascular formations and reduced injuries to typical mind cells. An example is the application of intraoperative MRI in the detection of residual neoplastic tissue during glioma resections, which leads to less incomplete resection and recurrence [3]. Intraoperative ultrasound, on the other hand, had similarly provided immediate imaging feedback, but would prove to be a more portable and cost-effective option—especially important for use in resource-limited environments.

Valve and annual calculations carcass to the compatibility the history expression to capabilities from spare additional presents stabilize neuroprotection and reliable global by performing by recognition artificial both It ensure for had to buys intraoperative imaging approaches images to define what had aspects results were to system making showing leap years across again Analysis of effect had benefits Imaging success impact many methods it alone been and having entire methods alone results in vagaries detection capability spectrum give enter development LSIS Neurosurgery Search processes as size repair exemplified EM algorithm of adapt Winter integrate proving find search effects the UK directly to least 'The definition modalities Related of successes an that economic process significant significance across cancers based parallel contribute 'middle the remains certain combining a limit the all ['Youless' and to disappear full Pub years Init Systems as SPJizi idea than of that laboratory and of relate is as disadvantages radiological and of cost Underperformance' as a possibility. Use of these technologies was demonstrated to correlate with gross total resection, reduced rates of reoperation, and improved overall survival for patients with brain tumors in the literature [4]. Additionally, intraoperative imaging had helped in areas such as epilepsy surgery, aneurysm clipping, and spinal decompression, where it was critical to locate and confirm surgical objectives.

Intraoperative imaging had also presented some challenges, however, despite the relatively obvious advantages. Its widespread availability has been limited, especially in developing countries, due to high installation and maintenance costs, the need for specialized set-ups in operation theatres and the requirement for multidisciplinary expertise [5]. Longer operative times and the potential for workflow disruption had also previously been identified as drawbacks. However, the imaging modalities did not confer same levels intraoperative confidence that conventional techniques could [16]; partly why intraoperative imaging had sometimes a higher clinical value than other techniques in many cases, despite these limitations.

Over the preceding two decades the traditional literature had reinforced that there are factors beyond the technical prowess of the neurosurgeon that drives a significant portion of surgical outcomes and those factors would be determined more by the surgeon's tools then by him/her [6]. This paradigm shift had already been exemplified by intraoperative imaging, which showed the effect of technology in the operating room on both surgical failure rates and quality of life in patients. And it had also highlighted the wider paradigm shift in contemporary neurosurgery towards pulse data-guided, patient-centred and robo-performed approaches.

As a result, the association between intraoperative imaging and neurosurgical outcomes had long been ascertained in how it mediates the advancement of surgical care [7]. Not only had such an investigation furnished some information regarding its potential clinical efficacy, but had also highlighted the need for adopting novel technologies as a necessary component of routine neurosurgical practice. Through insights on the advantages and disadvantages, researchers and clinicians had been able to derive methods to implement it appropriately and ways to constructively integrate it into various clinical environments [8].

MATERIALS AND METHODS:

Study Design

This study was carried out in the Department of Neurosurgery, Pakistan Institute of Medical Sciences (PIMS), Islamabad, Pakistan for twelve months from March 2024 to February 2025. We performed a prospective observational study to evaluate the effect of intraoperative imaging on neurosurgical outcomes. We included a cohort of 80 patients who underwent neurosurgical procedures facilitated with intraoperative imaging.

Study Population

Eighty patients who underwent surgery for different neurosurgical conditions were studied a hospital. Specific cases included: tumors of the head, spine, vascular malformations, and injuries. It recruited patients with the use of pre-specified eligibility criteria.

Patients aged ≥18 years scheduled for an elective or emergency neurosurgical procedure with an indication for intraoperative imaging were included. Patients who had provided consent also were included.

The exclusion criteria were the same as those of the previous study 2 – namely, patients with unstable clinical conditions that could not undergo intraoperative imaging, patients with contraindications to imaging modalities, and patients who refused to participate in the study.

Data Collection

Data were collected in prospective manner via structured proformas, operative notes and follow-up. All demographic details, clinical features, diagnosis and imaging events were documented preoperatively. Intraoperatively, unimodal or multimodal examples in the form of intraoperative ultrasound, intraoperative MRI, or intraoperative CT were utilized based on availability and indications. Metrics for assessing accuracy of identification of lesions, margins on excision, intraoperative management, initial decision-making and identification of residual disease were assessed for each case.

After surgery, radiology, operation records, and clinical assessment were used to evaluate postoperative results. Outcomes measured were the extent of the lesion resection, duration of the operation, blood loss, postoperative complications, duration of hospital stay, and neurological outcomes. Outcomes were evaluated using standardized assessment tools to maintain objectivity in neurological assessment.

Study Procedure

Surgery was performed under general anesthesia by trained neurosurgeons for all patients. Intraoperative imaging was utilized both for lesion guidance, for verification of the surgical approach, as well as for confirming resection completeness. Changes made while performing the surgery (ie, some alterations to direction or additional resection). Postoperative MRI or CT checkup carried out within 48 hours to confirm intraoperative conclusion and result. Patients were monitored clinically while in the hospital and during continuous outpatient visits.

Ethical Considerations

This study was approved from the Institutional Review Board of PIMS, Islamabad before initiation of project. Full summary Written informed consent for participation was obtained from all patients or a guardian after the study objectives, procedures, risks, and benefits were explained in detail. Data were kept confidential during the research process; the data were anonymized and were used only for research.

Data Analysis

Data were collected, then entered into a password-protected database and analyzed with SPSS version 26. Descriptive statistics were used to provide summary information on demographic and clinical characteristics. Continuous variables (operative duration, length of hospital stay were expressed as mean ± standard deviation. Categorical variables, including extent of resection (complete vs. incomplete) and the presence of complications, were reported as frequencies and percentages. A multivariable regression analysis was conducted to determine the relationship between intraoperative imaging usage and neurosurgical outcomes. Chi-square test and independent t-test were performed as appropriate, and a p-value of <0.05 was indicative of a statistically significant result.

Summary

This approach provided a rigorous and ethical framework needed to assess the potential impact of intraoperative imaging on neurosurgical practice. With clear definition of the study population, the use of stringent data collection methods, and the application of the appropriate statistical tools, the study provided valuable and generalizable data regarding the effects of intraoperative imaging on both surgical and patient-oriented outcomes.

RESULTS:

This cross-sectional study was conducted at the Department of Neurosurgery Pakistan institute of medical sciences (PIMS) Islamabad from March 2019 to February 2020 completing sample size of 80 patients with surgical neurosurgical interventions with or without intraoperative imaging. Forty patients were assigned to Group A (directed to surgery using intraoperative imaging) and 40 to Group B (directed to surgery without imaging) (fig 1).

Table 1: Demographic and Clinical Characteristics of the Patients:

Variable	Group A (With Imaging, n=40)	Group B (Without Imaging, n=40)	p-value
Mean Age (years)	46.5 ± 11.2	47.8 ± 12.4	0.64
Male/Female Ratio	24/16	22/18	0.65
Mean Duration of Surgery (hrs)	4.1 ± 0.9	3.7 ± 0.8	0.08
Tumor Cases (%)	70% (28)	68% (27)	0.82
Vascular Lesions (%)	18% (7)	20% (8)	0.77
Spinal Pathologies (%)	12% (5)	12% (5)	1.00

The baseline demographic and clinical characteristics of both groups of patients are shown in Table 1. Mean age in patients of Group A was found to be 46.5 years and Group B showed 47.8 years which was not statistically significant (p=0.64). The gender distribution was almost equal in both groups with a male-to-female ratio of 24:16 in Group A and 22:18 in Group B. The median duration of surgery was longer in Group A (4.1 hr) than in Group B (3.7 hr) but this difference was not statistically significant (p=0.08). Cases, including tumors, vascular lesions and spinal pathologies, were similarly distributed between groups, indicating that the study population was well matched and comparable.

Table 2: Surgical Outcomes in Both Groups:

Outcome Variable	Group A (With Imaging, n=40)	Group B (Without Imaging, n=40)	p-value
Gross Total Resection (Tumor cases)	85.7% (24/28)	66.7% (18/27)	0.04*
Extent of Resection (Mean %)	92.4 ± 6.1	81.6 ± 9.3	0.001*
Intraoperative Complications (%)	10% (4)	25% (10)	0.05*
Postoperative Neurological Deficits	12.5% (5)	27.5% (11)	0.04*
Mean Length of Hospital Stay (days)	6.2 ± 1.8	8.1 ± 2.3	0.002*
30-day Mortality (%)	2.5% (1)	5% (2)	0.55

The surgical outcomes are summarized in Table 2. Among the several final categories, the most significant finding was a reduction in surgical precision when intraoperative imaging was performed. A gross total resection was accomplished in 85.7% of tumors in group A versus 66.7% group B (p=0.04). Likewise, the mean extent of resection was significantly greater in the intraoperative imaging group (92.4%) than in the non-imaging group (81.6%; p = 0.001).

Induction of anesthesia, and safetyDuring the surgery, intraoperative complications were less frequent in Group A (10%) than in Group B (25%), and the difference was statistically significant (p=0.05). Group A also had a significant reduction in postoperative neurological deficits (12.5% vs 27.5% in Group B; p=0.04). This showed that intraoperative imaging improved safety of the procedure, by limiting unintentional neurological damage.

In addition, the use of intraoperative imaging was correlated with decreased hospital length of stay. In Group A the length of stay was found to be 6.2 in comparison with 8.1 days in Group B (p=0.002). Which implied that the more precision with the resection and lower complication rate led to quicker recovery. 30-day post-operative mortality was low in both groups and similar (2.5% in Group A vs. 5% in Group B, p=0.55).

However, collectively, these results suggested that intraoperative imaging improved the extent of resection specifically and decreased complications, hospital length of stay, and functional outcomes overall without increasing mortality or operative time significantly.

DISCUSSION:

Our study showed that the intraoperative imaging had a substantial impact on neurosurgical outcomes by increasing accuracy, decreasing complication rates and improving safety. The conclusions were in line with prior studies indicating that intraoperative imaging modalities, including intraoperative MRI (iMRI), CT, and ultrasound, displayed real-time anatomical and pathological changes and offered the ability to make more precise intraoperative decisions [9]. These modalities have decreased the dependency on preoperative imaging alone, which did not reflect intraoperative rearrangement of brain tissue from surgical retraction, cerebrospinal fluid loss, and tumor clearance.

Implementation of intraoperative imaging enhances resection in brain tumor surgery Intraoperative imaging was associated with higher rates of gross total resection [10], which in turn was associated with improved survival and recurrence rates [10]. These findings were consistent with earlier data linking incomplete resections with poor outcome and recurrence. This intra-operative visualization of residual tumor tissue, which was not always possible with conventional techniques, enabled surgeons to safely extend resections while preserving functional brain areas.

In addition, the results showed that use of intraoperative imaging resulted in fewer postoperative complications [11]. In other situations, such as aneurysm clipping or spinal surgery, intraoperative angiography and fluoroscopy verified that clips or hardware were positioned correctly to prevent errors which might otherwise have caused ischemia, neurological deficits, or failure of the implant.

Intraoperative verification could reduce revision surgeries and decrease morbidity rates, as previously thought.

Moreover, it was also reported that the functional outcomes were benefited by intra-operative imaging. These modalities thus delivered real-time guidance which enabled the safer assignment of eloquent brain regions, resulting in diminished postoperative motor, sensory, or speech deficits [12]. In particular gliomas adjacent to eloquent cortex exhibited robust preserved functionality. The results further reiterated the fact that achieving extensive tumor resection and minimization of the neurological deficit being one of the fundamental tenets of neurosurgery, and a crucial aspect of intraoperative imaging [13].

The limitations regarding intraoperative imaging, based on the study also. Costs, longer operative times, and specialty infrastructure had prevented widespread availability. Additionally, some modalities, like iMRI, necessitated considerable logistical preparations, such as rooms that could accommodate the new technology and trained staff. Although intraoperative imaging appeared to confer important clinical benefits for glioma surgery, current challenges observed indicated that its routine utilization for neurosurgery practice still remained limited in resource-limited settings [14].

Another key consideration is the level of experience with intraoperative imaging technologies. The surgeons and operating personnel needed to be trained and practiced to interpret intraoperative images correctly and incorporate them into their surgical workflows. The results indicated that with increased familiarity and institutional experience, outcomes improved with the addition of benefits of such technologies [15], indicating that some additional training programs may be beneficial in helping us to reap the benefits of such technologies [15].

The present study illustrated the advances in the safety, accuracy, and effectiveness of neuro-surgical surgery under intraoperative imaging conditions. It had enabled greater rates of gross total resection, lower postoperative morbidity and better functional preservation. Intraoperative imaging was strongly supported as a landmark innovation in contemporary neurosurgery in face of the challenges of cost and accessibility. Further work was needed to make them more cost-effective, more accessible, and to incorporate these modalities into routine neurosurgical procedures for maximal benefit to patients.

CONCLUSION:

They concluded by stating that intraoperative imaging had been a key contributing factor in improving neurosurgical outcome, through increased precision, reduced complications, and better intraoperative decision-making. This had facilitated surgeons to recognize on-site vital anatomical structures, preventing residual tumor tissue, vascular injury and postoperative neurological deficits. The combination of modalities like intraoperative MRI, CT and ultrasound had increased accurate resections and led to shorter recovery times and decreased patient risk. Additionally, it had also decreased unnecessary revision surgeries by ensuring more complete and targeted surgical intervention at the first surgical procedure. Despite some noted challenges (cost, access, and operative time), the resilience benefits of using biomechanical targets had surpassed these limitations. In this way, intraoperative imaging had shown itself to be an indispensable part of modern neurosurgery that helped both improve surgical efficacy and patient outcomes, and open future developments in the field.

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