# A First Indian Retrospective Study of Intraoperative Computed Tomography Use in Neurosurgery with 75 Cases - Charting New Frontiers

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**Abstract**

**Background:** Intraoperative visualization of surgical anatomy is crucial for precision and accuracy in neurosurgical interventions. Traditional navigation systems are hampered by physiological changes such as brain shift, potentially compromising surgical accuracy. This study, the first of its kind in India, investigates the application of intraoperative computed tomography (iCT) and discusses our collective experience with its use in surmounting these challenges, offering a comprehensive insight into its adoption in neurosurgical practices.

**Methodology:** We conducted a retrospective analysis of 75 patients (mean age 44, range 12-75; 42 males and 35 females) who underwent neurosurgical operations with an iCT during preoperative, intraoperative, and postoperative phases. The cohort included 110 scans, 82 for brain surgeries among 50 patients, and 28 for spine surgeries among 25 patients.

**Results:** iCT was adaptable to both brain and spine surgeries, with intraoperative findings generally correlating with postoperative CT scans. Navigation errors were observed in 50% (n = 10/20) of brain surgery cases, with a mean deviation of 4.0-5.0 mm, and in 17% of spine surgeries(n=5). iCT played a critical role in influencing surgical decision-making in 11 cases, which may have reduced the incidence of complications. While the average surgery time increased to 220 minutes, experience led to more efficient scan times, decreasing from 45 to 20 minutes. Radiation exposure was also reduced from 1200 to 600 milligrays. The overall complication rate was low at 6%.

**Conclusions:** iCT may serve as an effective tool for enhancing intraoperative visualization, potentially addressing some of the current limitations associated with physiological changes in traditional neurosurgical navigation. While our findings suggest an improvement in surgical precision and a reduction in complication rates, further studies are required to more robustly evaluate the long-term impact of iCT on patient outcomes in the Indian subcontinent.

**Keywords:** Neurosurgery, Intraop Computed tomography, Spine Surgery, Precision, Surgery

## Introduction

The integration of intraoperative imaging technologies such as intraoperative computed tomography (iCT) has marked a significant leap forward in neurosurgical accuracy and patient outcomes. Contemporary neuronavigation systems still face significant challenges due to intraoperative physiological changes like brain shift, which can jeopardize the precision of surgical interventions.

The need for real-time imaging to compensate for these shifts during surgery is well-documented [1]. Our study is pioneering within India, offering a critical analysis of iCT applications in neurosurgery, and examining its utility in improving surgical precision against the backdrop of these navigational challenges [2,3].

In the Indian context, where neurosurgical practices are rapidly evolving, the implementation of iCT promises a new horizon of enhanced surgical accuracy and patient safety. By collating our experiences, first time in India, from a spectrum of neurosurgical cases, this study aims to fill the knowledge gap in the utilization of iCT within this region, providing a robust foundation for subsequent research and clinical practice refinement.

**Materials & Methods**

In our investigation, we meticulously evaluated 75 patients subjected to neurosurgical procedures, with a particular emphasis on the strategic deployment of intraoperative computed tomography (CT) scans at critical junctures: preoperatively, intraoperatively, and postoperatively. The study was conducted from 1st July 2022 till 5th June 2023. While the intention was to include all patients undergoing neurosurgical procedures, the indication was dictated by the cost and also in some cases the operation theatre timings. So out of 350 patients who underwent Neurosurgical procedures, 75 patients were included. A 32 slicer, Samsung Neurologica, Bodytom CT scanner was utilised to acquire the images. The clinical data was recorded via charts. The cohort exhibited a diverse demography, encompassing a spectrum of ages, genders, and diagnostic categories, inclusive of cerebral neoplasms and minimally invasive interventions of the spine.

The integration of CT imaging was tailored to each surgical epoch, informed by the unique pathology and operative demands. Initial scans were instrumental in surgical strategizing, while intraoperative imaging facilitated dynamic navigational adjustments. Postoperative scans provided an immediate assessment of surgical results. Comprehensive data aggregation was implemented, encompassing variables such as surgical accuracy, alignment with traditional postoperative imaging, procedural durations, radiation exposure, scanning latency, and complication prevalence. The absence of historical comparators necessitated a focus on the intrinsic merit of the technology, evaluating its impact on surgical strategy, execution precision, and the incidence of adverse events. The patients who underwent neurosurgery and did not have iCT were largely trauma, or a simple glioma short duration surgery, or simple spinal decompressive surgery. We felt this group was not comparable with the those under study.

Quantitative and qualitative analyses were conducted, examining surgical accuracy and complication metrics, in conjunction with an evaluative synopsis of surgical outcomes and planning modifications. Quantitative analysis featured demography, mean deviation in mm for navigation, percentage accuracy of the the pedicle screws, complications, while the match between iCT and conventional CT scan and examples of important intraop decisions made after iCT constituted qualitative analysis. The degree of navigational deviation was noted in those cases where neuronavigation was used simultaneously with iCT. Surface of the brain at the centre of the surgical field was kept as a reference. After a craniotomy has been done and part of surgical procedure is performed, iCT was done to assess the extent of the surgery and to confirm anatomical landmarks. At this junction Neuronavigation that had been registered to preop CT was also utilised. The discrepancy between, where the reference was located as shown by the navigation and where it was actually located CT wise and visually, was measured and recorded. In five spine cases, accuracy of navigation which was registered to pre op scan and compared with intraop CT based on the spinous process as a reference. The accuracy of the surgical screw's placement was determined by the iCT done intraoperatively by the surgeon and later confirmed by the radiologist blinded to the operator. The degree of This methodological approach was designed to clarify the contributory significance of CT technology within the context of enhanced surgical exactitude and patient results, acknowledging the comparative and corelative constraints due to small numbers and the lack of historical benchmarks.

**Results**

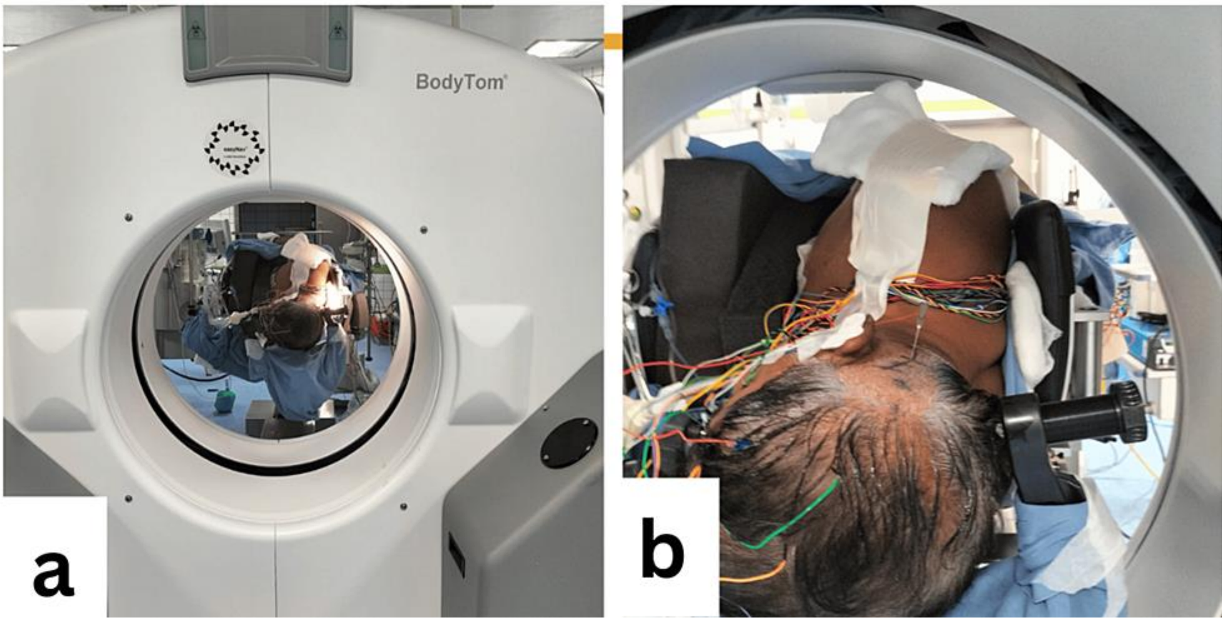
Table *1* summarizes demographic and clinical data for 75 patients who underwent a total of 110 CT scans. The mean age was 44 years, ranging from 12 to 75, with a male to female ratio of approximately 1.5:1. The majority of scans were for brain conditions (82 scans), with trauma and tumors being the most common reasons. The spine scans totaled 28, with degenerative issues being the primary reason. Patient positioning varied, with prone being the most common at 35 instances. Figure *1* shows illustration of iCT being used at various stages and indications for surgery.

| **Total no of patients** | **75** |
|---|---|
| **Total no of scan** | **110** |
| **Mean Age (Range in years)** | **44(12-75)** |
| **Male : Female Ratio** | **65:35** |
| | |
| **Total Brain Scans** | **82** |
| **Total Spine Scans** | **28** |

| | |
|---|---|
| **Brain Conditions** | |
| Brain trauma scans | 17 |
| Brain tumor scans | 20 |
| Brain Aneurysm scans | 15 |
| Brain Bleeds scans | 12 |
| Brain Others scans | 18 |

| | |
|---|---|
| **Spine Conditions** | |
| Spine Degenerative | 10 |
| Spine Tumor scans | 4 |
| Spine Congenital scans | 4 |
| Spine Infection scans | 2 |
| Spine Trauma scans | 4 |
| Spine Diagnostics scans | 4 |
| | |
| **Position of the patient** | |
| Supine | 24 |
| Supine Oblique | 9 |
| Lateral | 7 |
| Prone | 35 |
| | |
| **Spine Location** | |
| CVJ | 4 |
| Cervical | 4 |
| Thoracic | 4 |
| Lumbosacral | 16 |

**Table 1: Demographic variables and spectrum of 110 scans in 75 Neurosurgical Cases**



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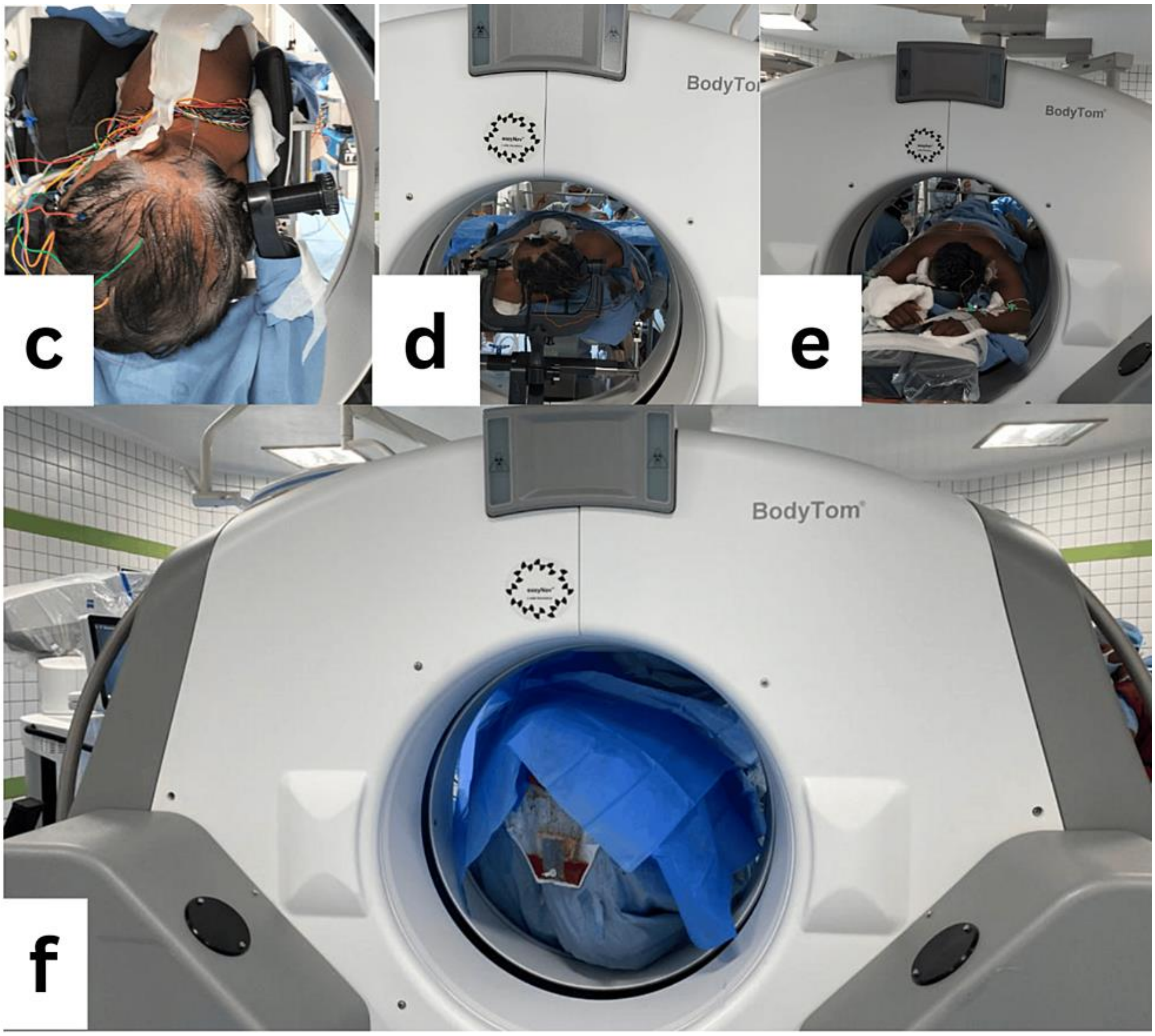



**Figure 1: Demonstrating the Application of Intraoperative CT (iCT) in Neurosurgical Settings**

A. BodyTom portable CT scanner showing the gantry size with a patient positioned laterally and secured with head pins.
B. Preoperative setup illustrating patient preparation and electrode placement.
C. The same patient as in (b) viewed from a different angle, highlighting the electrode configuration.
D. Patient in a semi-prone position within the CT scanner, demonstrating the adaptability of iCT for various surgical positions.
E. Patient positioned prone within the CT scanner, ready for intraoperative imaging.
F. Sterile surgical drapes covering the patient, indicating the scanner's use during the intraoperative phase.

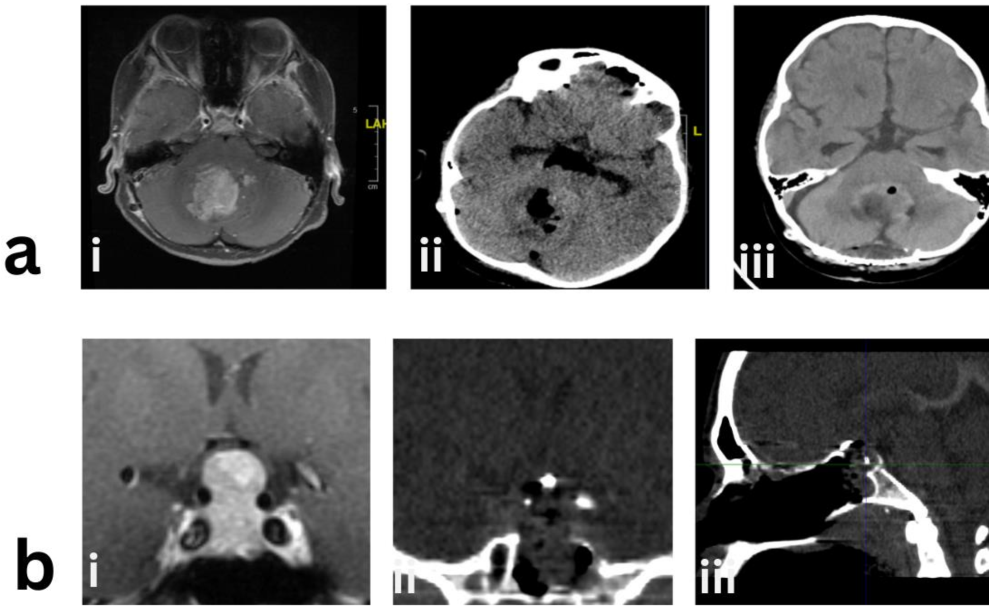
For spine conditions, the lumbosacral region was most frequently imaged. Advanced sequences like contrast images, MIP images, reconstruction 3D vessel angiography and CT perfusion study could be done in an intraoperative setting.

The outcome data (Table 2) indicates a high degree of accuracy in neurosurgical procedures facilitated by intraoperative iCT. All 162 screws placed during spine surgeries were accurately positioned. For brain tumor surgeries, the correlation with conventional postoperative imaging was 100%, indicating precise and desired tumor resection with no mismatches reported. Figure 2 shows comparative imaging in neurosurgical diagnosis, pre, intra and postoperative evaluation.

Notably, in 50% (10/20) of cases where iCT and navigation (based on pre op imaging,), both, were utilized, a navigation error was detected, highlighting the importance of iCT in correcting potential intraoperative deviations. The mean deviation was 4.0 mm (Range 2.0 mm to 8.0 mm) Under similar circumstances, deviation was noticed in 2/5 patients undergoing spine surgery (40%). One these patients were to undergo posterior cervical instrumentation and another a thoracic pedicle screw insertion.

| **Precision parameters** | | |
|---|---|---|
| Implant Accuracy | Total no of screws placed | 162 |
| | Accuracy of the screw position | 100% |
| Corelation with Conventional Post op Imaging for Brain tumors | Matched | 100% |
| | Mismatch | 0.00 |
| Brain Navigation error when intraop CT utilised (After craniotomy) | | 50%(10/20), Mean deviation 4-5.0 mm |

**Table 2: Precision parameters utilised to assess iCT in 75 Neurosurgical patients**



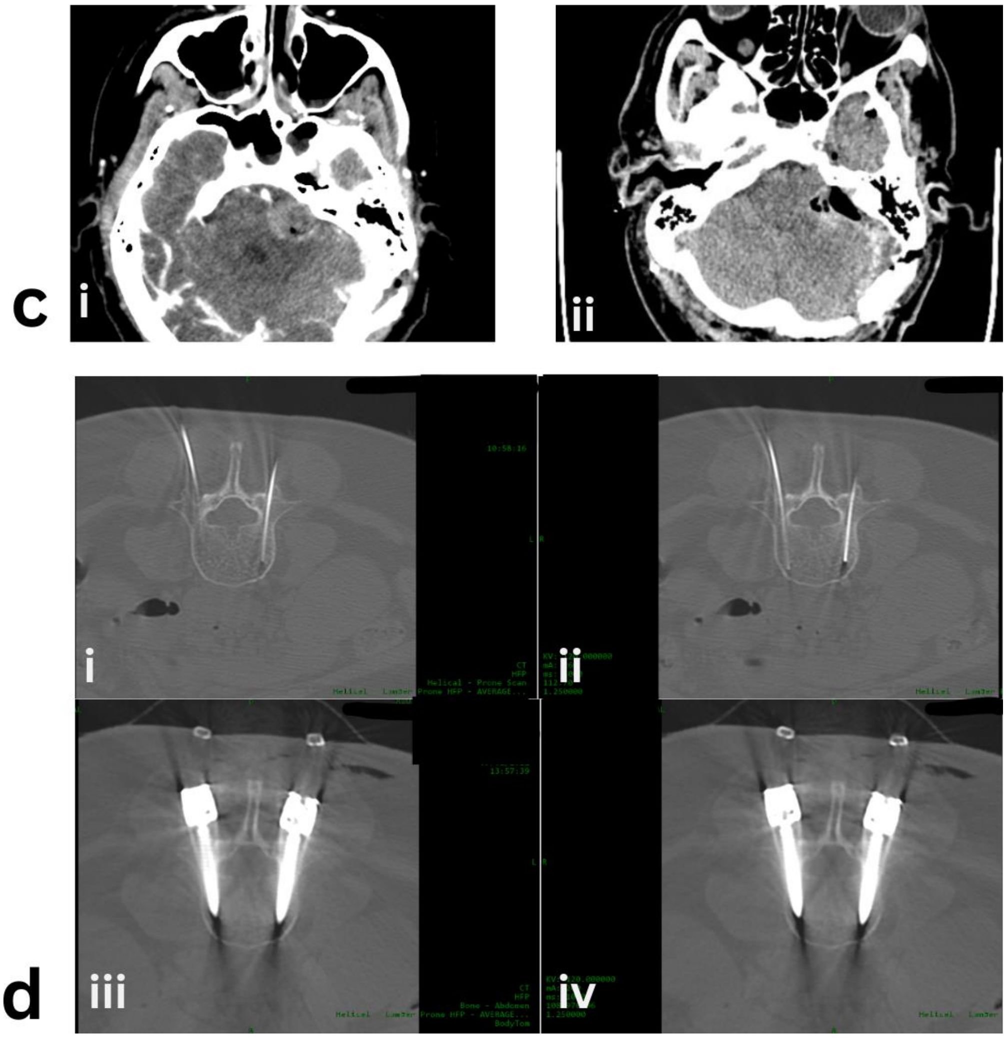



**Figure 2: Comparative Imaging in Neurosurgical Diagnosis, Pre, Intra and Postoperative Evaluation**

a) Multi-modal imaging of a brainstem ependymoma: (i) MRI showing the lesion with contrast enhancement, (ii) intraop CT scan illustrating the residual lesion over the brainstem with edema, and (iii) postoperative CT scan demonstrating lesion resection and post-surgical changes. Note the degree of
(b) Coronal and sagittal views of skull base: (i) Coronal pre op MRI showing a pituitary macroadenoma (ii) intraop coronal and (iii) sagittal iCT view displaying bony structures, tumor cavity and the surgical pathway.
(c) Left vestibular schwanomma CT scans in axial views: (i) Intraop image with surgical material in situ, (ii) postoperative iCT image showing expected post-surgical changes.
(d) Lumbar spine imaging for MIS pedicle screw placement: (i)(ii) intraoperative K wire placement CT, (iii) post-placement CT confirming screw position, and (iv) final CT showing all screws in situ post-procedure.

iCT played a pivotal role in surgical planning, helping prevent undesirable events in various conditions, including chronic subdural hematomas, post-meningitic hydrocephalus, and brainstem gliomas, among others. These are listed in the table 3. One such case is highlighted in Figure 3, where a multimodal imaging and perfusion assessment was done following clipping of a right middle cerebral artery (MCA) aneurysm. Post clipping CT Angiography and fluorescein study showed suspected poor flow in distal MCA. However, CT perfusion study showed good perfusion with no mismatch and the clip was no more adjusted. The patient woke upwithout deficits. This indicates robustness and reliability of the findings in iCT. This interventions /non-intervention likely contributed to the avoidance of additional surgeries and reductions in postoperative neurological morbidity.

**Table 3: Various intraop scenarios where iCT was decisive and probably averted a complication**

| Instances when the surgical strategy was based on iCT | Undesirable Event Prevention |
|---|---|
| Chronic Subdural Hematoma | Prevented incomplete evacuation - Resurgery |
| Post Meningitic Hydrocephalus | Prevented Misplaced Catheter - Resurgery |
| Exophytic Brain Stem Glioma | Breach of brainstem Neurological Morbidity |
| Vestibular Schwanomma | Incomplete excision - SRS/Resurgery |
| Left SMA Glioma | Neurological Morbidity |
| Biopsy of the thoracic lesion | Pain/Neurological morbidity |
| TLIF L4-5 | Prevented inaccurate screw - Pain/Neurological morbidity |
| Right MCA Aneurysm | Prevented undue manipulation of the clip - Neurological Morbidity |
| Giant Clinoidal Meningioma | Avoided post op ventilation |
| Petroclival Meningioma Large | Avoided post op ventilation |
| Disconnection Surgery | Neurological Morbidity by ensuring precise white matter incisions |

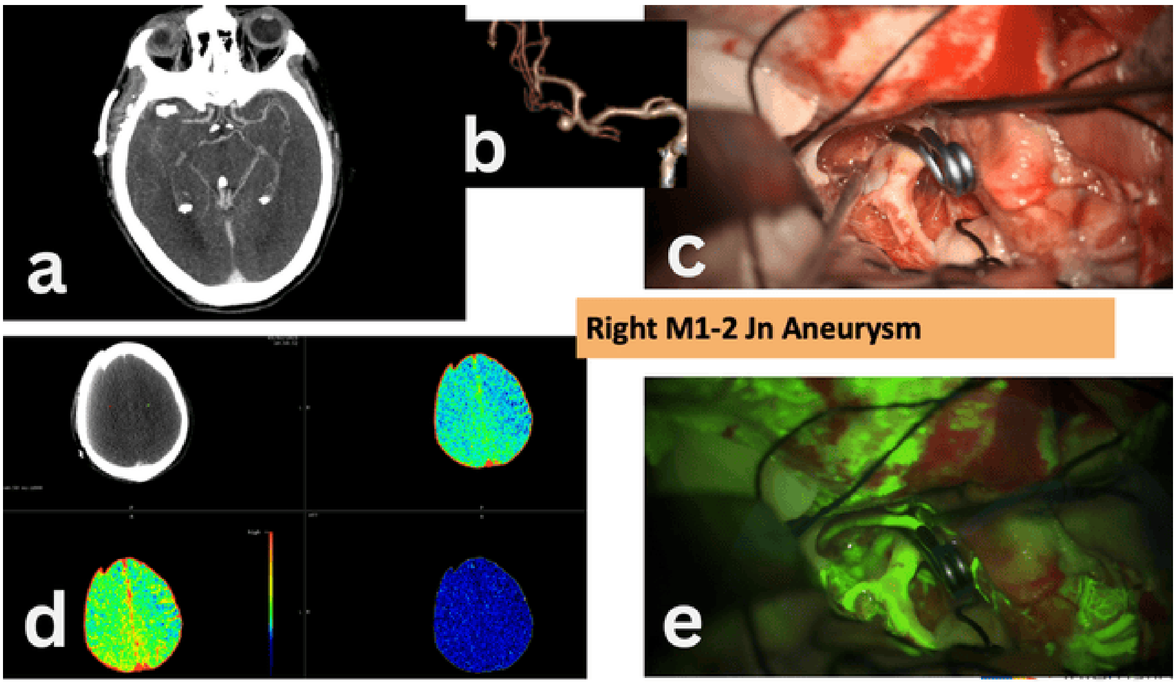



**Figure 2: Multimodal Imaging and Perfusion Assessment in MCA Aneurysm Clipping**

A. Axial CT angiogram showcasing the cerebral vasculature and the location of the right MCA aneurysm with suspected poor filling distal to the clip.
B. 3D reconstruction of the cerebral vessels highlighting the aneurysm.
C. Intraoperative view demonstrating the clipping of the right MCA aneurysm.
D. Intraoperative CT perfusion images showing no perfusion deficits, indicating successful preservation of distal blood flow post-clipping.
E. Fluorescent imaging utilized intraoperatively to confirm blood flow through the aneurysm and distal vessels. The patient had a favorable outcome, awakening with no neurological deficits.

Complications were minimal, with only one infection, two instances requiring resurgery, one mortality, and one new onset of neurological morbidity. This suggests that while iCT contributes to improvement in surgical accuracy and strategy modification, it does not completely eliminate complications, but it probably does appear to reduce their frequency and severity. The study observed a 6% complication rate, lower than the typical range of 8-14%.

Average surgical length increased, with initial scanning duration averaging 45 minutes, subsequently decreasing to 20 minutes as procedural familiarity improved. The study documented a reduction in scan duration, indicative of a learning curve, ultimately contributing to operational efficiency.

Radiation Exposure Optimization: Initial average radiation doses of 1200 milligrays were reduced to approximately 600 milligrays, underscoring a significant enhancement in patient safety.

Challenges with iCT included resolution impairment from pin artifacts and specific operational considerations. These insights emphasize the significance of an adjustment period when assimilating novel technologies into surgical practice, with the potential for improved efficiency and safety with continued application and proficiency.

Discussion

Our study's comprehensive assessment reaffirms the integral role of intraoperative computed tomography (iCT) in enhancing surgical precision, a finding consistent with current literature which touts its benefits for complex neurosurgical interventions. The precision in the placement of spinal screws and the exact correlation with postoperative imaging for brain tumors, both achieving a 100% success rate, underscore the enhanced accuracy facilitated by iCT, as documented in previous studies [4-8].

The navigation errors detected in 50% of cases where preoperative imaging was used for navigation highlight the critical role of iCT in real-time correction of deviations, a significant advancement over traditional methods that may not account for intraoperative brain shift. This rate of deviation emphasizes the dynamic nature of neurosurgical anatomy, necessitating intraoperative imaging to ensure accuracy. The navigation errors can be explained by the brain shift that happens after a while following completion of craniotomy. This is illustrated well in figure 4.

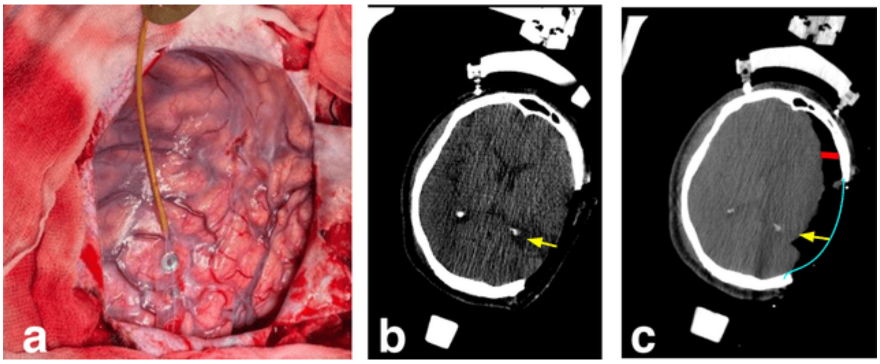



**Figure 3: Intraoperative Assessment and Brain Shift During Brain (Epilepsy) Surgery.**

(a) Intraoperative view showing the exposed brain during epilepsy surgery.
(b) Intraoperative computed tomography (iCT) image post-craniotomy indicating the brain surface alignment with skull. Notice head clamps.
(c) Subsequent iCT image demonstrating brain shift (yellow arrow) relative to the craniotomy edge (red line) and the skull (blue curve), illustrating the contribution of brain shift to potential navigation errors.

Our findings also indicate that iCT can be instrumental in surgical planning and intraoperative decision-making, potentially preventing adverse events and postoperative neurological morbidity, which resonates with the literature's advocacy for iCT's utility in complex cases. The study's ability to prevent undesirable events through the use of iCT, particularly in cases of brain tumors and vascular anomalies, aligns with contemporary research advocating for the integration of advanced imaging modalities into surgical workflows [9-13]. Our results reinforce the notion that iCT can enhance surgical strategy, contributing to patient safety and potentially reducing the need for reoperation.

Complications in our small series were minimal which is about 6%, lower than the typical range of 8-14% [14-16]. This suggests that while iCT contributes to improvement in surgical accuracy and strategy modification, it does not completely eliminate complications, but it probably does appear to play a role in reducing their occurrence. There were at least 11 instances where, we thought iCT was decisive at a critical stage of the surgery, and if overlooked, could have led to adverse event post operatively. But this approach is purely probabilistic and subjective needing a better way to analyse this in future studies. Despite the advantages, the observed complications, albeit minimal, align with the broader consensus that while iCT enhances surgical outcomes, it is not a panacea for all surgical risks, yet it likely contributes and reduces their incidence. It probably signals a positive shift in postoperative outcomes associated with the use of iCT. This could be a critical finding, as the reduction of complications directly translates to improved patient prognosis and reduced healthcare costs. This has been noted in other studies as well [17-20].

The increase in surgical length due to iCT usage initially, which improved with team experience, reflects a learning curve similar to other studies. The operational efficiency gained here is a testament to the adaptability and potential long-term benefits of iCT integration in neurosurgical practices.

The significant reduction in radiation exposure from an average of 1200 milligrays to 600 milligrays not only aligns with the push for safer surgical practices but also showcases the advancements in iCT technology aimed at patient safety.

The challenges faced, such as resolution impairment due to pin artifacts, remind us of the importance of the careful integration of iCT into surgical protocols, balancing the adoption of innovative technology with the necessity for procedural adaptation and team training. The study's findings encourage the ongoing refinement of iCT utilization to harness its full potential in improving surgical outcomes.

The challenges encountered with iCT also provide valuable lessons for the neurosurgical field. They underline the need for ongoing technical improvements and adaptability of surgical teams to new technologies. As iCT becomes more integrated into surgical practices, the learnings from these challenges can inform better protocols and training programs, ensuring the highest standards of patient care are upheld.

***Strategies for Reducing Radiation Exposure***

In conjunction with the noted reduction in radiation dose, several strategies were implemented to achieve this outcome. The primary methods included:

Optimized Scanning Protocols: By adjusting the scanning parameters such as the tube current and voltage, and optimizing the field of view to the area of interest, the radiation dose was minimized without compromising image quality.
Selective Scanning: Instead of conducting full scans in all cases, selective scanning was employed where only the critical areas relevant to the surgical procedure were imaged. This approach significantly reduced the overall radiation exposure.
Advanced Imaging Software: The use of advanced software for image processing allowed for better image quality at lower radiation doses. This software enhanced the clarity and contrast of images, enabling effective surgical guidance with less radiation.
Education and Training: Continuous education and training of the surgical and radiological teams played a vital role. As the team became more proficient with the technology, they were able to more efficiently utilize the CT scanner, reducing unnecessary exposure and optimizing scan times.

***Comparing Intraoperative CT (iCT) with Intraoperative MRI (iMRI):***

After having worked with the iMRI prior, the author has noted some distinct advantages of iCT. While iMRI is renowned for its high-resolution images, particularly in soft tissue contrast, it comes with notable challenges. iMRI often requires a specialized operating room with MRI-compatible equipment, which can be significantly more expensive and less available than standard operating environments. Additionally, iMRI procedures generally take longer due to the time required to obtain images, potentially extending the duration of surgeries [21-22].

In contrast, iCT offers several advantages. Firstly, it is more adaptable to standard operating rooms, avoiding the need for specialized MRI-compatible equipment. This flexibility can make iCT more accessible and cost-effective. Secondly, the quicker imaging process of iCT, as observed in the reduction of scan times over the course of our study, can minimize surgery duration. Finally, the reduced radiation exposure achieved in our study highlights advancements in iCT technology, addressing one of the primary concerns associated with CT scans.

Comparing iCT with the O-arm - While the O-arm provides real-time, high-quality 3D imaging useful in spinal instrumentation, iCT's broader applications in both brain and spine surgeries offer greater flexibility [23]. The reduced scan times and radiation doses with iCT demonstrate its practicality in a clinical setting.

Overall, iCT's versatility, efficiency, and reduced infrastructure requirements make it a valuable tool across a wide range of neurosurgical procedures. Despite the study's limitations, including a small sample size, retrospective in nature and lack of a control group, the findings suggest that further research into iCT's long-term impact on patient outcomes is warranted. Future studies should aim to incorporate larger sample sizes and control groups for a more robust comparative analysis. Integration with advanced surgical tools and emerging technologies like AI-assisted diagnostics, robotics, could further enhance the precision and care in neurosurgery.

## Conclusions

This study highlights the potential of intraoperative CT (iCT) scans in enhancing surgical precision and reducing complications in brain and spine surgeries. Key findings demonstrate that iCT contributes to improved surgical accuracy, facilitates real-time intraoperative adjustments, and probably minimizes overall complication rates. Despite initial challenges like a learning curve and radiation exposure, advancements in iCT technology have led to improved efficiency and safety. The versatility and adaptability of iCT underscore its value as a transformative tool in modern neurosurgery, offering substantial benefits in surgical outcomes and patient care.

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