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CT ASSESSMENT OF POSTOPERATIVE CRANIOTOMY COMPLICATIONS

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ABSTRACT

Background: Craniotomy is a key neurosurgical procedure often performed to manage life-threatening intracranial conditions, including tumours and haemorrhages. Despite its therapeutic benefits, it entails a high risk of postoperative complications that can significantly affect patient outcomes. Thus, detecting postoperative complications early is essential for timely intervention and improved prognosis. Computed tomography (CT) plays a crucial role in the early postoperative period. It enables the rapid identification of haemorrhage, pneumocephalus or midline shift, making it an indispensable tool in acute neurosurgical care. This study aims to retrospectively analyse the prevalence and characteristics of postoperative complications following craniotomy and evaluate the effectiveness of CT imaging in their detection.

Methods: This study retrospectively analysed data for 70 patients (40 males and 30 females) aged 20–86 years (mean: 45.0 ± 14.7 years) who underwent a craniotomy at King Abdulaziz University Hospital between September 2016 and October 2024. They underwent postoperative CT imaging according to standardised protocols, and board-certified radiologists reviewed the findings.

Results: Among participants, the most common indications for craniotomy were haemorrhage (n = 20, 28.6%), malignant neoplasms (n = 19, 27.1%) and meningioma (n = 11, 15.7%). The most frequent complication was pneumocephalus (*n* = 49, 70.0%), followed by haemorrhagic changes (*n* = 43, 61.4%), cerebral oedema (*n* = 32, 45.7%), midline shift (*n* = 16, 22.9%)

and brain herniation (n = 10, 14.3%). Most complications were identified within the first postoperative week (n = 62, 88.6%).

Conclusions: Postoperative CT imaging plays a vital role in the early detection of postoperative complications following craniotomy, with pneumocephalus being the most common. The findings emphasise the importance of routine CT scans within the first postoperative week for timely clinical intervention. Thus, CT is a practical and accessible tool that can significantly improve patient outcomes in the postoperative neurosurgical setting.

Keywords: Computed Tomography, Craniotomy, Pneumocephalus, Post-Operative, Haemorrhage

1. INTRODUCTION

Neurosurgical procedures are associated with high morbidity and mortality due to the complexity and fragility of brain structures. Craniotomy is among the most frequently performed procedures, playing a vital role in the treatment of various intracranial conditions. However, these procedures are often followed by postoperative complications that can significantly compromise patient outcomes [1]. The most commonly reported complications include intracranial haemorrhage, tension pneumocephalus, tonsillar herniation, wound/soft tissue infection, oedema and a shift of midline structures [2].

Craniotomy, defined as the surgical removal of part of the skull to access intracranial structures, is performed for multiple indications. One of the primary indications for craniotomy is tumour resection, particularly for tumours in or near eloquent brain regions, where preserving critical brain functions such as speech and motor control is essential. Craniotomy allows for real-time cortical and subcortical mapping, minimising the risk of neurological deficits while enabling maximum tumour removal. It is particularly instrumental in the treatment of high-grade gliomas, where achieving gross total resection can improve survival [2]. Another major indication for craniotomy is the evacuation of intracranial haemorrhages, including subdural, epidural and intracerebral haematomas.

These conditions constitute a neurosurgical emergency, as rapid increases in intracranial pressure can lead to brain herniation and death, and thus require urgent intervention [3]. Computed tomography (CT) is the first-line imaging modality in these contexts due to its short acquisition time, accessibility, cost-effectiveness and high diagnostic accuracy, particularly in emergencies [4]. It

provides detailed images of the brain, skull and surrounding structures, which can be crucial in diagnosing various neurological conditions [4]. It is also a key means of assessing the integrity of surgical interventions, such as burr holes, craniotomies and craniectomies. Importantly, CT enables the prompt identification of postoperative complications, including tension pneumocephalus and haemorrhage, which must be detected early to allow for timely intervention [5].

Although previous studies have demonstrated the utility of CT in postoperative neurosurgical cases, few studies have specifically analysed the prevalence and characteristics of complications following craniotomy within a defined population. Therefore, this study aimed to retrospectively analyse the prevalence and characteristics of common postoperative complications following craniotomy and to evaluate the diagnostic efficacy of CT in their early detection and management. The findings highlight the instrumental role of CT in optimising patient outcomes after neurosurgical procedures.

2. METHODOLOGY

2.1 Study design and ethical considerations

This retrospective study received ethical approval from the Unit of Biomedical Ethics Research Committee at King Abdulaziz University (KAU) Hospital in Jeddah, Saudi Arabia (Reference No 388-24).

2.2 Study cohort

This retrospective study included all adult patients who underwent a craniotomy at KAU Hospital between September 2016 and October 2024 and had post-craniotomy CT data and a complete medical history available. It excluded patients with degenerative diseases and those with an incomplete medical history. Based on these eligibility criteria, this study included 70 patients (40 males and 30 females) aged 20–86 years (mean: 45.0 ± 14.7 years).

2.3 CT data acquisition

All patients underwent brain CT scans using multi-detector CT scanners in the Department of Radiology at KAU Hospital following a standard brain imaging protocol, which involved an initial scout scan, followed by sequential non-contrast and contrast-enhanced CT sequences to ensure a comprehensive assessment. First, a non-contrast CT scan of the brain was performed to evaluate pneumocephalus, acute haemorrhage, midline shift, hydrocephalus and other structural abnormalities. When clinically indicated, a contrast-enhanced CT scan

was performed using intravenous iodinated contrast, providing improved visualisation of vascular structures, infections and residual tumours.

The standard CT protocol included axial non-contrast brain CT with thin slices (≤5 mm) to produce high-resolution images, along with coronal and sagittal reformations for enhanced anatomical assessment. Bone window settings were applied to evaluate postoperative bone alterations, while soft-tissue window settings were applied to assess brain parenchyma and related abnormalities.

All CT images were systematically reviewed by a team of board-certified radiologists, who categorised the findings as either normal or abnormal. The patients' demographic (age and sex) and clinical (medical history, CT findings, surgery location, and the interval between surgery and postoperative imaging) characteristics were retrospectively collected. This structured imaging approach ensured a comprehensive postoperative assessment of neurosurgical patients, facilitating the early detection and management of potential complications.

2.4 Statistical analysis

All the collected data were reviewed for completeness and logical consistency. Pre-coded data were first entered into Microsoft Excel (version 2019) and then imported into the Statistical Package for the Social Sciences (SPSS), version 26, for analysis. Quantitative variables were summarized using mean and standard deviation (SD) as well as median and interquartile range (IQR), and qualitative variables are reported as the count (percentage). Associations between patients' characteristics and postoperative complications were examined using chi-square tests, with a p-value of <0.05 considered statistically significant.

3. RESULTS

This study included 70 patients with a mean age of 45.0 ± 14.7 years and a median age of 44.0 (34.0–55.0) years. Most participants were aged 35 years or older (n = 49, 70.0%) and male (n = 40, 57.1%). Regarding postoperative procedures, most participants had undergone standard non-contrast CT scans (n = 64, 91.4%), while some had undergone both non-contrast and contrast-enhanced CT scans (n = 6, 8.6%).

Regarding indications for craniotomy (Table 1), the most frequent were intracranial haemorrhage (n = 20, 28.6%). and malignant neoplasms (n = 19, 27.1%). The least frequent indications were vestibular neuronitis (n = 1, 1.4%) and other less common indications (Table 1).

Table 1. The indications for craniotomy in the study cohort.

Surgical Indications	Number	Percentage
Haemorrhage	20	28.6%
Malignant neoplasm	19	27.1%
Meningioma	11	15.7%
Uncertain neoplasm	8	11.4%
Benign neoplasm	8	11.4%
Cerebral aneurysm, non-ruptured	1	1.4%
Obstructive hydrocephalus	1	1.4%
Fracture at the base of the skull	1	1.4%
Vestibular neuronitis	1	1.4%

Among the 20 haemorrhagic cases, subdural haemorrhage was the most common (n = 8, 40.0%), followed by intracranial haemorrhage (n = 6, 30.0%), epidural haemorrhage (n = 3, 15.0%), focal haemorrhage (n = 2, 10.0 %) and extradural haemorrhage (n = 1, 5.0%). Among the 19 malignant neoplasm cases, the site distribution varied: (n=12, 63.2 %) of malignant tumours were unspecified in the report , and (n=7, 36.8 %) were in the brainstem.

Regarding the affected brain regions (Table 2), the frontal lobe (n = 20, 28.6%) and right hemisphere (n = 35, 50.0%) were the most commonly involved. Regarding when complications were detected (Table 2), most were identified within the first postoperative week (n = 62, 88.6%).

Table 2. The affected brain region and side, as well as the timing of complication detection.

		Number	Percentage
Region	Frontal	20	28.6%
	Parital	10	14.3%
	Occipital	9	12.9%
	Temporal	8	11.4%

	Frontoparietal	8	11.4%
	Paritotemporal	6	8.6%
	Subdural	5	7.1%
	Temprofrontal	3	4.3%
	Paritooccpital	1	1.4%
Side	Right	35	50.0%
	Left	24	34.3%
	Not specified	11	15.7%
Postoperative timing of Complication detection	Early (≤1 week)	62	88.6%
	Late (>1 week)	8	11.4%

Regarding the complications detected via postoperative CT (Table 3), the most common was pneumocephalus (n = 49, 70.0%; Figure 1), followed by haemorrhagic changes (n = 43, 61.4%; Figure 2). Moreover, Oedema was noted in (n = 32, 45.7%; Figure 3) of patients and midline shift in (n =16, 22.9%; Figure 4).

Table 3. The frequency of observed postoperative complications.

Finding	Number	Percentage
Pneumocephalus	49	70.0%
Haemorrhage	43	61.4%
Oedema	32	45.7%
Midline shift	16	22.9%
Brain herniation	10	14.3%
Residual tumour	4	5.7%
Calcification	1	1.4%
Collection of cerebrospinal fluid	1	1.4%

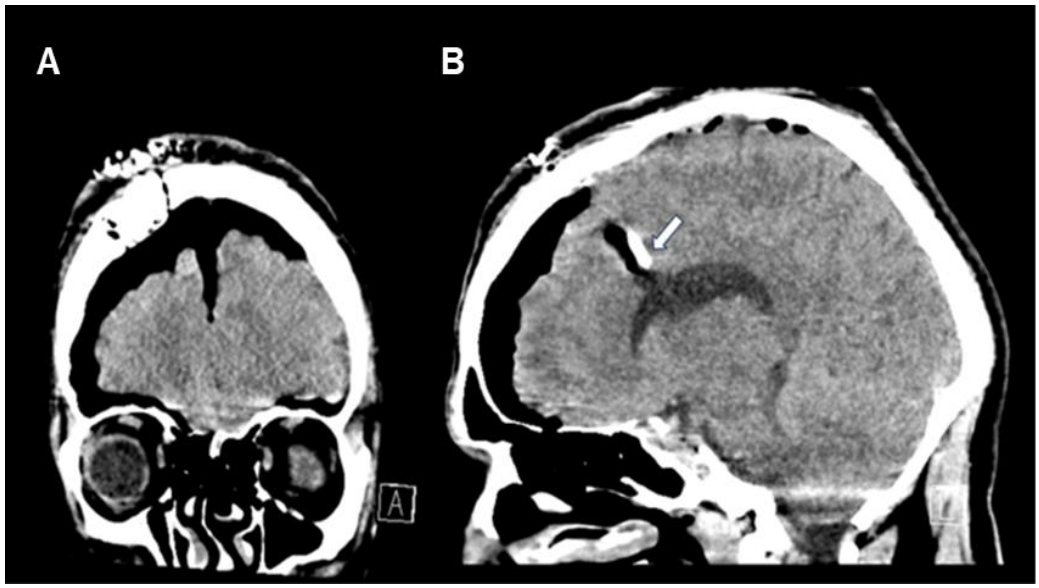

Figure 1: A coronal and B sagittal reformats of unenhanced CT brain showing post craniotomy changes with extensive pneumocephalus. An External Ventricular Drain is noted (arrow).

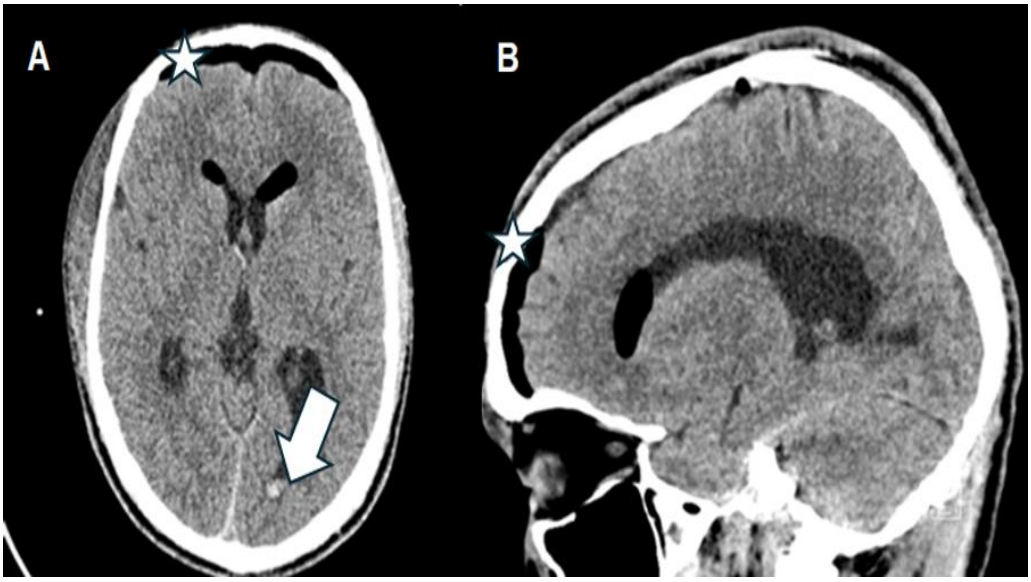

Figure 2: A and B Axial and sagittal non contrast CT of the brain show frontal pneumocephalus (white stars) with air pockets within the frontal horns of the lateral ventricles. Minimal intraventricular haemorrhage is seen within the occipital horn of the left lateral ventricle (white arrow).

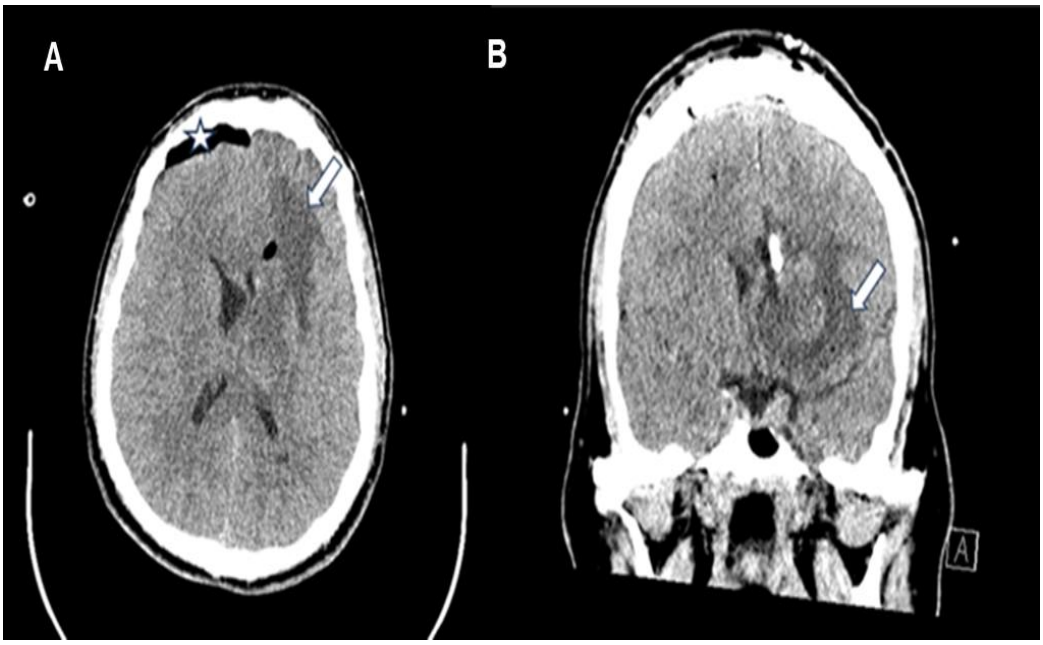

Figure 3: A Axial unenhanced CT brain post craniotomy with brain oedema (white arrow), with effacement of the left lateral ventricle and midline shift. Right frontal Pneumocephalus (Astrex) and within the left ventricle. B Coronal reformat unenhanced CT brain showing post craniotomy changes and left parietal oedema (white arrow). External Ventricular Drain partially seen.

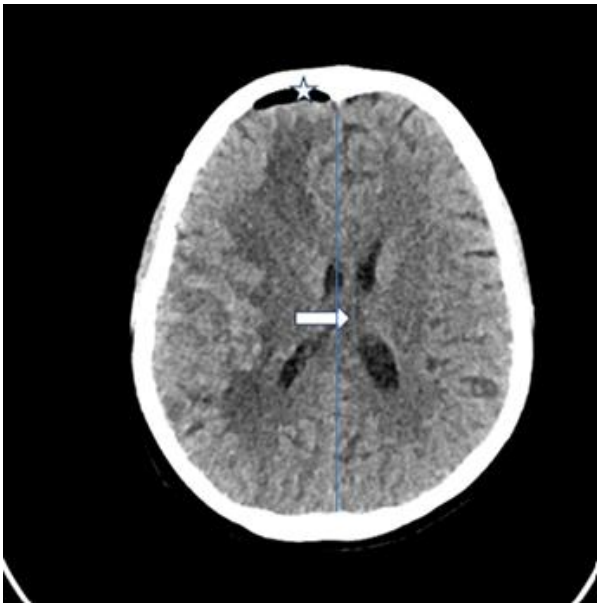

Figure 4: Axial unenhanced CT brain showing right frontal pneumocephalus (star) with midline shift to the left side (arrow).

To complement the descriptive statistics, possible associations between patients' characteristics and the major complications detected via CT (pneumocephalus, haemorrhage, oedema, midline shift and brain herniation) were examined. However, none of the tests were statistically significant.

4. DISCUSION

In our retrospective cohort, the most common postoperative complications observed were pneumocephalus, oedema and haemorrhage. These findings highlight the clinical value of structural CT in detecting postoperative complications that could influence patients' recovery and clinical decision-making. Indeed, the early detection of such complications is critical for improving patient outcomes [6].

The most common complication following craniotomy in our cohort was pneumocephalus. This finding is consistent with Ihab (2012), who reported that pneumocephalus was a frequent complication following craniotomy, particularly within the first few postoperative days. This external evidence further supports our findings and emphasises the typical timeframe in which pneumocephalus is most likely to occur. Although most cases of pneumocephalus are asymptomatic, close monitoring is essential to prevent progression to critical conditions such as tension pneumocephalus [6]. Thus, proactive imaging and clinical surveillance are vital in mitigating potential risks [6].

Haemorrhage is another significant early complication after craniotomy, typically occurring within the first few hours to days postoperative [7]. In our cohort, 43 (61.4%) patients demonstrated evidence of haemorrhage on early postoperative CT imaging. This finding is consistent with Algattas et al. who also reported a high incidence of postoperative bleeding in the early period following craniotomy. While many haemorrhagic cases can be managed effectively, early detection is crucial, as it can prevent serious neurological outcomes such as brain herniation or further bleeding. Thus, close postoperative monitoring is vital [7].

Oedema was the third most common postoperative complication in our cohort, with 32 (45.7%) patients demonstrating brain swelling on early imaging. This finding is consistent with Kaal and Vecht, who identified vasogenic oedema as a common complication after craniotomy, particularly in the early postoperative days. Early detection of oedema via CT imaging proved crucial, as unchecked swelling can markedly increase intracranial pressure, potentially leading to midline shift and further impairment of brain function. Thus, intervention is

essential to prevent the progression of oedema into more severe complications, such as neurological deficits [8].

Brain herniation was observed in 10 (14.3%) patients in our cohort, highlighting the ongoing risk of cerebral herniation even after surgical intervention. Although the incidence was lower in our study than in previous studies, it is nonetheless consistent with reported incidences. For example, Honeybul reported cortical herniation in 18 out of 41 (51%) patients following decompressive craniectomy for traumatic brain injury [9]. The discrepancy in incidence between our study and Honeybul may be attributed to differences in patient pathology, surgical technique, the extent of decompression, and variations in postoperative monitoring protocols. Gopalakrishnan et al. also described cerebral herniation as typically occurring within the first postoperative week, classifying it as an early complication. Thus, our observation and that of Gopalakrishnan et al. emphasise that brain herniation remains a serious and potentially life-threatening postoperative concern [10].

Midline shift was another key postoperative complication in our cohort, identified in 16 (22.9%) patients. Thus, early CT imaging is crucial in detecting complications that may adversely affect patients' recovery. In contrast, Tu et al. evaluated midline shift as a prognostic marker in patients following decompressive hemicraniectomy for malignant middle cerebral artery infarction, reporting that a shift of <5 mm by postoperative day 4 was associated with better long-term outcomes [11]. While our study views midline shift as a marker of surgical complication, Tu et al. viewed it as a prognostic indicator of surgical success. This difference reflects the indication and type of operation performed. Nonetheless, midline shift represents a versatile and clinically relevant imaging marker across different neurosurgical settings.

While some studies have highlighted limitations in the sensitivity of CT in certain applications, our findings reinforce its substantial value in accurately identifying postoperative complications following craniotomy. CT provides crucial diagnostic insights that directly influence patient management, challenging prior assertions of its limitations. When applied appropriately, our results support CT as an effective tool for monitoring patients following craniotomy. Notably, early CT imaging facilitates the prompt identification of postoperative complications, which helps prevent treatment delays and improves patient outcomes.

However, our study had some limitations that should be acknowledged. Firstly, its retrospective, single-centre design and relatively small sample size restrict the

generalizability of the findings. Secondly, as many patient records were outdated or difficult to locate, the data collection process was time-consuming, and some eligible patients may have been missed or excluded due to incomplete data.

Clinical practice should incorporate early postoperative CT selectively, guided by patient-specific risk factors and neurological status, as it is especially valuable for detecting immediate postoperative complications, such as haemorrhage, oedema and pneumocephalus. Its short acquisition time, accessibility and compatibility with implanted devices make it an ideal imaging modality in the early postoperative period [12]. However, emerging technologies such as electrical impedance tomography CT (EPOCT) require evaluation to further enhance patient safety and reduce radiation exposure. This non-invasive, radiation-free modality has shown promise in experimental models for detecting intracranial haemorrhage and could provide real-time, bedside monitoring, particularly for critically ill patients. Integrating such innovations could significantly improve the early detection of postoperative complications, guide timely interventions and improve the clinical outcomes after neurosurgical procedures [13].

5. CONCLUSION

Our study highlighted the instrumental role of postoperative CT imaging in the early detection of postoperative complications following craniotomy. Our findings confirm that pneumocephalus, hemorrhagic changes, cerebral oedema, midline shift and brain herniation are among the most common postoperative complications, with most occurring within the first postoperative week. The relatively high incidence of these complications underscores the necessity of routine, early postoperative CT imaging to ensure prompt clinical intervention and improve patient outcomes.

CT has proven to be a highly effective, widely accessible and rapid diagnostic modality in the postoperative period, particularly in emergencies. Its short acquisition time, suitability for critically ill patients and ability to detect life-threatening complications make it an indispensable tool in early postoperative care.

5.1 Recommendations

Prospective studies with larger patient cohorts and longer follow-up are recommended to evaluate the progression and long-term impact of postoperative complications following craniotomy. Additionally, integrating advanced imaging modalities such as CT perfusion and CT angiography into clinical protocols may

enhance diagnostic accuracy and help assess vascular and perfusion-related complications. Moreover, neurosurgeons and radiologists should continue to collaborate in refining imaging protocols and incorporating artificial intelligence-based tools for faster and more accurate interpretation. Finally, comparing postoperative CT and magnetic resonance imaging findings may provide deeper insights into optimal imaging strategies for various neurosurgical conditions.

6. CONFLICT OF INTEREST

The authors declare that they have no commercial or financial ties that might be viewed as a possible conflict of interest.

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We declare that AI tools were used solely for language enhancement purposes and not for generating content, data analysis, or interpretation.

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