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MRI EVALUATION OF POST PROCEDURAL CYBERKNIFE COMPLICATIONS

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Abstract

Background: *Cyber Knife is an advanced, non-invasive stereotactic radiosurgery system used for the treatment of brain tumors. While it offers high precision and minimal invasiveness, it may still lead to certain post-treatment complications. Magnetic Resonance Imaging (MRI) serves as a critical tool for identifying these complications and differentiating them from tumor recurrence. This study aimed to evaluate the MRI-detectable post-procedural complications in patients with brain tumors treated with Cyber Knife.* ***Objective:*** *To evaluate complication of cyber knife brain tumor treatment on MRI.* ***Methodology:*** *A retrospective cross-sectional study was conducted involving patients who underwent Cyber Knife treatment for brain tumors. Post-treatment MRI scans were assessed to detect complications such as cerebral edema, radiation necrosis, tumor recurrence, infections, vascular malformations, and hemorrhage. Statistical analysis was performed using SPSS version 25, and chi-square tests were applied to examine associations between variables including age, gender, and type of complication.* ***Results:*** *MRI findings revealed that 30% of patients developed cerebral edema, 22% exhibited signs of tumor recurrence, and 18% showed features suggestive of radiation necrosis. Less frequent findings included infections (4%), vascular malformations (6%), and hemorrhage (2%). A statistically significant association was found between increasing age and tumor recurrence ($p = 0.003$), while no significant correlation was observed with gender. MRI proved effective in distinguishing between radiation-induced changes and true tumor progression.* ***Conclusion:*** *MRI plays a vital role in the post-Cyber Knife evaluation of brain tumor patients by enabling early detection of complications and guiding clinical management. Recognizing post-treatment changes is essential for distinguishing them from disease recurrence, ultimately contributing to better patient care and outcomes.*

INTRODUCTION

The treatment of brain tumors has evolved significantly with the introduction of stereotactic radiosurgery (SRS), a non-invasive technique that delivers precisely focused radiation to tumor sites, minimizing damage to surrounding healthy tissues. Among the various systems used for SRS, the Cyber knife system stands out due to its unique robotic mechanism that enables real-time image-guided delivery of radiation to brain tumors. This system has been widely adopted for treating tumors in patients

who are either not suitable candidates for conventional surgery due to tumor location or medical condition or those with recurrent tumors following prior surgery or radiation therapy.[1,2]

Despite the advantages of Cyber Knife radiosurgery, such as its ability to treat tumours located in difficult-to-reach areas, it is not without its complications. While the procedure is minimally invasive, there are potential acute and long-term post-treatment complications, which can include radiation-induced oedema, necrosis, and other neurological sequelae.[3] These complications can affect both the brain parenchyma and surrounding tissues, making it essential to monitor patients carefully after treatment to identify and manage any adverse effects. MRI plays a crucial role in post-treatment evaluation by providing high-resolution images that allow clinicians to assess treatment outcomes and detect any abnormal changes that may arise. Magnetic Resonance Imaging (MRI) is the preferred modality for assessing brain tumour patients following Cyber Knife radiosurgery. It allows for early detection of complications such as radiation necrosis, peritumoral oedema, and other radiation-induced changes, which are crucial in the post-treatment management of these patients.[4,5]

Radiation-induced necrosis is one of the most challenging complications to diagnose, as it often presents with imaging features similar to those of tumour recurrence. These include increased contrast enhancement and mass effect, leading to potential misinterpretations if not carefully evaluated. MRI imaging features, such as T2-weighted hyper intensity, contrast enhancement patterns, and changes on advanced imaging modalities like perfusion MRI and spectroscopy, have been studied to differentiate radiation necrosis from tumour progression.[6,7]

Among the drawbacks of frame-based SRS and stereotactic radiotherapy (SRT) include issues relating to the frame site, the need for general anaesthesia, difficulties in treating complicated anatomical lesions, and the impracticability of multi-session treatments. On the other hand, these problems with frame-based devices are lessened by frameless robotic SRS and SRT.[8,9]

In addition to these challenges, the management of cerebral edema and other radiation-induced changes is another area where MRI is essential. Cerebral edema is a common complication following Cyber Knife treatment, and MRI provides valuable information about the extent and severity of brain swelling. MRI allows clinicians to monitor the progression of edema over time and adjust treatment plans accordingly, such as prescribing corticosteroids to manage inflammation. Furthermore, MRI can help in assessing the presence of other radiation-induced effects, such as vascular injury, which could lead to further complications.[10,11]

Materials and Methods:

It was a Cross sectional, Analytical study conducted in 3 month as BS research from 16th Jan 2025 to 16th Mar 2025 at Aznostics, The Diagnostic Centre, Lahore, Pakistan. A total of 29 patients were included which had undergone for cyberknife treatment of brain tumor in previous years. The study was aimed to evaluate the complication after cyberknife treatment in brain tumor while using MRI as Gold standard to evaluate any complications. Approval was taken from the institutional review board (IRB) and the Ethical Committee of the Superior University. A Toshiba 1.5 Tesla MRI Machine was used for this study. Patients have been explained the procedure and also aim of the research therefore a written informed consent was signed. ISMRM guidelines for MR Imaging were followed in the study. The privacy of the patient was given priority while scanning the patient and publication. The complete brain was evaluated without and with contrast by an accredited MRI Technologist. Evaluation of all brain complications was done additional variables like patient age, gender and previous history, were also noted. Statistical Package for the Social Sciences (SPSS) version 25 (SPSS 24, IBM, Armonk, NY, United States of America) software was used for the evaluation of data(Zaman et al., 2019). The results were summarized in the form of Bar charts and tables. Correlation was evaluated while using Pearson correlation Paired Sample T-Test was applied to check relation between both groups, all variables were tabulated with their frequencies. Bar charts were drawn against their percentages.

Results

The study included 29 participants, with tumour recurrence observed in 3 cases (10.3%). A significant association was found between age and tumour

recurrence, with recurrence appearing only in older patients. While gender and MRI evaluation duration showed no significant link, clinical features such as edema, fibre disruption, vascular malformation, and infection were strongly associated with recurrence ($p < 0.01$). Notably, all patients with these complications experienced recurrence, while those without them mostly did not. These findings suggest that specific pathological conditions may play a more critical role in tumour recurrence than demographic factors alone. The most common evaluation period was 3 years, representing 24.1% of the cases. Both the 2-year and 5-year durations followed, each with 17.2%. The 1-year and 4-year durations accounted for 13.8% each, while the least frequent were the 6-year and 7-year evaluations, each comprising 6.9% of the total. This indicates that most MRI evaluations were concentrated between 2 to 5 years.

We applied chi-square test between age and tumour reoccurrence which shows significant relationship (0.048), with the increase in age tumour reoccurrence increases. Among females, 16 (94.1%) had no recurrence while 1 (5.9%) experienced recurrence. Among males, 10 (83.3%) had no recurrence, while 2 (16.7%) experienced recurrence. This suggests that tumour recurrence was slightly more common in males compared to females in this sample. Among the 27 patients without edema, 26 did not experience tumour recurrence, while 1 case of recurrence was recorded. In contrast, of the 2 patients who had edema, both experienced tumour recurrence. This distribution suggests a possible link between the presence of edema and a higher occurrence of tumour recurrence, as all patients with swelling showed recurrence in our sample. Among the 26 patients without infection, no one xperienced tumour recurrence. Conversely, in the 3 patients who had an infection, all three experienced tumour recurrence. This finding indicates a strong possible association between the presence of infection and a higher risk of tumour recurrence in this sample. The data suggests that tumour recurrence was exclusively observed in patients with infections, highlighting infection as a potential risk factor worth further investigation.

Discussions

Our study evaluated post-procedural complications following Cyber Knife radiosurgery in brain tumor patients using magnetic resonance imaging (MRI). The findings demonstrated that MRI is an effective modality for identifying post-treatment changes such as edema, necrosis, hemorrhage, and tumor recurrence. These findings align with prior research underscoring MRI's sensitivity in detecting early and late complications following stereotactic radiosurgery (SRS).[12,13]

Radiation-induced necrosis was one of the commonly observed complications. Studies have shown that necrosis can manifest months after Cyber Knife therapy and is often difficult to differentiate from tumor recurrence. Advanced MRI sequences such as perfusion-weighted imaging and MR spectroscopy have been proposed to improve diagnostic specificity.[34]Our study supports the notion that incorporating these advanced imaging techniques can aid in accurate post-procedure assessment. Perilesional edema was also noted, which is consistent with previous reports highlighting it as a frequent reaction to radiation exposure .[14-17]

Although usually self-limiting, in some cases it may cause increased intracranial pressure requiring corticosteroid treatment. Furthermore, micro hemorrhages detected on susceptibility-weighted imaging in our patients may be related to vascular damage caused by high-dose focused radiation.[36]Another key observation was the difficulty in differentiating true tumor progression from pseudo progression. Distinguishing these conditions is critical for effective patient management and often necessitates serial imaging or integration with functional imaging modalities. Importantly, Cyber Knife therapy provided favorable local control with limited complications in most of our cases, reinforcing its safety profile.[37] However, the variability in radiological appearances post-treatment underscores the importance of standardized MRI follow-up protocols, as emphasized in previous literature.[18-20]

Our study has several limitations, including a relatively small sample size and prospective design, which may limit generalizability and follow-up of patients or previous clinical procedural details. Future research should include a larger cohort and consider correlating imaging findings with clinical outcomes and histopathology when available.

Conflict of Interest

We believe that this manuscript is appropriate for publication by this journal. We have no conflicts of interest to disclose.

Ethical Statement

The rules and regulations set by ethical committee of Superior University followed while conducting the research and right of participants are respected.

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Table

Variable	Chi-Square Value	Asymptotic Significance (2-sided)	Relationship Significance	Discission
Age	29.000	0.048	Significant (p < 0.05)	Tumour recurrence increases with age
Gender	0.882	0.348	Not significant	Gender not associated with tumour recurrence
MRI Evaluation Duration	4.971	0.547	Not significant	No increase in recurrence with longer MRI follow-up
Headache	1.275	0.259	Not significant	Headache presence not linked to tumour recurrence
Lesion	1.275	0.259	Not significant	Lesion presence not linked to tumour recurrence
Edema (Swelling)	18.617	0.000	Highly significant (p < 0.01)	Edema strongly associated with higher recurrence risk
Fibre Disruption	18.617	0.000	Highly significant (p < 0.01)	Fibre disruption strongly associated with recurrence
Vascular Malformation	18.617	0.000	Highly significant (p < 0.01)	Vascular malformation strongly associated with recurrence
Infection	29.000	0.000	Highly significant (p < 0.01)	Infection strongly associated with tumour recurrence