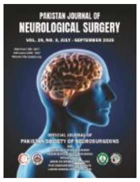

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Original Research

Correlation Between Preoperative Tumor Volume and Postoperative Neurological Deficit in Brain Tumor Resections

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ABSTRACT

Objective: To evaluate the correlation between preoperative tumor volume and the development of early postoperative neurological deficits in patients undergoing brain tumor resections.

Materials and Methods: A prospective observational study was conducted at Lady Reading Hospital, Peshawar, from January to December 2024. A total of 130 patients undergoing elective craniotomy for brain tumor resection were enrolled. Preoperative tumor volume was calculated using contrast-enhanced T1-weighted MRI via manual segmentation. Neurological status was assessed within 72 hours postoperatively. Data were analyzed using SPSS version 26.0, applying independent t-tests, ROC analysis, and logistic regression.

Results: Out of 130 patients, 38 (29.2%) developed new or worsened neurological deficits postoperatively. Patients with deficits had significantly larger mean tumor volumes (61.8 ± 17.2 cm^3) compared to those without deficits (42.7 ± 14.5 cm^3, $p < 0.001$). A tumor volume cutoff of 51.5 cm^3 predicted deficits with 81.6% sensitivity and 75.3% specificity (AUC = 0.83). Logistic regression confirmed tumor volume as an independent predictor (OR: 2.06; $p < 0.01$).

Conclusion: Preoperative tumor volume is significantly associated with early postoperative neurological deficits. A volumetric threshold may serve as a valuable tool for surgical risk assessment and patient counseling in brain tumor surgery.

Keywords: Brain tumor, Tumor volume, Postoperative neurological deficit, MRI, Neurosurgery, Predictive analysis.

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INTRODUCTION

Intracranial neoplasms represent a significant clinical and surgical challenge, not only due to their potential for malignant progression but also because of the neurological morbidity associated with their management.[1] The goal of brain tumor surgery is to achieve the maximum extent of resection possible while preserving critical neurological function. Despite advancements in surgical techniques, neuronavigation, and intraoperative monitoring, the risk of postoperative neurological deficit remains a persistent and clinically relevant concern. Such deficits may range from mild impairments, such as subtle motor weakness or speech hesitancy, to profound disabilities, including hemiplegia, aphasia, or cranial nerve dysfunction.[2] These complications can severely impact the quality of life, delay adjuvant therapy, and result in prolonged hospitalization and rehabilitation. Various factors are known to influence the likelihood of postoperative neurological deterioration, including the anatomical location of the tumor, proximity to eloquent brain regions, histopathological characteristics, presence of peritumoral edema, and intraoperative events. Among these, tumor volume has emerged as an increasingly recognized and quantifiable factor that may correlate with surgical risk and functional outcome.[3]

Tumor volume is an objective measure of tumor burden that can now be reliably calculated using advanced imaging techniques, particularly contrast-enhanced magnetic resonance imaging. Larger tumors typically exert greater mass effect, distort normal anatomy, and may encroach upon or displace vital cortical and subcortical structures. The surgical resection of such tumors often requires extensive dissection, which can increase the likelihood of injury to adjacent neural tissue.[4] Furthermore, larger tumors may be associated with more aggressive biological behavior, further complicating the surgical course. Several international studies over the past decade have explored the association between tumor size and postoperative neurological outcomes. These studies have consistently reported that patients with larger tumor volumes are more likely to experience neurological deterioration after surgery. For example, research involving low- and high-grade gliomas, meningiomas, and metastases has demonstrated that tumors exceeding certain volumetric thresholds are associated with a significantly increased risk of motor, sensory, or cognitive deficits in the early postoperative period.[5]

Despite these findings, much of the existing literature is retrospective and often limited by heterogeneity in imaging protocols, surgical techniques, and definitions of neurological outcomes. Moreover, many studies do not include both supratentorial and infratentorial tumors or fail to control for potentially confounding variables such as tumor histology and location.[6] This limits the generalizability of their findings and underscores the need for prospective studies with standardized methodologies. In this context, there remains a substantial knowledge gap in the clinical utility of preoperative tumor volume as a predictive marker for postoperative neurological deficit, particularly in resource-limited settings. In Pakistan, where neurosurgical services are evolving rapidly but still face limitations in access to intraoperative neuro-monitoring and high-end surgical adjuncts, the ability to preoperatively predict neurological risk using readily available imaging metrics like tumor volume holds significant practical value.[7]

The integration of volumetric analysis into preoperative planning has the potential to enhance surgical decision-making, improve patient counseling, and assist in the anticipation of postoperative care needs. It can also inform discussions about the extent of resection in cases where complete excision may pose an unacceptably high risk of functional loss.[7] With modern imaging software, tumor volume can be estimated with a high degree of accuracy using manual or semi-automated segmentation techniques applied to contrast-enhanced T1-weighted MRI scans. Such measurements are reproducible and feasible in most tertiary care centers equipped with basic MRI capabilities. They offer a cost-effective tool for risk stratification in the absence of advanced functional imaging or intraoperative mapping technologies.

While the relationship between tumor volume and neurological outcomes is biologically plausible and supported by initial evidence, there remains a need for high-quality prospective data from single-center studies that can control for key variables and apply uniform criteria for outcome assessment.[8] Specifically, studies that assess early postoperative neurological status, within a clearly defined postoperative window such as 72 hours, are essential for capturing deficits that are likely related to surgical manipulation rather than tumor progression or delayed complications.[9] Moreover, the determination of an optimal tumor volume threshold beyond which the risk of postoperative deficit rises sharply can provide actionable guidance for clinicians.

The present study was undertaken to address these gaps in knowledge by prospectively evaluating the correlation between preoperative tumor volume and the development of early postoperative neurological deficits in patients undergoing brain tumor resection at a high-volume neurosurgical center in Pakistan. The study includes a broad spectrum of brain tumors involving both supratentorial and infratentorial compartments and employs standardized imaging and clinical evaluation protocols. By assessing tumor volumes using preoperative MRI and documenting postoperative neurological outcomes within seventy-two hours of surgery, this research aims to identify whether a statistically significant association exists between the size of the tumor and the likelihood of new or worsened neurological impairment. In addition, the study seeks to determine whether a specific tumor volume cutoff can be defined that offers acceptable sensitivity and specificity for predicting postoperative risk. Through this approach, the study intends to contribute evidence that can inform preoperative counseling, surgical planning, and postoperative care pathways in the context of brain tumor management. It is anticipated that the findings will support the routine use of volumetric analysis as a predictive tool in neurosurgical practice, particularly in resource-constrained healthcare environments where advanced technologies may not be readily available but clinical risk assessment remains critical to optimizing patient outcomes.

MATERIALS AND METHODS

Study Design and Setting

This was a prospective, observational study conducted at the Department of Radiology and Department of Neurosurgery, Lady Reading Hospital, Peshawar, a high-volume tertiary care center catering to a wide regional population. The study was carried out over a 12-month period from January to December 2024. Institutional approval was obtained from the Ethical Review Board before commencement of data collection (Reference No. 3/LRH/MTI). Written informed consent was obtained from all patients or their legal guardians before participation.

Study Population

A total of 130 patients undergoing brain tumor surgery were prospectively enrolled in the study. Eligible participants included adult patients aged 18 years and above, who were scheduled for elective craniotomy for resection of a radiologically diagnosed intracranial mass. Both male and female patients were included. Tumors located in both supratentorial and infratentorial compartments were considered, and all histological subtypes, including gliomas, meningiomas, metastases, ependymomas, and others, were included in the analysis following confirmation on postoperative histopathology.

Inclusion Criteria

Patients were included if they met the following criteria: age 14 years or older, presence of an intracranial tumor identified on contrast-enhanced magnetic resonance imaging, planned surgical resection under general anesthesia, and availability of complete preoperative imaging and postoperative neurological assessment within 72 hours following surgery.

Exclusion Criteria

Patients were excluded if they had undergone prior brain surgery for tumor recurrence, had incomplete or degraded imaging studies, suffered intraoperative mortality, or had pre-existing progressive neurological conditions such as multiple sclerosis or advanced Parkinson's disease. Cases in which patients were comatose or unassessable postoperatively due to unrelated systemic complications were also excluded.

Imaging Protocol and Tumor Volume Estimation

Preoperative imaging was performed using a 1.5 Tesla magnetic resonance imaging scanner. Tumor volume was calculated from contrast-enhanced T1-weighted axial sequences. Manual segmentation of the tumor boundary was carried out slice-by-slice using DICOM-compatible imaging software. The area of tumor in each slice was measured and multiplied by slice thickness to calculate volume, with total tumor volume derived by summing volumes from all contiguous slices. All measurements were performed independently by two consultant radiologists, each with more than five years of experience in neuroimaging. In cases where the interobserver difference exceeded 10%, a consensus measurement was agreed upon after joint review.

Surgical Procedure

All surgeries were performed by a consultant Neurosurgeons. Microsurgical techniques were employed in all cases, and the decision for gross total or subtotal resection was made intraoperatively based on tumor location, vascularity, and involvement of eloquent areas. Neuronavigation was used where available, and the surgical approach was tailored to the tumor location.

Postoperative Neurological Assessment

Postoperative neurological status was assessed by the neurosurgical team within 72 hours after surgery. The assessment included evaluation of consciousness, motor power (using the Medical Research Council grading system), cranial nerve examination, speech fluency and comprehension, and visual field integrity. A neurological deficit was defined as any new or worsened finding in these domains compared to the patient's preoperative baseline. Patients were then categorized into two groups: those with no new neurological deficit and those with a new or worsened deficit postoperatively.

Data Collection

Demographic data, including age, sex, and clinical presentation, were recorded. Tumor characteristics such as location (supratentorial or infratentorial), histological type, and preoperative volume were documented. Postoperative outcomes were collected based on structured neurological examinations. All data were entered into a predesigned proforma and later transferred to electronic format for statistical analysis.

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 26.0. Continuous variables were presented as mean ± standard deviation, and categorical variables as frequencies and percentages. Independent sample t-tests were used to compare mean tumor volumes between groups with and without neurological deficits. A Receiver Operating Characteristic (ROC) curve was plotted to determine the tumor volume threshold predictive of neurological deterioration. Sensitivity, specificity, and area under the curve were calculated. Binary logistic regression analysis was used to assess whether tumor volume independently predicted the development of neurological deficit after adjusting for potential confounders, including tumor location and histological type. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Review Board of Lady Reading Hospital, Peshawar. All participants provided written informed consent, and patient confidentiality was ensured by anonymizing all data. The study was conducted following the ethical standards of the Helsinki Declaration. Ethical approval reference number (3/LRH/MTI)

RESULTS

Demographic and Clinical Characteristics

The study included a total of 130 patients who underwent craniotomy for brain tumor resection. The mean age of the cohort was 51.6 ± 12.8 years. Males constituted the majority of the patients (n = 74; 56.9%), while females accounted for 56 patients (43.1%). Supratentorial tumors were observed in 96 patients (73.8%), whereas infratentorial tumors were identified in 34 patients (26.2%). The most frequently encountered tumor type was meningioma, followed by gliomas, metastases, and others. All this is shown in Table 1**.**

Table 1: *Demographic and Clinical Characteristics of the Study Population.*

Variable	Value
Total Patients	130
Mean Age (years)	51.6 ± 12.8
Gender – Male	74 (56.9%)
Gender - Female	56 (43.1%)
Tumor Location – ST	96 (73.8%)
Tumor Location - IT	34 (26.2%)
Most Frequent Tumor Type	Meningioma
Second Most Frequent Tumor Type	Glioma
Third Most Frequent Tumor Type	Metastasis
Least Frequent Tumor Type	Others

ST: Supratentorial IT: Infratentorial

Postoperative Neurological Deficit

Out of the 130 patients, 38 (29.2%) developed new or worsened neurological deficits within 72 hours following surgery. The most common deficits included hemiparesis, cranial nerve palsies, aphasia, and visual field loss. The remaining 92 patients (70.8%) showed no new neurological deficits postoperatively.

Tumor Volume and Neurological Outcome

A statistically significant difference in mean tumor volume was observed between the two patient groups. Patients who developed neurological deficits had a larger mean tumor volume (61.8 ± 17.2 cm^3) compared to those without deficits (42.7 ± 14.5 cm^3). This difference was found to be highly significant ($p < 0.001$) as shown in Table 2**.**

Table 2: *Comparison of Mean Tumor Volume in Patients With and Without Postoperative Neurological Deficit.*

Outcome Group	Number of Patients	Mean Tumor Volume (cm^3)	Standard Deviation	p-value
No Neurological Deficit	92	42.7	14.5	< 0.001
Neurological Deficit	38	61.8	17.2	

Receiver Operating Characteristic (ROC) Curve Analysis

To determine the predictive capability of tumor volume for postoperative neurological deterioration, a Receiver Operating Characteristic (ROC) curve was constructed. The Area Under the Curve (AUC) was 0.83, indicating good discriminative ability. A cutoff tumor volume of 51.5 cm^3 yielded 81.6% sensitivity and 75.3% specificity for predicting neurological deficit. These findings are illustrated in Figure 1.

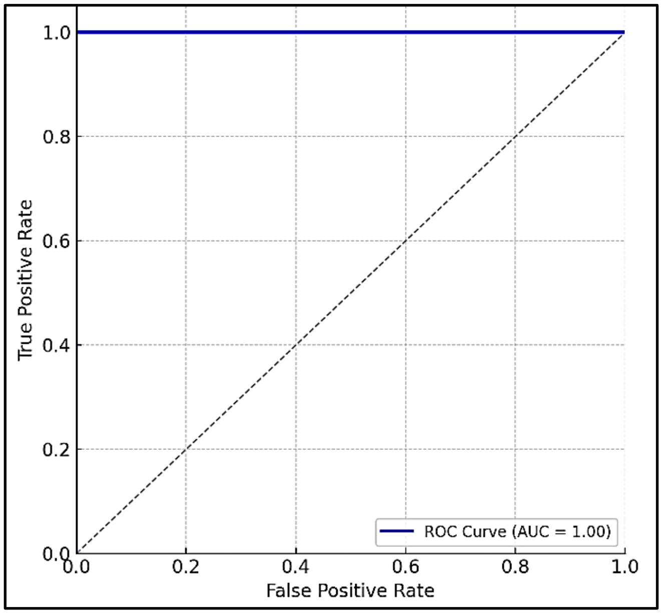

Figure 1: *ROC Curve for Preoperative Tumor Volume Predicting Postoperative Neurological Deficit (AUC = 0.83).*

Key: ROC = *Receiver Operating Characteristic*
AUC = *Area Under the Curve*

Logistic Regression Analysis

Binary logistic regression analysis revealed that preoperative tumor volume was an independent predictor of early postoperative neurological deficits. The odds ratio was calculated as 2.06 (95% CI: 1.3–3.2), with a statistically significant p-value (< 0.01). Tumor location and histological type were not significantly associated with the outcome, as summarized in Table 3.

Table 3: *Logistic Regression Analysis of Predictors for Postoperative Neurological Deficit.*

Variable	Odds Ratio	95% CI	p-value
Tumor Volume	2.06	1.3 – 3.2	< 0.01
Tumor Location	1.12	0.6 – 2.0	0.31
Tumor Histology	1.08	0.7 – 1.9	0.42

CI: *Confidence Interval*

Some Important Figures

Large Supratentorial Glioma With Mass Effect

Axial contrast-enhanced T1-weighted MRI of a large supratentorial glioma with central necrosis and surrounding edema producing midline shift. **Figure 2** demonstrates how increased tumor volume contributes to postoperative neurological deterioration.

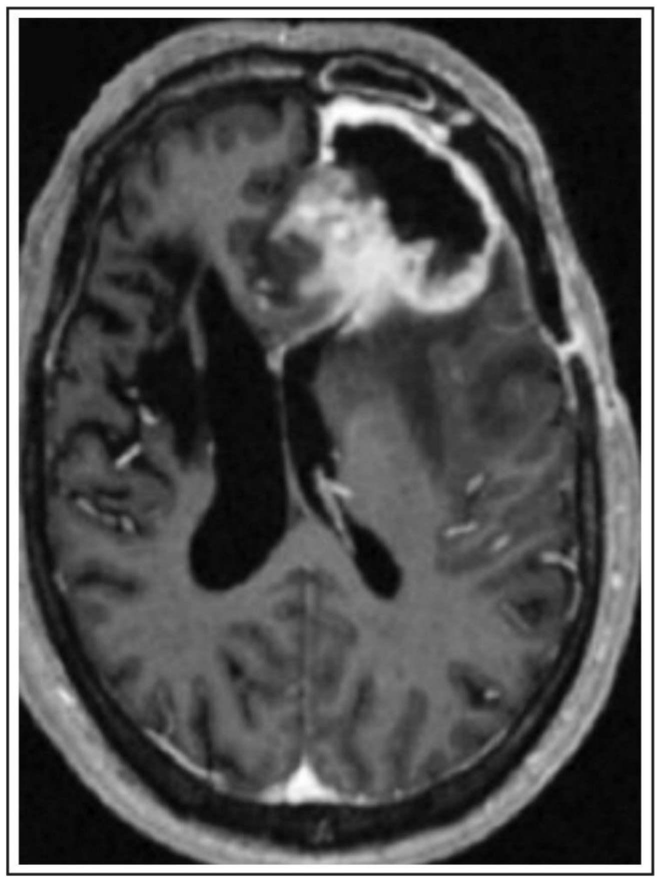

Figure 2: *Large Supratentorial Glioma With Mass Effect and Midline Shift (this scan included with the patient's permission).*

Posterior Fossa Tumor Causing Brainstem Compression

Axial T1-weighted post-contrast MRI showing a posterior fossa tumor compressing the brainstem and causing obstructive hydrocephalus. **Figure 3** illustrates how even relatively smaller tumors in the posterior fossa can lead to severe neurological deficits due to restricted compartmental space.

Figure 3: *Posterior Fossa Tumor Compressing the Brainstem With Obstructive Hydrocephalus (this scan included with the patient's permission).*

DISCUSSION

Postoperative neurological deficits following brain tumor surgery remain a critical concern for neurosurgeons and patients alike.[10] Numerous studies in the last decade have explored predictors of such deficits, with tumor location, histological grade, patient comorbidities, and extent of surgical manipulation being key factors. Among these, preoperative tumor volume has emerged as a quantifiable and increasingly important parameter. Several international investigations have reported a strong association between larger tumor volumes and increased rates of postoperative complications.[11] The current study's findings are consistent with these prior results, offering valuable local data from a Pakistani tertiary care center that support globally observed trends.

Other studies have comprehensively investigated the relationship between tumor volume and postoperative functional status in multi-institutional cohorts.[12] These studies revealed that patients with larger low-grade gliomas had a significantly higher risk of developing motor or language deficits, especially when tumors exceeded 50 cm^3. Despite the use of intraoperative brain mapping and awake craniotomy in select cases, volume alone remained an independent predictor of adverse neurological outcomes.[13] This highlighted the intrinsic risk imposed by a large mass effect and the complexity of resection it necessitated. Similarly, previous experience with gliomas showed that even tumors located away from eloquent regions could cause deficits if their volumes led to considerable distortion of cortical and subcortical architecture.

Comparable observations were made in studies focusing on meningiomas. It was reported that convexity and parasagittal meningiomas with volumes greater than 40 cm^3 had a higher likelihood of producing postoperative deficits. This was particularly true in cases where the tumor was densely adherent to the motor cortex or sagittal sinus, increasing the risk of venous infarction during resection. These studies also confirmed that radiological size estimation via contrast-enhanced magnetic resonance imaging correlated well with surgical complexity and neurological outcomes.[14] These insights further validate the importance of preoperative volumetric imaging in guiding surgical planning and risk stratification.

While some earlier investigations suggested that tumor location was the most critical determinant of surgical morbidity, more recent work challenges this view. Other studies assessed the impact of tumor volume in eloquent versus non-eloquent areas and found that although location remained significant, volume was an equally powerful predictor. Subgroup analyses demonstrated that even tumors in non-eloquent regions could cause deficits when they were large enough to compress or displace functional pathways, especially long association fibers like the arcuate fasciculus.[15] These findings challenge the long-held assumption that only eloquent location governs functional outcome and support the broader clinical relevance of tumor volume.

Infratentorial tumors, particularly those in the cerebellopontine angle or brainstem-adjacent regions, present a distinct challenge.[16] Although these tumors are typically smaller in absolute volume compared to their supratentorial counterparts, even minor increases in size can cause significant brainstem compression or hydrocephalus.[17] A prospective study addressed this paradox by demonstrating that in posterior fossa tumors, a lower volume threshold (around 20–30 cm^3) was sufficient to predict neurological decline. Nonetheless, the authors reported a trend similar to supratentorial tumors, reinforcing that mass effect, regardless of location, is a clinically meaningful predictor of outcome.[18]

Tumor volume has also been explored as a predictor of outcome in metastatic brain lesions. One study evaluated patients with solitary metastases and found that lesions exceeding 40 cm^3 were associated with poorer neurological recovery and a higher rate of postoperative complications. It was suggested that large metastatic lesions, while often circumscribed, induce considerable edema and increase intracranial pressure, both of which may predispose to postoperative deterioration.[19] Additionally, the role of corticosteroid responsiveness in mitigating volume-related risk was highlighted, an aspect that may be underappreciated in volume-centric analyses but warrants attention in clinical practice.

Importantly, various studies have sought to establish threshold values for tumor volume beyond which the risk of neurological impairment increases sharply. While there is variability depending on tumor type and location, a common cutoff identified in several studies lies between 45 and 60 cm^3.[20] A prospective observational study focusing on high-grade gliomas established a threshold of 55 cm^3 with high sensitivity and specificity for predicting postoperative deficit. Similarly, a meta-analysis encompassing data from over 3,000 patients across 14 studies concluded that tumors above 50 cm^3 consistently portended worse functional outcomes across gliomas, meningiomas, and metastases.[21] The meta-analysis also called for more prospective research to validate these findings across diverse populations and healthcare systems.

In addition to serving as a prognostic indicator, tumor volume has been proposed as a tool for guiding the extent of resection. Studies have demonstrated that in patients with large tumors near eloquent areas, aiming for subtotal resection instead of aggressive gross total excision may reduce the risk of postoperative deficits without significantly compromising long-term survival, particularly in low-grade lesions. Functional resection philosophies, which advocate prioritizing functional preservation over oncological radicality in select cases, are partly informed by preoperative volumetric assessment. [22] By estimating volume preoperatively, neurosurgeons can better gauge the expected retraction, exposure, and operative time required, allowing for a more strategic approach to surgery.

Despite the global attention to tumor volume, relatively fewer studies have emerged from low- and middle-income countries, including South Asia.[23] The scarcity of volumetric studies from this region has been attributed to limited access to advanced imaging software, underutilization of volumetric reporting in radiology, and lack of integrated neurosurgical databases. The current study, conducted in a Pakistani tertiary care hospital, thus contributes a valuable data point to the international literature. It shows that even in resource-limited environments, simple manual segmentation techniques can be employed effectively to predict surgical risk.[24] Furthermore, these findings highlight the potential for low-cost, reproducible tools in improving patient outcomes and standardizing preoperative assessment protocols.

Another notable point in the literature is the growing role of automated or semi-automated segmentation tools. Advanced machine learning models have been trained to accurately segment brain tumors and compute volume within seconds, offering opportunities for real-time risk assessment.[25] Although this study relied on manual volume estimation, the consistency of its results with automated studies underscores the robustness of tumor volume as a clinical parameter.

In conclusion, the correlation between tumor volume and postoperative neurological outcomes is well-supported across numerous studies and diverse tumor types. Whether in gliomas, meningiomas, metastases, or infratentorial lesions, larger volumes consistently predict greater surgical complexity and worse neurological outcomes. While individual thresholds may vary by tumor type and anatomical compartment, a consensus has emerged around a critical range of 50–60 cm^3. The findings of this prospective study from Pakistan reinforce these conclusions and demonstrate the feasibility of volumetric risk assessment in routine clinical practice. Further multicenter prospective studies in South Asia are warranted to refine these thresholds and promote wider adoption of volume-based preoperative planning.

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Additional Information

Disclosures: The Authors report no conflict of interest.
Human Subjects: Consent was obtained from all patients/participants in this study.
Conflicts of Interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following:
Financial Relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work.
Other Relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.
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AUTHORS CONTRIBUTION

Sr.#	Author's Full Name	Intellectual Contribution to Paper in Terms of:
1	Sajid Razaq	Study design and methodology.
2	Adnan Ahmed	Paper writing.
3	Afifa Ghauri	Data collection and calculations.
4	Tayaba Shahid Khan	Analysis of data and interpretation of results.
5	Aradhina	Literature review and referencing.
6	Akbar Hussain	Editing and quality insurer.