Evaluation of the Role of Intraoperative Ultrasound in Resection of High and Low-Grade Gliomas

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Abstract:

Background: Glioma procedures require accurate intraoperative EOR assessment because complete resection improves prognosis and reduces recurrence. Compared to postoperative MRI, the reliability of intraoperative imaging depends on glioma grade and location. This study examines the consistency between intraoperative resection assessments and postoperative MRI results in high- and low-grade gliomas.

Methods: This descriptive analysis comprised 45 patients with high-grade (n = 31) and low-grade (n = 14) gliomas verified by MRI, contrast-enhanced MRI, and MR spectroscopy. Klinikum St. Marien Amberg, Bavaria, Germany, and Assiut University Hospital's Neurosurgery Department, Egypt, performed surgeries. Using intraoperative ultrasound, entire, subtotal, and partial resections were assessed. After surgery, residual tumor volume was assessed by MRI within 72 hours.

Results: There were significant demographic variations across groups. High-grade glioma patients were older (52.61 ± 13.18 years vs. 36.93 ± 14.90 years, $p < 0.001$) and generally male (61.3% vs. 28.6%, $p = 0.042$). Intraoperative resection evaluation matched postoperative MRI results for high-grade ($\kappa = 0.666$, $p < 0.001$) and low-grade gliomas ($\kappa = 0.772$, $p < 0.001$). Total resection was discovered intraoperatively in 15 of 16 high-grade and 6 of 7 low-grade instances. Intraoperative and postoperative assessments of subtotal and partial resections were also consistent. Lower-grade gliomas had more subtotal resections (35.7% vs. 25.8%), the biggest difference.

Conclusions: In both high-grade and low-grade gliomas, intraoperative imaging, particularly ultrasonography, is useful for measuring resection extent. Advanced imaging modalities can increase intraoperative evaluation accuracy and surgical results for high-grade gliomas, which agree significantly less with postoperative MRI findings.

Keywords: Intraoperative Ultrasound, Glioma Resection, Residual Tumor Detection.

Introduction

Depending on histology and severity, gliomas are the most frequent primary brain tumors. Accurate extent of resection measurement during surgery improves outcomes and reduces recurrence. Resection precision can be improved by intraoperative ultrasound (iUS) and MRI (iMRI). IMRI can reach 96% gross total resection rates in high-grade gliomas [1], whereas iUS is an option in low-grade gliomas [2].

This research compared Intraoperative resection assessments to postoperative MRI results in high-grade and low-grade gliomas. It also compared the demographic and clinical characteristics of the two groups and examined how intraoperative imaging properly determined resection extent.

Patients and Methods

Study design and setting:

This descriptive research was conducted from May 2021 to December 2023 at the Klinikum St. Marien Amberg, Bavaria, Germany, and the Department of Neurosurgery, Assiut University Hospital (the primary center of the study).

Participants:

The study included a total of 45 patients with gliomas of varying grades, categorized into two groups: high-grade gliomas (n = 31) and low-grade gliomas (n = 14), as confirmed by MRI, contrast-enhanced MRI, and MR spectroscopy. There were no restrictions on gender or age. Patients were excluded if they were deemed unsuitable for neurosurgical intervention, had recurrent cases, or had non-glioma tumors confirmed by histopathology and preoperative imaging.

Data Collection:

A full admission history, physical examination, and screening lab testing were performed on all patients. On admission, age, sex, neurological symptoms, Glasgow Coma Scale score, and Medical Research Council Scale motor power were recorded. MRI was performed on all patients before surgery to evaluate tumor location, size, and grade. CT with contrast was done 48 hours following surgery.

Surgical Procedure:

Most patients were admitted the day before surgery and operated on within 24 hours. We performed all surgeries under general anesthesia. Immobilization used MAYFIELD head holder. After sterile preparation, skin incision and craniotomy were surgically customized. Dura was probed with the Hitachi Arietta V60, c42k intraoperative ultrasonography probe to confirm lesion location, boundaries, and depth. After the durotomy, the surgeon removed the tumors. Ultrasound probe sweeping verified complete resection. Resection was classified as whole (100%), subtotal (60-90%), or partial (≤60%). Bone flap replacement and closure were common.

Outcome Measures:

Intraoperative ultrasonography assessed resection completeness as the primary result. Contusions were recorded. Postoperative CT with contrast within 72 hours for persistent tumor. Demographic and lesion data were examined as outcome risk factors.

Ethical Considerations:

We obtained informed consent through an opt-out condition. The research ethics committee of the Faculty of Medicine at Assiut University (IRB:05-2022-17101755) has approved this study in compliance with the 1964 Declaration of Helsinki and its amendments.

Statistical Analysis:

SPSS v28 (IBM Inc., Armonk, NY, USA) analyzed data. Mean and SD were used to compare quantitative variables between groups using an unpaired Student's t-test. Quality variables were presented as frequency and percentage (%) and tested with Chi-square or Fisher's exact. A two-tailed P value < 0.05 was considered significant.

Results

Table 1 analysis of 45 glioma patients revealed significant differences between high-grade and low-grade groups. High-grade glioma patients were older (52.61 vs 36.93 years, p<0.001) and more likely to be male (61.3% vs 28.6%, p=0.042). Hemiparesis was the most common presentation for both groups. High-grade gliomas occurred most frequently in the parietal lobe (32.3%), while low-grade gliomas were equally common in the frontal and temporal lobes (35.7% each). Contusion rates were similar between groups. No significant differences were found in clinical presentation or tumor location distribution. Table 1

Table (1): Patient demographics, clinical presentation, location, and histopathology in the studied groups

Variable		High-Grade Glioma	Low-Grade Glioma	*p*-value
Age (years)		52.61 ± 13.18	36.93 ± 14.90	**<0.001***
Sex	Female	12 (38.7%)	10 (71.4%)	**0.042***
	Male	19 (61.3%)	4 (28.6%)	
Presentation	Hemi	14 (45.2%)	4 (28.6%)	0.154
	Sensory Aphasia	1 (3.2%)	0 (0.0%)	
	Confused	2 (6.5%)	1 (7.1%)	
	Headache	5 (16.1%)	3 (21.4%)	
	Fits	7 (22.6%)	4 (28.6%)	
	Motor Aphasia	2 (6.5%)	2 (14.3%)	
Location	Frontal	7 (22.6%)	5 (35.7%)	0.765
	Thalamic Sol	5 (16.1%)	2 (14.3%)	
	Parietal	10 (32.3%)	0 (0.0%)	
	Temporal	8 (25.8%)	5 (35.7%)	
	Occipital	0 (0.0%)	1 (7.1%)	
	Parasagittal	1 (3.2%)	1 (7.1%)	
Complication	Contusion	5 (16.1%)	2 (14.3%)	0.874

Data are represented as Mean ± Standard Deviation or number (percentage).
p: p-value for comparing the two studied groups. *: Statistically significant at $p \leq 0.05$

Figure 1 shows that total intraoperative resection has the highest percentage of high-grade and low-grade gliomas (61.3%) and low-grade (50.0%). Postoperative partial resection has the lowest percentages for both grades (16.1% high, 21.4% low). High-grade gliomas have higher percentages for total and intraoperative resections, while low-grade gliomas have higher percentages for partial and postoperative resections. The greatest difference between high and low grades is for intraoperative subtotal resection (25.8% vs 35.7%).

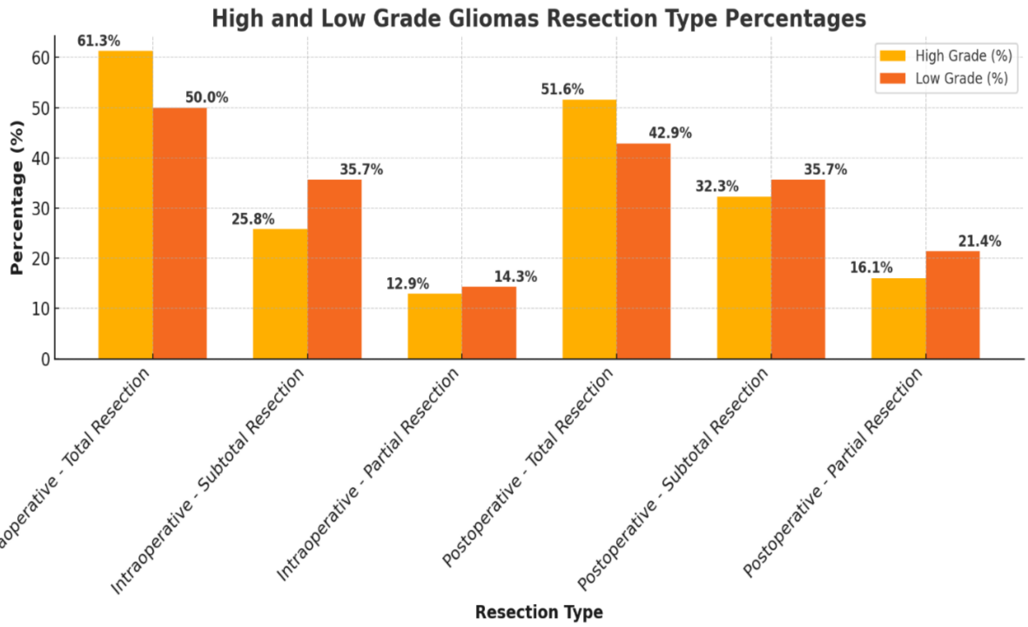

Figure 1: Intraoperative resection and postoperative resection in the studied groups

Table 2 evaluates the reliability of the extent of resection determined intraoperatively compared to the postoperative MRI findings. Analysis of intraoperative versus postoperative resection assessments showed substantial agreement for both glioma types. High-grade gliomas had a kappa of 0.666 (p < 0.001), with 15/16 total, 6/8 subtotal, and 4/4 partial resections accurately identified intraoperatively. Low-grade gliomas showed higher agreement (kappa = 0.772, p<0.001), with 6/7 total, 4/5 subtotal, and 2/2 partial resections correctly assessed. Intraoperative overestimation occurred in 5 high-grade and two low-grade cases.

Table 1: Reliability of intraoperative resection and postoperative resection in the studied groups

High grade		Intraoperative resection assessment			Measure of Agreement (kappa)	P value
		Total resection	Subtotal resection	Partial		
Postoperative resection assessment	Total resection	15	1	0	0.666	<0.001*
	Subtotal resection	4	6	0		
	Partial	0	1	4		
Low grade		**Intraoperative resection assessment**			**Measure of Agreement (kappa)**	**P value**
		Total resection	Subtotal resection	Partial		
Postoperative resection assessment	Total resection	6	0	0	0.772	<0.001*
	Subtotal resection	1	4	0		
	Partial	0	1	2		

*: significant as P value < 0.05.

Discussion:

The most frequent primary brain tumors, gliomas, ranged from low-grade (WHO Grade I-II) to high-grade (WHO Grade III-IV). Depending on tumor grade, location, and resection, gliomas had different prognoses and treatments. Optimal surgical results and patient survival require accurate preoperative and intraoperative evaluation and monitoring. MRI, contrast-enhanced MRI, and MR spectroscopy became standard for identifying and stratifying gliomas. Due to their infiltrative nature, gliomas were difficult to grade and diagnose for resection. [3]. This study aimed to evaluate the effectiveness of these imaging techniques in differentiating glioma grades and compared intraoperative assessments with postoperative outcomes.

In our study, HGG and LGG patients are very different in age and gender. Patients with HGG had a substantially higher mean age (52.61 ± 13.18 years) compared to LGG patients (36.93 ± 14.90 years, p < 0.001). A large Danish population-based study indicated a mean age of 60 for high-grade glioma patients and a much younger age for low-grade gliomas [4].

Our analysis found that females comprised 71.4% of the LGG group, while males comprised 61.3% of the HGG group (p = 0.042). Studies that found a male predominance across all glioma grades but found oligodendrogliomas to be more gender balanced found similar results [5].

In terms of clinical presentation, our study found that seizures were more common in LGG (28.6%) compared to HGG (22.6%), which aligns with the study by Jo et al., 2021 [6], who identified seizures as a frequent symptom in low-grade gliomas, particularly in oligodendrogliomas.

Additionally, Rasmussen et al. (2017) [4] reported that epileptic seizures were the most frequent presenting symptom in grade II gliomas, whereas higher-grade gliomas were more likely to present with focal neurological deficits and cognitive impairment.

Contusions did not differ between groups in this study ($p = 0.874$). According to studies, glioma consequences are more connected to tumor size and location than grade (Eichberg et al., 2020).

When evaluating the extent of resection, Masuda et al. (2019) [7] demonstrated that intraoperative MRI significantly improves the extent of resection in high-grade gliomas, with 96% of patients achieving complete resection compared to 68% in the conventional surgery group ($p = 0.023$). This aligns with our study's findings that intraoperative assessments closely matched postoperative MRI evaluations.

Our analysis found significant agreement between intraoperative resection evaluation and postoperative MRI for both high-grade ($\kappa = 0.666$, $p < 0.001$) and low-grade gliomas ($\kappa = 0.772$, $p < 0.001$). The intraoperative identification of 15 of 16 total, 6 of 8 subtotal, and all four partial resections of high-grade gliomas was correct. Intraoperative assessments properly detected 6/7 total, 4/5 subtotal, and 2/2 partial resections in low-grade gliomas.

Recent investigations confirm intraoperative assessment reliability. According to Munkvold et al. (2018) [2], intraoperative ultrasound (IOUS) can confirm full resections with 85% specificity compared to postoperative MRI. IOUS had a 46% sensitivity; therefore, small remaining tumors were commonly missed. Masuda et al. (2019) also found that intraoperative MRI (iMRI) had fewer postoperative reactive alterations than early postoperative MRI, improving residual tumor volume correlation. Ischemic lesions were less sensitively detected by iMRI than early postoperative MRI (16.7% vs. 53.3%, $p = 0.003$), suggesting a restriction in thorough tumor evaluation.

Despite these findings, Pača et al. (2016) [8] found that early postoperative MRI overestimated residual tumor volumes in low-grade gliomas compared to intraoperative MRI, potentially leading to overestimating treatment needs.

Further supporting these results, Scherer et al. (2016) [9] found that 70% of glioma resections needed continued resection after iMRI, with greater residual volumes in eloquent regions and recurrent tumors ($p < 0.001$). Even in difficult instances, iMRI can improve surgical decisions and EOR.

Roder et al. (2016) [10] compared surgical outcomes using conventional surgery and intraoperative MRI-guided surgery in pediatric low-grade gliomas. The study found a significant increase in the rate of complete resections from 41% to 71% with the use of iMRI ($p = 0.05$). This improvement in resection rates underscores the reliability of intraoperative MRI in pediatric low-grade glioma surgeries.

In agreement with our findings, Moiyadi et al. (2019) [1] investigated how intraoperative ultrasonography (iUS) affected 47 gliomas, including HGGs and low-grade gliomas. It was shown that iUS detected gliomas with 88% sensitivity and 70% specificity. The positive predictive value of iUS for gliomas was 75%, and the negative predictive value was 84%. In 78% of cases, iUS identified gliomas.

A 2018 study by Šteňo et al. [11] evaluated the efficacy of iUS in 28 diffuse low-grade gliomas DLGGs. IUS was flawless, with 25 true positives, zero false negatives, and three true negatives. IUS is 100% sensitive, specific, and accurate for positive and negative diagnoses.

A study by Sweeney et al. (2018) [12] compared iUS to postoperative imaging in 95 HGGs and 23 low-grade gliomas. It detected HGG with 48.9% sensitivity and 100% specificity. DLGG has 20% and 100%. HGG had 100% and 67% predictive values, while low-grade gliomas had 100% and 81.8 %. IUS detected HGG at 74.7% and low-grade gliomas at 82.6%.

Conclusions

In conclusion, the extent of resection in high-grade and low-grade gliomas can be reliably assessed using intraoperative imaging, particularly intraoperative ultrasonography. While postoperative MRI findings are slightly less consistent with high-grade gliomas, integrating advanced imaging modalities can improve surgical outcomes and increase the accuracy of intraoperative assessments.

Availability of Data and Materials:

The corresponding author can be contacted to request the dataset of this work.

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