

Postoperative functional status, rather than extent of resection, predicts survival in butterfly glioblastoma: A single-center retrospective study

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Abstract

Purpose

Butterfly glioblastoma (bGBM) presents major neurosurgical challenges. We investigated prognostic factors and the role of surgical resection in bGBM.

Methods

We retrospectively reviewed 23 consecutive patients with bGBM treated between 2007 and 2025. Overall survival (OS), progression-free survival (PFS), and postoperative deterioration in Karnofsky Performance Status (KPS), assessed immediately after surgery and at 2 weeks, were analyzed using Cox and logistic regression models.

Results

Biopsy and surgical resection were performed in 9 and 14 patients, respectively. Radiotherapy plus temozolomide was administered to 22 patients. Median OS and PFS were 10.0 and 4.4 months. On univariable Cox analysis, age (hazard ratio [HR], 1.04; $p = 0.015$), immediate postoperative KPS (HR, 0.96; $p = 0.004$), and KPS at 2 weeks (HR, 0.96; $p = 0.002$) were associated with OS; however, only KPS at 2 weeks remained an independent prognostic factor on multivariable analysis. Similar variables were associated with PFS, with age remaining an independent predictor (HR, 1.06; $p = 0.018$). Kaplan-Meier analysis showed no significant difference in PFS by extent of resection (EOR; $\geq 85\%$ vs. $< 85\%$) using the log-rank test ($p = 0.214$), whereas the Wilcoxon test was significant ($p = 0.036$), suggesting improved early disease control with EOR $\geq 85\%$. In the multivariable logistic regression, surgical complications independently predicted KPS deterioration at 2 weeks (odds ratio, 16.7; $p = 0.017$).

Conclusion

In bGBM, surgical resection may be beneficial only when it preserves postoperative functional status and avoids complications. When safely achievable, EOR $\geq 85\%$ may contribute to early disease control.

Introduction

Butterfly glioblastoma (bGBM) is a radiological subtype of glioblastoma (GBM) that extends into both cerebral hemispheres through the corpus callosum. It is a rare entity, accounting for 2–14% of all GBM cases, and is associated with a poor prognosis [1–9]. Historically, surgical resection for bGBM was approached with reluctance because of its anatomical complexity and the high risk of surgical complications [2, 10]. More recently, accumulating evidence has suggested that, similar to GBMs in other locations, maximal tumor resection may prolong survival. Consequently, many institutions now favor surgical resection over biopsy for patients with bGBM [1, 3, 7, 8, 11–13]. However, the associations between clinical and surgical factors and survival outcomes in bGBM remain controversial, largely because evidence is derived from small case series. In this study, we retrospectively reviewed the clinical data of patients with bGBM treated at our institution and investigated prognostic factors as well as the role of surgical resection in this patient population.

Materials and Methods

Patient Population

This study was approved by the Ethics Committee of Kyoto University Graduate School of Medicine (approval number: R2088). The requirement for individual informed consent was waived by the same committee. The study was conducted in accordance with the Declaration of Helsinki. In this single-center retrospective study, data were collected from a consecutive series of patients with bGBM who underwent surgical treatment and received adjuvant therapy between January 2007 and December 2025.

Treatment Strategy for bGBM

The treatment strategy for bGBM was similar to that for GBM in other locations. Maximal safe resection is performed first, followed by radiotherapy (60Gy) with concomitant and adjuvant temozolomide [14]. In cases of tumor recurrence or progression, additional radiotherapy is administered, followed by repeated ifosfamide, carboplatin, and etoposide and bevacizumab (BEV) every 4 weeks [15]. When the surgeon determined that an extent of resection (EOR) of $\geq 80\%$ could be achieved without major complications, surgical resection was performed. Conversely, when achieving an EOR $\geq 80\%$ without major complications was considered unlikely, stereotactic biopsy was selected.

Volumetric Analysis

The Brainlab Elements software was used to perform volumetric analyses of preoperative and postoperative tumor volumes based on contrast-enhanced T1-weighted magnetic resonance imaging. The EOR was calculated for all patients, including those who underwent stereotactic biopsy, using the following formula: (preoperative tumor volume – postoperative tumor volume) / preoperative tumor volume.

Survival Outcomes and Clinical and Surgical Factors

We investigated the associations between overall survival (OS) and clinical and surgical factors, between progression-free survival (PFS) and clinical and surgical factors, and between postoperative Karnofsky performance status (KPS) deterioration and clinical and surgical factors. OS was defined as the time from surgery to death from any cause. PFS was defined as the time from surgery to radiographic or clinical progression according to the Response Assessment in Neuro-Oncology (RANO) criteria [16], or death from any cause, whichever occurred first. The clinical and surgical factors evaluated included age, sex, preoperative KPS, immediate postoperative KPS, immediate postoperative KPS deterioration, KPS at 2 weeks postoperatively, KPS deterioration at 2 weeks postoperatively, surgical procedure (biopsy or resection), preoperative tumor volume, postoperative tumor volume, EOR, corpus callosum resection, and surgical complications (hemorrhage, infarction, and supplementary motor area syndrome). Immediate postoperative KPS was defined as the KPS score assessed 48 hours postoperatively. KPS deterioration was defined as any decrease in KPS compared with the preoperative value.

Statistical Analysis

Continuous variables are presented as medians and ranges. Univariable and multivariable Cox proportional hazards regression analyses were conducted to evaluate factors associated with OS and PFS. Univariable and multivariable logistic regression analyses were performed to identify factors associated with immediate postoperative KPS deterioration and KPS deterioration at 2 weeks postoperatively. There were no missing data for the variables included in the analyses. A p -value of < 0.05 was considered statistically significant. Variables with a p -value < 0.05 in the univariable analysis were included in the multivariable model, while avoiding multicollinearity among postoperative functional variables. All statistical analyses were performed using the JMP software (version 16.1.0, SAS Institute Inc., Cary, NC, USA, <https://www.jmp.com/en/software>).

Results

Clinical Characteristics

A total of 23 patients who underwent surgical treatment were included in this analysis (Table 1). The median age was 62 years (range, 27–92 years), and 12 patients were male. Stereotactic biopsy and surgical resection were performed in 9 and 14 patients, respectively. The median preoperative KPS was 70 (range, 30–90), the median immediate postoperative KPS was 60 (range, 10–90), and the median KPS at 2 weeks postoperatively was 60 (range, 10–90). The median preoperative tumor volume was 41.1 cm^3 (range, $11.7\text{--}157.6 \text{ cm}^3$), the median postoperative residual tumor volume was 8.51 cm^3 (range, $0\text{--}100.2 \text{ cm}^3$), and the median EOR was 82.2% (range, 1.1–100%). The tumor-infiltrated corpus callosum was resected in eight patients. Surgical complications occurred in seven patients, including two hemorrhagic complications, two ischemic complications, two surgery-related neurological deterioration, and one case of supplementary motor area syndrome. Regarding adjuvant therapy, concurrent radiotherapy and temozolomide (RT/TMZ) was administered to 22 patients, BEV to 11 patients, and tumor-treating fields (TTFs) to 4 patients. The median PFS was 4.4 months (95% confidence interval [CI], 2.7–7.6 months), and the median OS was 10.0 months (95% CI, 7.3–12.1 months).

Table 1
Clinical characteristics of the overall cohort

Variables	Overall cohort (N = 23)
Age (Median, range)	62, 27–92
Male	12
Surgery	
Stereotactic biopsy	9
Surgical resection	14
Preoperative tumor volume (cm ³) (Median, range)	41.1, 11.7–157.6
Postoperative residual tumor volume (cm ³) (Median, range)	8.51, 0–100.2
EOR (%) (Median, range)	82.2, 1.1–100
Corpus callosum resection	8
Surgical complication	7
Adjuvant treatment	
RT and TMZ	22
BEV	11
TTFs	4
KPS (Median, range)	
Preoperative KPS	70, 30–90
Immediate postoperative KPS	60, 10–90
KPS at 2 weeks postoperatively	60, 10–90
OS (Median, 95% CI)	10.0, 7.3–12.1
PFS (Median, 95% CI)	4.4, 2.7–7.6
CI = Confidence interval; BEV = Bevacizumab; EOR = Extent of resection; KPS = Karnofsky performance status; OS = Overall survival; PFS = Progression free survival; RT = Radiation therapy; TMZ = Temozolomide; TTFs = Tumor Treating Fields	

Association of Clinical and Surgical Factors with OS and PFS in bGBM

In the univariable Cox regression analysis for OS, age and postoperative functional status variables, including immediate postoperative KPS, KPS at 2 weeks postoperatively, and KPS deterioration at 2 weeks postoperatively, were significantly associated with OS (Table 2). In the multivariable analysis, KPS at 2 weeks postoperatively remained an independent prognostic factor for OS (Table 2). In the univariable Cox regression analysis for PFS, age and postoperative functional status variables, including immediate postoperative KPS and KPS at 2 weeks postoperatively, were significantly associated with PFS (Table 3). In the multivariable analysis, age remained an independent prognostic factor for PFS (Table 3). Kaplan-Meier analysis of PFS comparing patients with an EOR $\geq$ 85% with those with an EOR < 85% is shown in Fig. 1. Although the log-rank test did not demonstrate a significant difference between the groups ($p = 0.214$), the Wilcoxon test was significant ($p = 0.036$), suggesting improved early disease control among patients who achieved an EOR $\geq$ 85%.

Table 2
Univariable and multivariable Cox regression analysis for overall survival (OS)

Clinical and surgical factors	Univariable Cox regression			Multivariable Cox regression		
	HR	95% CI	p	HR	95% CI	p
Age (per year)	1.04	1.01–1.08	0.015	1.01	0.98–1.06	0.461
Male	1.41	0.59–3.37	0.446			
Surgical resection	0.99	0.41–2.39	0.978			
Preoperative tumor volume	0.99	0.98–1.01	0.383			
Postoperative residual tumor volume	0.99	0.97–1.00	0.198			
EOR	0.91	0.34–2.57	0.854			
Corpus callosum resection	1.06	0.44–2.57	0.895			
Preoperative KPS	0.99	0.97–1.02	0.539			
Immediate postoperative KPS	0.96	0.93–0.99	0.004			
KPS at 2 weeks postoperatively	0.96	0.93–0.99	0.002	0.97	0.94–1.00	0.047
Immediate postoperative KPS deterioration	2.10	0.87–5.11	0.101			
KPS deterioration at 2 weeks postoperatively	3.83	1.19–12.25	0.024			
CI = Confidence interval; EOR = Extent of resection; HR = Hazard ratio; KPS = Karnofsky performance status						

Table 3
Univariable and multivariable Cox regression analysis for progression-free survival (PFS)

Clinical and surgical factors	Univariable Cox regression			Multivariable Cox regression		
	HR	95% CI	p	HR	95% CI	p
Age (per year)	1.07	1.03–1.11	0.001	1.06	1.01–1.11	0.018
Male	1.29	0.55–3.03	0.555			
Surgical resection	0.73	0.30–1.76	0.484			
Preoperative tumor volume	0.99	0.97–1.00	0.122			
Postoperative residual tumor volume	0.99	0.97–1.00	0.181			
EOR	0.69	0.26–1.94	0.466			
Corpus callosum resection	0.75	0.31–1.81	0.512			
Preoperative KPS	0.99	0.97–1.01	0.187			
Immediate postoperative KPS	0.97	0.95–0.99	0.023			
KPS at 2 weeks postoperatively	0.97	0.95–0.99	0.012	0.99	0.96–1.02	0.455
Immediate postoperative KPS deterioration	1.34	0.56–3.21	0.511			
KPS deterioration at 2 weeks postoperatively	1.89	0.65–5.50	0.262			
CI = Confidence interval; EOR = Extent of resection; HR = Hazard ratio; KPS = Karnofsky performance status						

Association of Clinical and Surgical Factors with Immediate Postoperative KPS deterioration and KPS deterioration at 2 weeks postoperatively in bGBM

In the univariable logistic regression analysis of immediate postoperative KPS deterioration, postoperative residual tumor volume, corpus callosum resection, and surgical complications were significantly associated with immediate postoperative KPS deterioration (Table 4). In the multivariable logistic regression analysis, corpus callosum resection remained an independent risk factor for immediate postoperative KPS deterioration (Table 4). In the univariable logistic regression analysis of KPS deterioration at 2 weeks postoperatively,

surgical complications were significantly associated with KPS deterioration at 2 weeks postoperatively, whereas corpus callosum resection was not (Table 5). In the multivariable logistic regression analysis, surgical complications remained an independent risk factor for KPS deterioration at 2 weeks postoperatively (Table 5).

Table 4
Univariable and multivariable logistic regression analysis for immediate postoperative KPS deterioration

Clinical and surgical factors	Univariable logistic regression			Multivariable logistic regression		
	OR	95% CI	p	OR	95% CI	p
Age (per year)	1.01	0.96–1.07	0.726			
Male	0.28	0.04–1.53	0.144			
Surgical resection	3.5	0.59–29.53	0.174			
Preoperative tumor volume	0.99	0.96–1.01	0.357			
Postoperative residual tumor volume	0.94	0.85–1.00	0.036			
EOR	3.95	0.48–43.90	0.206			
Corpus callosum resection	12	1.80–119.6	0.009	9.91	1.27–115.5	0.028
Surgical complication	7.5	1.14–69.89	0.036	5.80	0.64–72.04	0.117
CI = Confidence interval; EOR = Extent of resection; KPS = Karnofsky performance status; OR = Odds ratio						

Table 5
Univariable and multivariable logistic regression analysis for KPS deterioration at 2 weeks postoperatively

Clinical and surgical factors	Univariable logistic regression			Multivariable logistic regression		
	OR	95% CI	p	OR	95% CI	p
Age (per year)	1.05	0.98–1.15	0.224			
Male	0.53	0.06–3.99	0.541			
Surgical resection	3.2	0.38–69.44	0.305			
Preoperative tumor volume	2.55	0.05–94.06	0.615			
Postoperative residual tumor volume	0.97	0.88–1.02	0.300			
EOR	1.84	0.16–30.73	0.630			
Corpus callosum resection	3.90	0.54–37.30	0.190	2.12	0.16–28.50	0.553
Surgical complication	20	2.10–479.60	0.008	16.66	1.61–412.7	0.017
CI = Confidence interval; EOR = Extent of resection; KPS = Karnofsky performance status; OR = Odds ratio						

Discussion

bGBM is anatomically defined by tumor extension across the corpus callosum and has long been regarded as a particularly unfavorable subtype of GBM. To clarify determinants of outcome in this subgroup, we investigated the associations between clinical and surgical factors and survival outcomes in 23 consecutive patients treated in the temozolomide era at a single institution.

Historically, median OS in bGBM has been reported to range from approximately 3–9 months [1–4, 8, 10–12]. However, more recent studies have reported more favorable survival outcomes. A large Surveillance, Epidemiology, and End Results (SEER)-based analysis by Laviv and Kasper reported a median OS of 10.0 months overall, reaching a mean of 18.9 months in patients undergoing gross total resection [7]. Hekimoglu et al. also reported a favorable mean OS of 20 months in bGBM [13]. The median OS of 10.0 months observed in our cohort is comparable to these contemporary reports and slightly more favorable than earlier series summarized in Table 6 [1–4, 7, 8, 10–13]. Notably, there was no statistically significant difference in OS between the surgical resection group (10.1 months) and the biopsy group (10.0 months) in our cohort, whereas most prior studies reported a 1- to 12-month survival advantage favoring resection (Table 6). Two non-mutually exclusive explanations may account for this pattern. First, our institutional treatment algorithm preferentially selects

patients for resection when safe cytoreduction is feasible and assigns biopsy to patients in whom an EOR $\geq 80\%$ cannot be achieved without significant morbidity. This selection strategy may attenuate apparent survival differences by allowing biopsy patients to proceed to adjuvant therapy with preserved neurological function. Second, adjuvant therapy uptake was high in our cohort (96% received concurrent radiotherapy with temozolomide, 48% received BEV, and 17% received TTFs), alongside relatively preserved baseline functional status (median preoperative KPS, 70). Consistent with this, Bjorland et al. reported that best supportive care was associated with markedly worse OS than multimodal treatment (adjusted HR, 5.11) [4]. Similarly, Hekimoglu et al. suggested that favorable OS outcomes may be partly attributable to high rates of standard adjuvant therapy [13]. These findings collectively suggest that survival in bGBM is highly dependent on the patient's ability to tolerate and complete standard adjuvant therapy. The median PFS of 4.4 months in our series was somewhat shorter than that reported by Boaro et al. (5.9 months) and Franco et al. (5.0 months) (Table 6) [1, 11]. This difference may reflect our strict adherence to RANO-based progression criteria, which may lead to earlier radiographic classification of progression.

Table 6 Summary of previous studies on survival outcomes in bGBM										
Dziurzynski, 2012 ¹⁰	Number of cases	Median age, years	Median preoperative KPS	Adjuvant therapy	Median OS, overall cohort	Median OS, surgical resection	Median OS, biopsy	Median PFS, overall cohort	Median PFS, surgical resection	Median PFS, biopsy
	23	59	80	52.2%	6.0 months	8.8 months	1.6 months	N/A	N/A	N/A
Chaichana, 2014 ²	48	60.5*	80	66.7%	5.1 months	7.0 months	3.5 months	N/A	N/A	N/A
Dayani, 2018 ³	39	57.8*	80	71.8%	3.2 months	14.1 months	2.5 months	N/A	N/A	N/A
Opoku-Darko, 2018 ⁸	29	59.8*	N/A	65.5%	3.3 months	7.8 months	2.8 months	N/A	N/A	N/A
Boaro, 2021 ¹	62	62	70	81.7%	8.7 months	11.5 months	6.3 months	5.9 months	8.7 months	4.6 months
Franco, 2021 ¹¹	55	66	N/A	58.2%	8.3 months	8.5 months	7.2 months	5.0 months	4.8 months	5.1 months
Bjorland, 2022 ⁴	33	66.6	N/A	81.8%	5.5 months	N/A	N/A	3.8 months	N/A	N/A
Hazaymeh, 2022 ¹²	27	62.1*	77.4*	65.6%	7 months	N/A	N/A	N/A	N/A	N/A
Hekimoglu, 2024 ¹³	41	55.9*	90	100%	20 months	N/A	N/A	N/A	N/A	N/A
Laviv, 2025 ⁷	521	62.9*	N/A	30.6%	10.0 months	GTR: mean 18.9 months Non-GTR: mean 13.0 months	7.2 months	N/A	N/A	N/A
Our study	23	62	70	95.7%	10.0 months	10.1 months	10.0 months	4.4 months	5.4 months	2.2 months
*Mean value (median not reported in the original article).										
bGBM = butterfly glioblastoma; KPS = Karnofsky Performance Status; N/A = Not available; OS = Overall survival; PFS = Progression-free survival										

Multiple prognostic factors have been proposed in bGBM, including age, preoperative KPS, tumor volume (preoperative and postoperative), EOR, gross total resection, and receipt of adjuvant therapy [1–3, 7, 8, 11, 17]. In our cohort, age was associated with both OS and PFS in the univariable analysis and remained independent predictor of PFS in the multivariable analysis (Tables 2 and 3), consistent with its established prognostic importance in GBM overall. Of particular importance, postoperative functional status—captured by immediate postoperative KPS and KPS at 2 weeks postoperatively—was strongly associated with OS in the univariable analysis (HR, 0.96; $p = 0.004$ and HR, 0.96; $p = 0.002$, respectively). KPS at 2 weeks postoperatively remained an independent prognostic factor in the multivariable analysis (HR, 0.97; $p = 0.047$) (Table 2). A similar but weaker pattern was observed for PFS (Table 3). Furthermore, KPS deterioration at 2 weeks postoperatively was significantly associated with OS in the univariable analysis (HR, 3.83; $p = 0.024$), highlighting that sustained functional status, rather than transient postoperative decline, is a key determinant of outcome. The dominant role of functional status in our cohort aligns with Tunthanathip et al., who identified $KPS \leq 70$ as an independent predictor of poor OS in tumors involving the corpus callosum [17]. In contrast, preoperative tumor volume, postoperative residual tumor volume, EOR, and surgical strategy (resection vs. biopsy) were not significantly associated with OS or PFS. These findings are consistent with recent reports. Hekimoglu et al. demonstrated that extensive resection in isocitrate dehydrogenase (IDH)-wildtype bGBM prolonged time to recurrence/tumor-free period but did not significantly improve OS, even when stratified by molecular features [13]. Hazaymeh et al. similarly observed an OS benefit of gross total resection in GBM with unilateral corpus callosum involvement, but not in bilateral cases (i.e., bGBM) [12]. Together with our results, these studies suggest that the survival benefit of aggressive resection is attenuated in bGBM compared with GBM in general or unilateral callosal tumors. This contrasts with earlier reports emphasizing EOR or gross total resection as primary survival determinants in bGBM [1, 2, 7, 8] and aligns instead with studies indicating that aggressive resection does not improve survival when it compromises neurological function [3, 10, 11]. Our findings suggest that postoperative functional status, rather than resected tumor volume, is the primary determinant of survival in bGBM.

Kaplan–Meier analysis comparing PFS between patients with $EOR \geq 85\%$ and $EOR < 85\%$ provides additional insight. The log-rank test, which weights events evenly over time, showed no significant difference ($p = 0.214$), whereas the Wilcoxon test, which emphasizes early events, was significant ($p = 0.036$). This suggests that any benefit of more extensive resection is concentrated in the early postoperative period. This interpretation is consistent with meta-analyses reporting a short-term survival advantage of resection. Chojak et al. found reduced mortality at 6 months (relative risk, 0.63; 95% CI, 0.44–0.91), but no benefit at 12 or 18 months [6]. Soliman et al. similarly reported improved OS at 6 and 12 months, but no significant difference at later time points [9].

A key concern in bGBM surgery is the risk of neurological deterioration due to manipulation of the corpus callosum and adjacent eloquent structures, including the cingulate gyrus, supplementary motor area, and components of the default mode network [10]. In our cohort, resection of the tumor-infiltrated corpus callosum was independently associated with immediate postoperative KPS decline (OR, 9.91; $p = 0.028$) but was not associated with KPS deterioration at 2 weeks postoperatively (OR, 2.12; $p = 0.553$) (Tables 4 and 5). In contrast, surgical complications—including hemorrhage, infarction, and supplementary motor area syndrome—were the primary independent predictors of sustained KPS deterioration at 2 weeks (OR, 16.66; $p = 0.017$) (Table 5). The finding that callosal resection does not result in durable functional impairment is consistent with Palmisciano et al., who reported no significant differences in outcomes or complications between preservation and resection of tumor-infiltrated corpus callosum [18]. Hekimoglu et al. also observed sustained postoperative KPS improvement following extensive resection in bGBM [13]. Conversely, Soliman et al. reported higher rates of postoperative neurological deficits following resection than biopsy (OR, 2.05) [9]. Collectively, these findings indicate that outcomes depend less on callosal resection itself and more on whether surgery can be performed without vascular or eloquent cortex injury. These results have two practical implications. First, the functional decline after callosal resection is often transient, suggesting that resection of tumor-infiltrated callosal tissue may be tolerated in the medium term. Second, the primary surgical objective should be avoidance of complications rather than maximal cytoreduction. This is consistent with prior technical reports emphasizing safe surgical corridors that preserve perforating vessels and functional white matter tracts [8, 10, 18].

In synthesis, our study suggests that in bGBM, the survival benefit of surgery is mediated through preservation of postoperative functional status rather than extent of tumor resection. Median OS was nearly identical between biopsy and resection groups (10.0 vs. 10.1 months), and EOR was not an independent prognostic factor, whereas KPS at 2 weeks postoperatively was. Although several meta-analyses have reported a survival advantage of resection over biopsy in bGBM—including Chawla et al. (HR, 0.39 for OS, with the effect persisting in both the $\geq 80\%$ and $< 80\%$ EOR subgroups), Chojak et al., and Soliman et al. [5, 6, 9]—these benefits are often limited to early time points (6–12 months) and may reflect selection bias inherent to retrospective series. The absence of a clear resection benefit in our cohort likely reflects our institutional selection strategy, in which resection is performed only when $\geq 80\%$ EOR can be achieved safely. These findings argue against routine maximal cytoreduction in bGBM when it risks neurological morbidity. Simultaneously, the early PFS advantage observed in patients with $EOR \geq 85\%$, together with prior meta-analytic evidence [6, 9], suggests that safe, extensive resection

may provide short-term disease control that facilitates timely adjuvant therapy. Therefore, an individualized, function-preserving strategy is warranted: resection should be pursued when $\geq 80\%$ EOR can be achieved safely, whereas biopsy should be preferred when this threshold cannot be met without unacceptable risk.

Limitations

This study has several limitations. First, it is a retrospective single-center analysis with a modest sample size of 23 patients, which limits statistical power—particularly in multivariable models—and may mask smaller but clinically meaningful effects of EOR and other surgical variables. Second, the decision between surgical resection and biopsy was based on the operating surgeon's judgment of feasibility from preoperative imaging. Therefore, unmeasured selection bias cannot be excluded. Third, molecular data, including MGMT promoter methylation status and the integrated WHO 2021 classification—were not uniformly available across the long study period (January 2007 to December 2025) and were therefore not included in the multivariable analyses. Fourth, longitudinal neurocognitive and quality-of-life outcomes were not systematically collected. KPS is a relatively coarse measure of functional status and may not capture cognitive or behavioral effects of corpus callosum involvement or surgical injury. Larger, preferably multi-institutional and prospective studies incorporating comprehensive molecular profiling and detailed neurocognitive endpoints are needed to validate these findings and further refine surgical decision-making in bGBM.

Conclusions

Although bGBM is associated with a poor prognosis and greater EOR was not clearly associated with prolonged OS or overall PFS in this cohort, achieving an EOR $\geq 85\%$ may contribute to improved early disease control. In contrast, postoperative functional deterioration, particularly when persisting at 2 weeks after surgery, was associated with unfavorable survival outcomes. Therefore, these findings suggest that an EOR $\geq 85\%$ may be a reasonable surgical target when safely feasible, while minimizing surgical complications, preserving postoperative functional status, and facilitating subsequent radiotherapy with temozolomide.

Declarations

Ethics approval:

This study was approved by the Ethics Committee of Kyoto University Graduate School of Medicine (approval number: R2088) and was conducted in accordance with the Declaration of Helsinki.

Consent to participate:

The requirement for individual informed consent was waived by the Ethics Committee because of the retrospective design of the study.

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Author Contribution

Shigeki Takada: Formal analysis, Methodology, Writing – original draft. Etsuko Yamamoto Hattori: Writing – review & editing. Takeshi Miyata: Writing – review & editing. H.I.: Writing – review & editing. Noritaka Sano: Writing – review & editing. Masahiro Sawada: Writing – review & editing. Masahiro Tanji: Writing – review & editing. Yohei Mineharu: Supervision, Writing – review & editing. Takayuki Kikuchi: Writing – review & editing. Yoshiki Arakawa: Supervision, Writing – review & editing.

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Data availability:

The data that support the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical restrictions.

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Figures

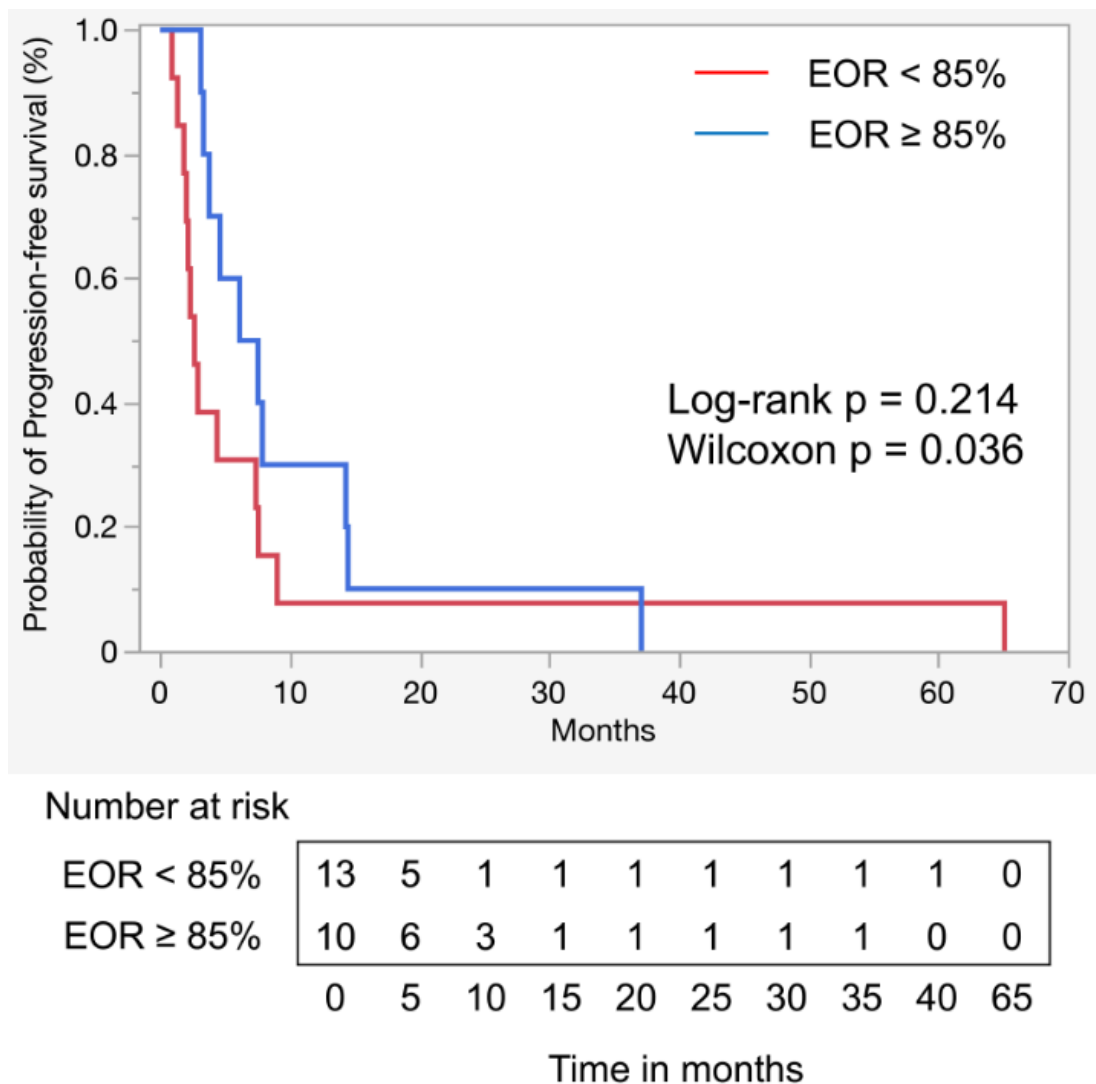


Figure 1

Kaplan-Meier estimates of progression-free survival (PFS) according to extent of resection (EOR)

Kaplan-Meier analysis of PFS comparing patients with an EOR ≥ 85% with those with EOR < 85%. The log-rank test did not demonstrate a significant difference between the groups ($p = 0.214$), whereas the Wilcoxon test was significant ($p = 0.036$), suggesting improved early disease control in the EOR ≥ 85% group.