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CASE STUDY

Decision system for extent of resection in WHO grade 3 gliomas: a Chinese Glioma Genome Atlas database analysis

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Abstract

Background Extensive surgical resection has been found to be associated with longer survival in patients with gliomas, but the interactive prognostic value of molecular pathology of the surgical resection is unclear. This study evaluated the impact of molecular pathology and clinical characteristics on the surgical benefit in WHO grade 3 IDH-mutant gliomas.

Methods Clinical and pathological information of 246 patients with WHO grade 3 IDH-mutant gliomas were collected from the Chinese Glioma Genome Atlas database (2006–2020). The role of the extent of resection on overall survival, stratified by molecular pathology and clinical characteristics, was investigated. We then assessed prognostic factors using a univariate log-rank test and multivariate Cox proportional hazards model in the subgroups.

Results The extent of resection was an independent prognostic factor in the entire cohort, even when adjusted for molecular pathology. Gross total resection was found to be associated with longer survival in all patients and in the astrocytoma group but not in the oligodendroglioma group. Compared with subtotal resections, gross total resections resulted in a longer survival time for astrocytoma patients aged ≤ 45 years. However, there was no survival benefit from total resection in patients with astrocytoma aged > 45 years.

Conclusions Extensive resection benefits only a proportion of patients with WHO grade 3 IDH-mutant gliomas. Younger patients with astrocytomas had survival benefits from extensive resection. In addition to clinical characteristics (especially age), molecular pathology impacted prognosis in patients with gliomas. Our findings provide guiding information to neurosurgeons while planning surgeries.

Keywords WHO grade 3 gliomas · Extent of resection · Molecular pathology · Chinese Glioma Genome Atlas · Survival

Introduction

Diffuse gliomas are the most common primary intracranial malignant tumor in adults, which display infiltrative growth and a high rate of recurrence [1]. Currently, surgical resection is still the first choice for treatment of gliomas. However, it was always a dilemma for neurosurgeons whether to expand the extent of resection (EOR) or preserve the neurological function. The default premise of this problem is that increasing the EOR brings survival benefits for all cases. However, this hypothesis has been demonstrated to be untrue when considering the molecular pathological type of gliomas [2–5]. If expanding the EOR cannot prolong survival time and yet will increase the risk of neurological damage for certain genetic types of gliomas, resection should be done conservatively for these cases.

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The prognostic value of surgical resection for different molecular pathological types of gliomas is still unclear. Patients with isocitrate dehydrogenase (IDH) wild-type gliomas have a poorer prognosis than those with IDH mutant gliomas [6, 7]. Additionally, IDH mutant astrocytomas benefit from complete resection [8]. Thus, a more extensive resection is suggested for IDH wild-type gliomas [9]. The 1p/19q co-deletion is a prognostic biomarker in glioma and was found to be associated with a longer survival time [10]. Gross total resection (GTR) does not prolong overall survival (OS) for lower-grade gliomas with 1p/19q co-deletion [4]. The current evidence suggests that the prognostic value of EOR could vary between gliomas with different molecular pathologies. Nevertheless, this issue is unclear since most previous studies lack analyses of the interactive effect between surgical resection, clinical characteristics, and genetic characteristics.

In the past, histopathological and molecular pathological information could only be obtained by postoperative assessment of tumor samples, and thus, the information cannot be used for guiding surgical resection. Recently, an artificial intelligence model based on radiomics features has enabled highly precise predictions of the molecular biomarker status of gliomas prior to surgery [11–16]. Additionally, the development of intraoperative rapid pathological assessment, such as Raman spectroscopy technology, has realized real-time tumor diagnosis [9, 17]. In the future, surgical planning considering molecular pathological information may be applied in practice.

To test our hypothesis that certain subtypes of World Health Organization (WHO) grade 3 gliomas would not benefit from extensive surgical resection, WHO grade 3 IDH-mutant gliomas were collected from the Chinese Glioma Genome Atlas (CGGA) database. According to the 2021 WHO Classification of Tumors of the Central Nervous System [18], WHO grade 3 gliomas encompass astrocytoma with IDH-mutant and oligodendroglioma with IDH-mutant and 1p/19q co-deletion. We analyzed the role of extensive EOR in prolonging OS for certain molecular subtypes of WHO grade 3 gliomas. We further explored whether the identified surgical benefit can be influenced by clinical factors, such as age at diagnosis. The knowledge we acquired from these meticulous analyses will be instrumental in guiding customized surgical resection for WHO grade 3 IDH-mutant gliomas.

Materials and methods

Patients

We conducted a retrospective analysis of a consecutive series of patients (n = 476) who were newly diagnosed with WHO grade 3 IDH-mutant gliomas and who underwent surgical resection from March 2006 to August 2020. All surgeries were carried out by highly experienced senior physicians. Clinical characteristics, MR images, histopathology, molecular pathology, adjuvant therapy after surgical resection, and follow-up were obtained from the CGGA database (http://www.cgga.org.cn) [19]. This study was approved by the ethics committee of Beijing Tiantan Hospital and was conducted in accordance with the principles of the Declaration of Helsinki (2008). Written informed consent was not required due to the retrospective design of the study.

The inclusion criteria for the cohort were as follows: (1) aged 18 years or older, (2) pathologically confirmed grade 3 gliomas based on the 2021 WHO classification, (3) availability of IDH and 1p/19q statuses, (4) pre- and postoperative MR scans, and (5) no previous adjuvant treatment.

Degree of tumor resection and volumetric analysis

The EOR was assessed by comparing postoperative MR images with preoperative MR images [20], and the tumor volume was performed using the free-access software, MRIcro (http://www.mccauslandcenter.sc.edu/mricro/). If the tumor was enhanced on preoperative MR images, GTR of the tumor was defined as resection with no residual enhanced tumor. In the case that the tumor was not enhanced or partially enhanced on preoperative MR images, the extent of resection was assessed based on the residual high intensity region on T2/fluid-attenuated inversion recovery MR images. EOR was calculated as (preoperative volume – postoperative volume) / preoperative volume. A gross total resection (GTR) was defined as the removal of more than 100% of tumor regions, indicating the absence of any remaining contrast-enhanced tissue or T2/FLAIR high signal area on postoperative MR images. A subtotal resection (STR) was defined as a resection of higher than 90% tumor regions. A partial resection (PR) was defined as a resection of less than 90% [21–23].

Molecular analysis

Glioma molecular pathologies were obtained from the CGGA database. Tumor tissue obtained from surgery were assessed to detect IDH mutations, 1p/19q co-deletion, and methylguanine-DNA methyltransferase (MGMT) promoter methylation. The IDH mutation and the methylation status

of the MGMT promoter were tested using DNA pyrosequencing [24, 25]. The 1p/19q co-deletion was detected using fluorescence in situ hybridization, as previously reported [26].

All patients in this study were classified into two subgroups according to the 2021 WHO classification of a Central Nervous System tumor: (1) astrocytoma (WHO grade 3), IDH mutant, and 1p/19q non-co-deleted; or (2) oligodendroglioma (WHO grade 3), IDH mutant, and 1p/19q co-deleted.

Statistical analyses

Categorical variables were demonstrated with frequencies and percentages, and continuous variables with medians and interquartile range. We used the unpaired t-test and chi-squared tests to identify differences in clinical characteristics between the cohorts. The Fisher's exact test was applied when the assumptions of the chi-squared tests were violated. OS was defined as the duration between the primary surgery and death or the last follow-up. Progression-free survival time was defined as the time from primary surgery to the first clinical or radiological progression as indicated by the clinicians. The Kaplan–Meier method and the log-rank test was used to assess survival differences between the groups. A univariate survival analysis was applied to assess the prognostic significance of the variables. Multivariate survival analyses of certain characteristics (sex, age, preoperative Karnofsky Performance Score [KPS], molecular subtype, MGMT methylation status, EOR, and adjuvant therapy after surgery) were performed using a Cox proportional hazards model. A $p < 0.05$ was considered statistically significant. Statistical analyses were performed using R-software (v 4.1.0 The R Foundation, Vienna, Austria) and GraphPad Prism 8.3. (GraphPad Software, La Jolla CA, United States).

Results

Patient characteristics

The records of 476 patients with WHO grade 3 IDH-mutant gliomas were retrieved from the CGGA database. Of them, 230 patients were excluded from the study cohort (3 were < 18 years old, 149 had recurrent gliomas, 12 lacked follow-up information, and 66 did not have molecular pathology data). A total of 246 patients were finally enrolled in this study (Fig. 1). Clinical characteristics of all patients are summarized in Table 1.

There were 127 (51.6%) males and 119 (48.4%) females; the median age at diagnosis was 42 (interquartile range [IQR], 36–50) years. The median preoperative KPS was 90 (IQR, 90–90). There were 131 (53.3%) patients with astrocytoma (IDH mutant and 1p/19q non-co-deletion) and 115 (46.7%) patients with oligodendroglioma (IDH mutant

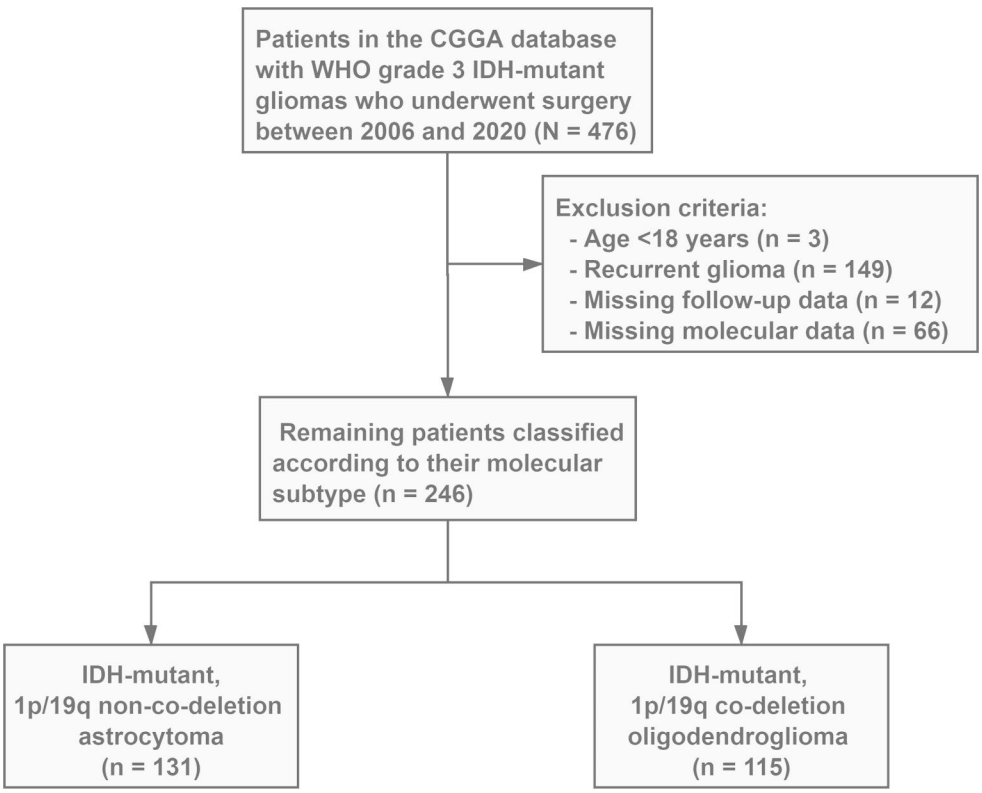

Fig. 1 Flow chart of data enrollment. Patients with WHO grade 3 IDH-mutant gliomas are classified based on their IDH mutation status and 1p/19q codeletion status. CGGA, Chinese Glioma Genome Atlas

Table 1 Clinical characteristics of all patients

Characteristics	All patients		Astrocytomas		Oligodendrogliomas		*p*-value [a]
	N	%	*N*	%	*N*	%	
Patients (n)	246	100	131	53.3	115	46.7	
Sex							0.545
Male	127	51.6	70	53.4	57	49.6	
Female	119	48.4	61	46.6	58	50.4	
Age, years							**< 0.0001**
Median (IQR)	42	(36–50)	39	(33–45)	46	(39–52)	
18–45	155	63.0	99	75.6	56	48.7	
> 45	91	37.0	32	24.4	59	51.3	
Presenting symptom							0.331
Epilepsy	118	48.0	63	48.1	55	47.8	
Incidental	15	6.1	5	3.8	10	8.7	
Headache	108	43.9	63	48.1	45	39.1	
Miscellaneous neurologic complaints	47	19.1	26	19.8	21	18.3	
Preoperative KPS							0.762
Median (IQR)	90	(90–90)	90	(90–90)	90	(90–90)	
> 80	190	77.2	100	76.3	90	78.3	
≤ 80	56	22.8	31	23.7	25	21.7	
Tumor location							0.181
Frontal	183	74.4	91	69.5	92	80.0	
Temporal	84	34.1	53	40.5	31	27.0	
Parietal	37	15.0	23	17.6	14	12.2	
Insular	55	22.4	34	26.0	21	18.3	
Other [b]	65	26.4	34	26.0	31	27.0	
Side of lesion							
Right	123	50	62	47.3	61	53.0	
Left	109	44.3	63	48.1	46	40.0	
Bilateral	14	5.7	6	4.6	8	7.0	
EOR							0.407
GTR	116	47.2	57	43.5	59	51.3	
STR	87	35.4	51	38.9	36	31.3	
PR	43	17.5	23	17.6	20	17.4	
Treatment after surgery							0.431
Chemotherapy	20	8.1	8	6.1	12	10.4	
Radiotherapy	35	14.2	21	16.0	14	12.2	
Chemo-radiation	163	66.3	85	64.9	78	67.8	
Wait and scan	28	11.4	17	13.0	11	9.6	

IQR, interquartile range; EOR, extent of resection; KPS, Karnofsky Performance Score; GTR, gross total resection; STR, subtotal resection; PR, partial resection.

[a] Comparison between astrocytoma and oligodendroglioma

[b] Corpus callosum, hippocampus, basal ganglia, thalamus, and other midline structures

and 1p/19q co-deletion). The major preoperative symptoms of patients were epilepsy (48.0%) and headache (43.9%). Patients with astrocytomas were younger than those with oligodendrogliomas ($P < 0.0001$). Compared with patients who underwent GTR, patients with STR and PR were more likely to have a tumor involving deep brain structures, such as the thalamus, basal ganglia, and corpus callosum ($P < 0.0001$) (Table 2).

Patient outcome per molecular subtype and extent of resection

The median follow-up time for all patients was 70 months, with oligodendroglioma and astrocytoma subgroups having median follow-up times of 58.4 months and 81.5 months, respectively. The entire cohort had a median overall survival (OS) of 112 months, while the median follow-up time of the 169 (68.7%) patients still alive upon data collection was 56 months. No operation-related mortalities were reported. The OS significantly differed between the astrocytoma and

Table 2 Patient characteristics based on surgical resection

Characteristics	All patients		GTR		STR		*p*-value [a]	PR		*p*-value [b]
	N	%	*N*	%	*N*	%		*N*	%	
Patients (n)	246	100	116	47.2	87	35.4		43	17.5	
Sex							**0.023**			0.504
Male	127	51.6	53	45.7	54	62.1		20	46.5	
Female	119	48.4	63	54.3	33	37.9		23	53.5	
Age, years							0.768			0.084
Median (IQR)	42	(36–50)	41	(35–49)	41	(33–48)		45	(37–51)	
18–45	155	63.0	77	66.4	56	64.4		22	51.2	
>45	91	37.0	39	33.6	31	35.6		21	48.8	
Presenting Symptom							**0.048**			0.904 [d]
Epilepsy	118	48.0	55	47.4	44	50.6		19	44.2	
Incidental	15	6.1	11	9.5	1	1.1		3	7.0	
Headache	108	43.9	43	37.1	45	51.7		20	46.5	
Miscellaneous neurologic complaints	47	19.1	21	18.1	19	21.8		7	16.3	
Preoperative KPS							0.615			0.843
Median (IQR)	90	(90–90)	90	(90–90)	90	(85–90)		90	(90–100)	
>80	190	77.2	91	78.4	65	74.7		34	79.1	
≤80	56	22.8	25	21.6	22	25.3		9	20.9	
Tumor location							**< 0.0001**			0.219
Frontal	183	74.4	94	81	65	74.7		24	55.8	
Temporal	84	34.1	28	24.1	38	43.7		18	41.9	
Parietal	37	15.0	17	14.7	13	14.9		7	16.3	
Insular	55	22.4	10	8.6	34	39.1		11	25.6	
Other [c]	65	26.4	1	0.9	48	55.2		16	37.2	
Side of lesion										
Right	123	50	56	48.3	45	51.7		22	51.2	
Left	109	44.3	58	50.0	34	39.1		17	39.5	
Bilateral	14	5.7	2	1.7	8	9.2		4	9.3	
Molecular diagnosis							0.202			0.973
Astrocytoma	131	53.3	57	49.1	51	58.6		23	53.5	
Oligodendroglioma	115	46.7	59	50.9	36	41.4		20	46.5	
Treatment after surgery							0.498			0.243 [d]
Chemotherapy	20	8.1	8	6.9	9	10.3		3	7.0	
Radiotherapy	35	14.2	14	12.1	13	14.9		8	18.6	
Chemo-radiation	163	66.3	80	69.0	59	67.8		24	55.8	
Wait and scan	28	11.4	14	12.1	6	6.9		8	18.6	

IQR, interquartile range; KPS, Karnofsky Performance Score; EOR, extent of resection; GTR, gross total resection; STR, subtotal resection; PR, partial resection.

[a] Comparison between GTR and STR.

[b] Comparison between GTR + STR and PR.

[c] Basal ganglia, corpus callosum, hippocampus, thalamus, and other midline structures

[d] Fisher's exact test

oligodendroglioma groups (hazard ratio [HR]: 2.6; 95% confidence interval [CI]: 1.7–4.1; P = 0.0001), with median OS of 79.7 months and 120.9 months for the astrocytoma and oligodendroglioma groups, respectively.

We analyzed the impact of EOR on the prognosis for WHO grade 3 IDH-mutant gliomas. Patients who underwent GTR (OS: undefined) showed a longer OS compared with those who underwent subtotal resection (OS: 99 months) or partial resection (OS: 26 months) ($P < 0.0001$). The value of GTR remained for IDH-mutant astrocytoma after adjusting for the molecular subgroups ($P < 0.0001$) (Fig. 2). However, those with oligodendroglioma did not benefit more from GTR than from subtotal resection ($P = 0.1701$) (Fig. 2). Additionally, the similar results were also found in PFS.

In the univariate survival analysis of all patients, the EOR (non-GTR vs. GTR; HR, 3.416; $P < 0.0001$), molecular subtype (astrocytoma vs. oligodendroglioma; HR, 2.619; $P = 0.0001$), MGMT (unmethylated vs. methylated; HR, 1.795; $P = 0.0141$) and adjuvant therapy (no vs. yes; HR, 2.109; $P = 0.0094$) were significant prognostic factors for OS

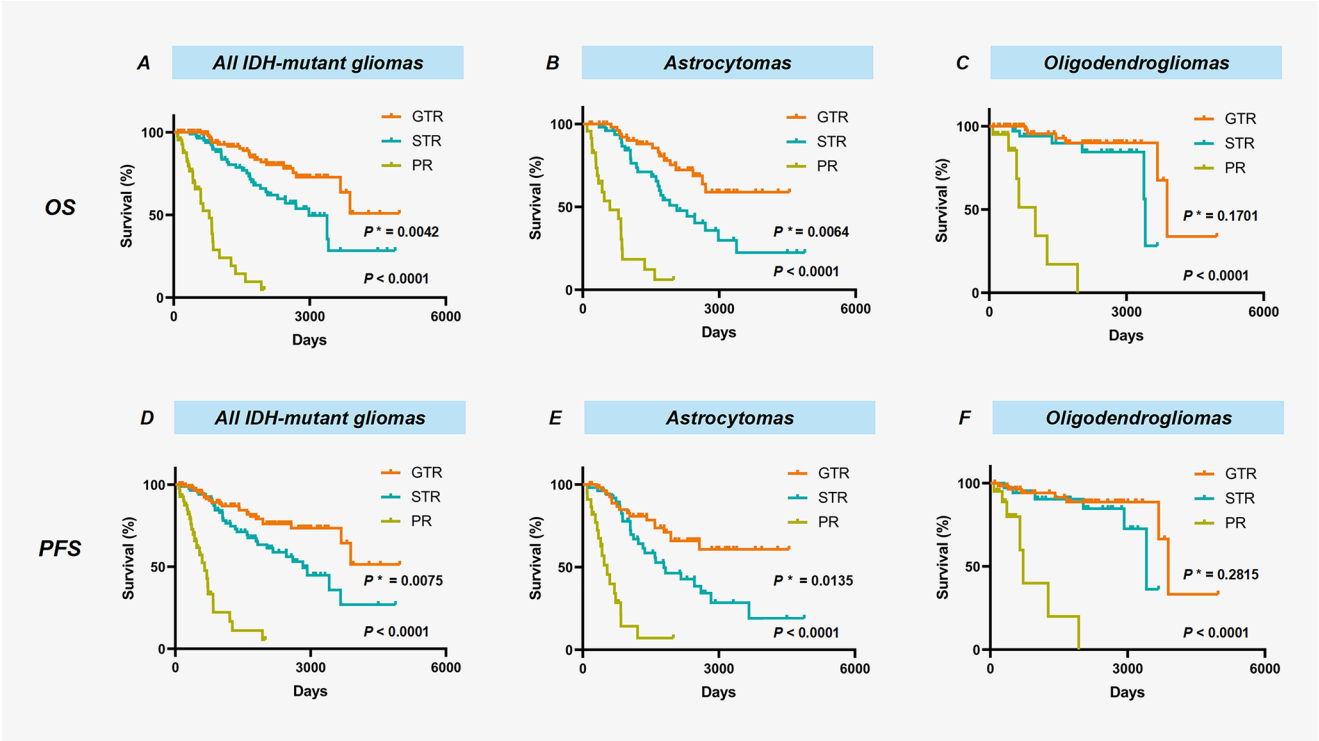

Fig. 2 Kaplan–Meier curves of overall survival (OS) and progression-free survival (PFS) stratified by extent of resection. (**A**) and (**D**) All IDH-mutant gliomas; (**B**) and (**E**) astrocytomas; (**C**) and (**F**) oligodendrogliomas. *Comparison between GTR and STR; GTR, gross total resection; STR, subtotal resection; PR, partial resection

Table 3 Multivariate Cox regression of OS in astrocytomas and oligodendrogliomas

Subgroups	Variables	OS		*P - value*
		HR	95% CI	
Astrocytoma	EOR (Non-GTR vs. GTR)	3.955	2.106–7.426	**< 0.0001**
	Pre-operation KPS (≤ 80 vs. > 80)	2.390	1.278–4.471	**0.006**
	MGMT (Unmethylated vs. Methylated)	2.154	1.226–3.784	**0.008**
	Adjuvant therapy (No vs. Yes)	2.447	1.130–5.297	**0.023**
Oligodendroglioma	EOR (Non-GTR vs. GTR)	5.180	1.439–18.644	**0.012**
	Adjuvant therapy (No vs. Yes)	3.266	1.000-10.666	**0.050**

OS, overall survival; HR, hazard ratio; CI, confidence interval; EOR, extent of resection; GTR, gross total resection; MGMT, promoter region of the DNA repair enzyme O6-methylguanine-DNA methyltransferase.

(Table S1). Similarly, the multivariate analysis revealed that sex (female vs. male, HR, 1.922; $P=0.011$), preoperative KPS (≤ 80 vs. > 80, HR, 2.074; $P=0.008$), EOR (Non-GTR vs. GTR, HR, 4.144; $P<0.0001$), MGMT (unmethylated vs. methylated, HR, 1.876; $P=0.011$), adjuvant therapy (no vs. yes, HR, 2.834; $P=0.002$), and molecular subtype (astrocytoma vs. oligodendroglioma, HR, 3.151; $P<0.0001$) were identified to be significant prognostic factors for the OS of patients (Table S2).

A multivariate analysis of the astrocytoma group demonstrated that EOR (non-GTR vs. GTR; HR, 3.955; $P<0.0001$), preoperative KPS (≤ 80 vs. > 80; HR, 2.390; $P=0.006$), MGMT (unmethylated vs. methylated; HR, 2.154; $P=0.008$), and adjuvant therapy (no vs. yes; HR, 2.447; $P=0.023$) were significant prognostic factors for OS. Non-GTR (HR, 5.180; $P=0.012$) led to worse OS for oligodendrogliomas (Table 3).

Impact of EOR in different age groups

The role of EOR on survival was assessed in subgroups of WHO grade 3 IDH-mutant gliomas (Fig. 3) according to their clinical characteristics and molecular pathology. A cut-off point of 45 years was chosen as it revealed the greatest survival difference between groups. In the astrocytoma group (IDH mutant and 1p/19q non-co-deletion), patients with age ≤ 45 years had a higher survival benefit from GTR than from subtotal resection ($P=0.0133$). In contrast,

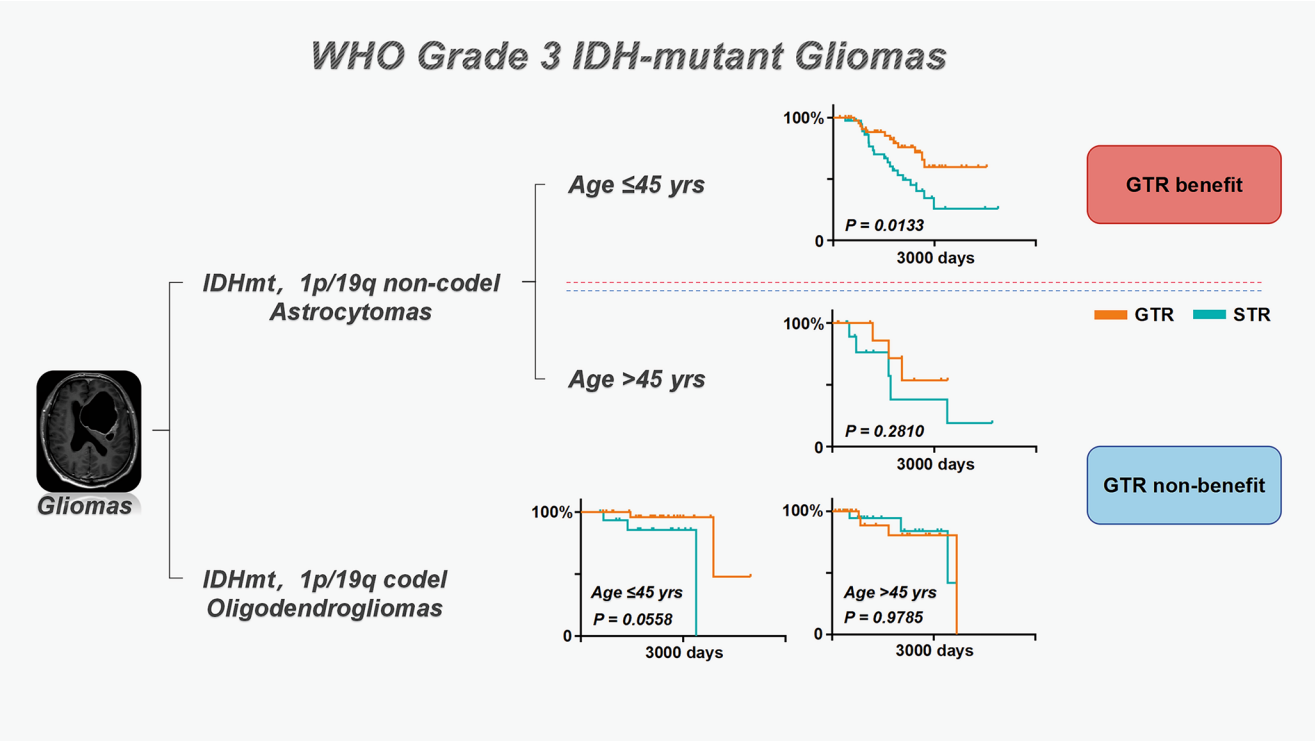

Fig. 3 Survival analysis of patients with WHO grade 3 IDH-mutant gliomas stratified by clinical characteristics and molecular pathology. GTR was identified to benefit patients aged ≤ 45 years with astrocytoma. No benefit of GTR was found for patients aged > 45 years with astrocytomas. Patients with oligodendrogliomas do not have a survival benefit from GTR regardless of age. GTR, gross total resection; STR, subtotal resection

there was no difference in the OS between subtotal resection and GTR in the subgroup of patients with astrocytoma aged > 45 years ($P = 0.2810$). In the oligodendroglioma group, there was no difference in the OS between GTR and subtotal resection regarding age (age ≤ 45 years, $P = 0.0558$; age > 45 years, $P = 0.9785$).

Discussion

Currently, surgical resection is the preferred treatment for diffuse gliomas. Nevertheless, the impact of surgical resection to survival should be reevaluated in this era of molecular pathology, concerning the diagnosis and treatment of gliomas. Prior studies suggested that the prognostic value of EOR should be different for specific molecular subtypes of gliomas [2, 4, 27, 28], although the conclusion is not clear. This study aimed to investigate the impact of the EOR in patients with WHO grade 3 gliomas with IDH-mutant, while considering the molecular pathology and clinical characteristics. We found that the value of the EOR depended on molecular subtypes and clinical characteristics. Notably, EOR holds greater significance in astrocytomas compared to oligodendrogliomas, particularly for young patients. For younger patients diagnosed with astrocytoma, advocating more active surgical strategies and performing more extensive resections is recommended. However, for other groups, including older patients with astrocytoma and patients with oligodendroglioma, complete resection did not result in a prolonged OS. Consequently, relatively conservative surgical methods can be adopted in these cases, with a primary focus on preserving neurological function. This discovery can enable the strategy of pathology-guided surgery to be applied. Combined with molecular pathology considerations, the idea of maximum safe resection would be promoted for effective safe resection because extensive resections are not always beneficial to the survival time of patients with glioma.

Several studies have demonstrated that extensive surgical resection has a positive impact on the survival of patients with glioma. A greater EOR was associated with longer OS [20, 29–32]. This study revealed that the EOR is an independent prognostic factor for WHO grade 3 gliomas, even after adjusting for the molecular type. Specifically, this study identified a particularly strong positive prognostic value for GTR in astrocytomas. A previous study found that even a small postoperative residual tumor has a negative impact on OS in IDH-mutant astrocytoma, which advocates for a secondary operation in this subtype to remove minor residues if safe [27]. However, for oligodendrogliomas with 1p/19q

co-deleted, increasing the EOR does not ensure prolonging the OS [4, 27]. This study further confirms the inconsistency of prognostic values for extensive surgical resection regarding the subtypes of gliomas.

Clinical characteristics (such as age at diagnosis, KPS) are also considered as significant prognostic factors for patients with gliomas [33–36]. A few studies focused on the interaction between molecular pathology and surgical resection. Notably, this study investigated the interaction effect between clinical characteristics, surgical resection, and molecular pathology. The molecular pathology was applied as the first-level classifier and the clinical characteristic (age) as the second-level classifier, and our analysis revealed that the prognostic benefits from surgical resection varied between specific clinicopathological subgroups in this study.

For patients with astrocytomas aged ≤ 45 years, GTR was associated with a longer OS and is therefore encouraged. However, for patients with astrocytoma aged > 45 years, a higher survival benefit was not identified with GTR than with subtotal resection. Considering the fact that extensive resection greatly increases the risk of postoperative neurological dysfunction, pursuing complete resection is not necessarily optimal for these cases, as preservation of neurological function should be primarily considered. For oligodendrogliomas, no prognostic value for GTR was found to prolong OS, even after age stratification. The absence of a strong association between GTR and OS in oligodendrogliomas might be explained by the indolent natural course of these tumors [37] and their sensitivity to radiotherapy and chemotherapy [38]. Patients with oligodendrogliomas therefore still have a long survival time even if complete resection is not achieved. Based on these results, there is no need to pursue the complete resection for all WHO grade 3 gliomas. Both clinical features and molecular pathology characteristics are important considerations in customized surgical planning.

To date, molecular pathology information can only be obtained days after surgery, limiting its value in surgical planning. However, artificial intelligence (AI) technology has made it possible to accurately predict the molecular biomarker status of gliomas before surgery using radiomics features [11–16]. Additionally, Raman spectroscopy technology obtains a highly accurate diagnosis for glioma intraoperatively [17]. This study proposes a possible new surgical strategy, based on evidence, that molecular pathology could be considered preoperatively to guide surgery. This study provides a practical solution for the dilemma regarding choosing between maximum resection and function preservation by updating the concept of maximum safe resection to the strategy of effective safe resection.

There are limitations to this study. The study is retrospective and it was collected from a database with limited clinical details. The lack of the status of CDKN2A/B homozygous deletion in this study cannot exclude some grade 4 astrocytomas. And due to the retrospective design, the sample sizes of each subgroup were unbalanced. A prospective clinical trial is therefore highly encouraged. Although molecular pathology information is still obtained after surgery, technologies for preoperative prediction and those for intraoperative detection are advancing. The results of this study may possibly contribute to realizing pathology-guided neurosurgery in the near future. Additionally, as information on the extent of resection was not provided in The Cancer Genome Atlas and other open accessed glioma databases, independent validation was not available in this study. Further testing of our findings in an independent dataset is needed in future studies.

Conclusions

This study found that younger (≤ 45 years old) patients with WHO grade 3 astrocytoma can benefit from extensive surgical resection, while others may not. Age and molecular pathology are critical factors influencing the surgical resection prognosis. Therefore, these factors should be thoroughly considered in the surgical planning for WHO grade 3 gliomas. Our findings provide guiding information to neurosurgeons while planning surgeries.

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Declarations

Competing interests The authors declare no competing interests.

Conflict of interest The authors indicated no potential conflicts of interest.

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