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Efficacy of various extent of resection on survival rates of patients with pilocytic astrocytoma: based on a large population

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Pilocytic astrocytoma (PA) is classified as a Grade I benign neuroglial tumor. The extent of surgical resection is a critical factor influencing the prognosis for patients with PA. In prior researches of PA, the extent of surgical resection is generally categorized into GTR, STR and biopsy. In some researches on brain tumor surgeries, the extent of resection also includes GTL. There is no existing research specifically comparing the efficacy of GTR versus GTL in PA treatment. In this study, the data we used are from the SEER database. We categorized the extent of resection into GTL, GTR, STL, STR, biopsy, and no surgery based on SEER classification of surgical procedures, to investigate the impact of extent of resection on PA patient survival. A multivariate logistic regression model was utilized to acquire odds ratios (OR) for different extent of resection. Survival outcomes across different extent of resection (GTL, GTR, STL, STR, biopsy, no surgery) were assessed using Kaplan–Meier survival curve analysis, with curve comparisons conducted via log-rank tests. The impact of various risk factors on survival was assessed using the Cox proportional hazards model. The hazard ratio (HR) was employed to quantify the influence of one or more factors on overall survival throughout the follow-up period. Multivariate Cox analysis revealed that age, tumor location, extent of resection, as well as the application of radiotherapy and chemotherapy, all significantly impacted prognosis. Compared to GTL, GTR did not significantly increase the risk of mortality (HR 1.17; 95% CI 0.73–1.86, $p = 0.5$). Furthermore, there was no statistically significant difference between the Kaplan–Meier survival curves of the two groups ($p = 0.18$). We employed propensity score matching (PSM) to balance the differences in baseline characteristics of patients receiving chemotherapy or radiotherapy. A total of 4429 patients were included in this study. Age, diagnosis period, race, tumor size, and tumor location as influential on the extent of resection. Age, tumor location, extent of resection, and application of radiotherapy and chemotherapy influenced the survival of PA patients. The Kaplan–Meier survival curves revealed that the long-term survival rate for GTR is slightly higher than that for GTL. The PSM analysis revealed that the application of radiotherapy and chemotherapy was associated with the reduction of overall survival in PA patients. In conclusion, there was no significant difference in survival between GTR and GTL, so GTR with less damage was preferred. The application of radiotherapy and chemotherapy can reduce overall survival of patients with PA.

Keywords Pilocytic astrocytoma, Glioma, Extent of resection (EOR), Overall survival, SEER

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Pilocytic astrocytoma (PA) is classified as a Grade I benign neuroglial tumor[1,2]. It typically manifests with a range of clinical symptoms that adversely impact patients' quality of life, including headaches, motor impairments, and speech difficulties[3]. According to the Central Brain Tumor Registry of the United States (CBTRUS), the incidence of PA in the U.S. population is 2.9 per 100,000[4], with a predominance among adolescents[5]. The overall prognosis for PA is generally favorable, with a 10-year postoperative survival rate reaching up to 95.8%[6]. The extent of resection is a critical factor influencing the prognosis for patients with PA[7].

In prior researches of PA, the extent of resection is generally categorized into gross total resection (GTR), subtotal resection (STR), and biopsy. Compared to patients undergoing subtotal resection, biopsy, or no surgery, those who undergo GTR typically exhibit a more favorable prognosis[8,9]. In some researches on brain tumor surgeries, GTR is classified as a form of supramarginal resection. Besides GTR, supramarginal resection includes gross total resection with lobectomy (GTL)[10,11], which is recognized as a more extensive form of resection, known as supramaximal resection[12]. Although there is no existing research specifically comparing the efficacy of GTR versus GTL in PA treatment, detailed comparisons between the GTL and GTR have been explored in researches of glioblastoma (GBM). Theoretically, GTL, with its clearer resection margins and broader extent, allow for more comprehensive removal of malignant and pre-malignant cells, potentially extending the time to tumor recurrence and overall survival[13]. Extensive researches in glioblastoma have indicated that GTL is often associated with improved survival outcomes compared to GTR, extending patient survival and enhancing overall survival rates[10,14–17]. However, some early researches suggest that there is no significant difference in survival times between GTL and GTR[18].

Although both PA and GBM are classified as gliomas, they exhibit substantial differences. PA is a WHO Grade I benign tumor, predominantly observed in children and adolescents, characterized by slow growth and non-invasive behavior[19]. In contrast, GBM is a WHO Grade IV malignant tumor, typically occurring in adult and elderly individuals, with rapid growth and highly invasive characteristics[20]. The molecular genetics of these two tumors also differ significantly. PA is commonly associated with alterations in the Ras/RAF/mitogen-activated protein kinase/extracellular signal-regulated kinase pathway[19], whereas GBM is characterized by mutations in genes regulating receptor tyrosine kinase /rat sarcoma /phosphoinositide 3-kinase, p53, and retinoblastoma protein signaling[20]. These distinctions contribute to differences in treatment strategies and survival time. PA is predominantly treated through surgical intervention, typically without the need for radiotherapy or chemotherapy, and has a favorable prognosis[19]. GBM is managed through a combination of surgical resection, radiotherapy, and chemotherapy. However, the prognosis remains unfavorable, with limited survival time despite these aggressive treatment modalities[20]. Therefore, the treatment protocols and clinical practices for GBM cannot be directly applied to PA, indicating that findings from studies comparing GTL and GTR in GBM should not be extrapolated to PA.

Given the low incidence of PA, conducting large-scale clinical studies poses significant challenges. Consequently, it becomes crucial to identify databases with rigorous data recording standards, precise parameter classification, large sample sizes, and long follow-up durations for research on PA. In this study, the Surveillance, Epidemiology, and End Results (SEER) program is particularly well-suited for our study. We categorized the extent of resection based on the SEER surgery codes into GTL, GTR, STL, STR, biopsy, and no surgery, to investigate the impact of extent of resection on PA patient survival. We hope that our findings will assist neurosurgeons in making informed clinical decisions and contribute to further improving the prognosis of PA patients.

Materials and methods

Data source and selection

Data for this study were obtained from the Surveillance, Epidemiology, and End Results (SEER). The SEER provides cancer statistics through population-based cancer registries, covering 35% of the U.S. population, and includes data on incidence, survival rates, and clinical interventions[21].

To ensure statistical robustness and stability, two SEER datasets released in April 2021 were utilized to maximize sample size. The International Classification of Diseases for Oncology, 3rd Edition (ICD-O-3), was employed to identify the code for PA as 9421. All PA patients from the 1992–2018 (13 Registries) and 2000–2018 (18 Registries) datasets were included. Tumors located in the brain were screened, and duplicate entries across the two datasets were removed, resulting in a cohort of 5,283 patients. Exclusions were applied to 13 cases with unknown survival time, 282 cases that did not meet primary tumor criteria or presented with multiple tumors, and 562 patients lacking documented information on lobectomy, tumor resection, biopsy, unspecified surgery types, or with unknown surgery. After applying these criteria, a total of 4429 patients was selected for analysis (see Fig. 1).

Study variables and significance

This study included variables such as the extent of resection, age, sex, diagnosis period, race, tumor size, tumor location, radiotherapy, chemotherapy, and follow-up status. The extent of resection was categorized as GTL (code 55), GTR (code 30), STL (code 40), STR (code 21), biopsy (code 20), and no surgery (code 00). Age was stratified into four groups: 0–19 years, 20–39 years, 40–59 years, and > 60 years. The diagnosis periods were divided into three intervals: 1998–2004, 2005–2011, and 2012–2018. Race was delineated as White, Black, American Indian/Alaska Native, Asian or Pacific Islander, and unknown. Tumor locations included the cerebellum, brainstem, cerebrum, frontal lobe, occipital lobe, overlapping lesions in the brain, parietal lobe, temporal lobe, ventricle, and brain NOS (not otherwise specified). Tumor size was classified into the following categories: < 20 mm, 20–40 mm, > 40 mm, and unknown size. The primary endpoint of this study was overall survival, defined as the time from diagnosis to death from any cause, measured in months.

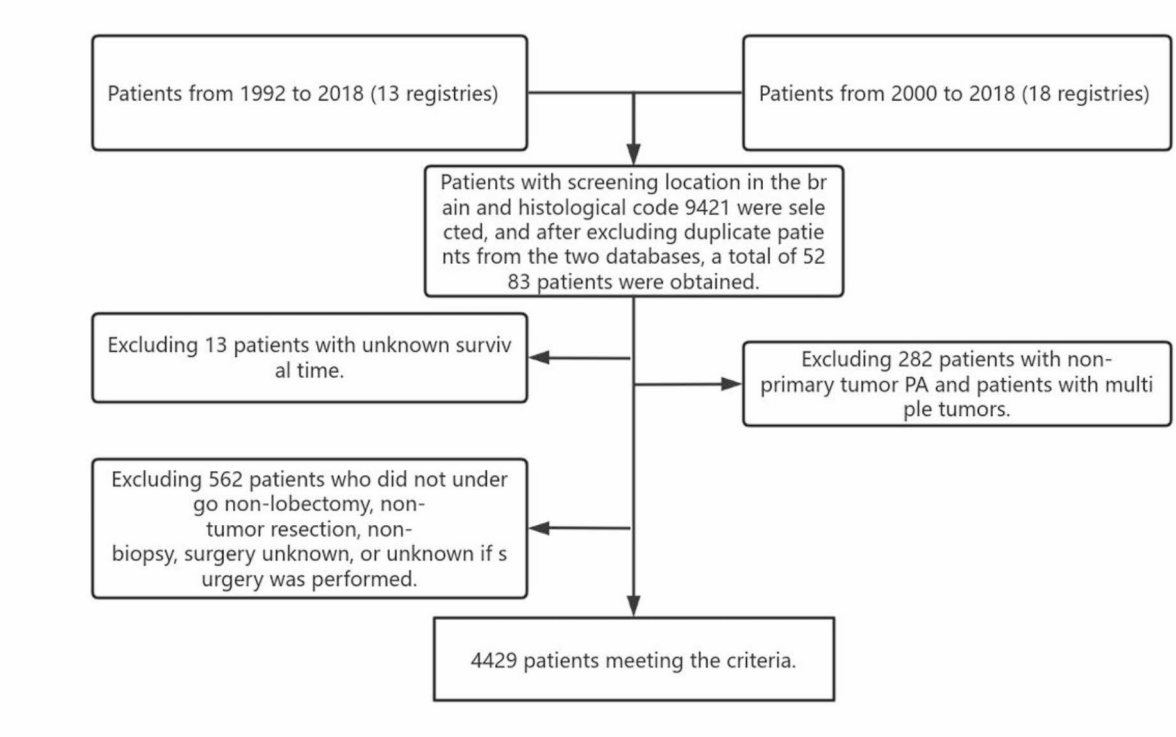

Fig. 1. Patient selection flowchart.

Data analysis methods

Pearson's chi-square test was used to compare clinical characteristics among different extent of resection. The extent of resection was treated as the dependent variable, with GTL as the reference group. Multivariate logistic regression analysis was performed to obtain odds ratios (ORs) for different extent of resection. Kaplan–Meier survival analysis was conducted for patients with different extent of resection, and log-rank tests were used to compare differences between Kaplan–Meier curves. The Cox proportional hazards model was used to assess the impact of various risk factors on survival, with hazard ratios (HRs) indicating the effect of one or more factors on overall survival throughout the follow-up period. Propensity score matching (PSM, 1:1 matching) was employed to balance baseline characteristics between patients who received chemotherapy or radiotherapy and those who did not. Kaplan–Meier survival analysis was then performed on the matched results to further investigate whether other factors influenced the prognosis of patients who received chemotherapy or radiotherapy. A significance level of $p < 0.05$ was set for all statistical analyses in this study.

Results

Overall findings and baseline characteristics

This study included a total of 4429 patients. Patients were categorized into groups based on the extent of resection, including GTL, GTR, STL, STR, biopsy, and no surgery. The analyzed factors included age, sex, diagnosis period, race, tumor size, tumor location, radiotherapy, and chemotherapy. Significant differences were observed among the groups in terms of age, diagnosis period, tumor size, tumor location, radiotherapy, chemotherapy, and the number of deaths ($p < 0.001$). However, no statistically significant differences were observed for sex ($p = 0.827$) and race ($p = 0.176$) (Table 1).

In the entire cohort of 4429 patients, a substantial portion underwent gross total resection (GTR and GTL), accounting for 47.1% of the cases. Subtotal resection (STR and STL) and biopsy were performed in 23.5% and 20.1% of patients, respectively. Tumors were predominantly observed in the 0–19 years age group, comprising 73.3% of cases. The most common tumor location was the cerebellum (39.6%), followed by the brainstem (12.2%), with other locations less frequently involved. A significant proportion of patients did not receive radiotherapy (92.1%) or chemotherapy (88.7%). During the follow-up period, 316 patients (7.1% of the total cohort) died (Table 1).

Different tumor locations and diagnosis periods affect extent of resection

Univariate and multivariate logistic regression analyses were conducted to evaluate the predictive significance of various extent of resection. Factors that reached statistical significance ($p < 0.05$) in the univariate logistic regression analysis were subsequently included in the multivariate logistic regression (Table 2), with GTL as the reference group. Univariate logistic analysis revealed that sex did not significantly influence the selection of extent of resection ($p > 0.05$). In the multivariate logistic analysis, we observed a gradual increase in the likelihood of selecting GTR and STR over time. Figure 2 also demonstrates the same trend. Compared to patients with

	Overall	GTL	GTR	STL	STR	Biopsy	No surgery	*p* value
N	4429	1115	972	520	522	890	410	
Age group								
00-19 years	3245	842 (25.9%)	735 (22.7%)	375 (11.6%)	368 (11.3%)	642 (19.8%)	283 (8.7%)	< 0.001
20-39 years	792	203 (25.6%)	162 (20.5%)	89 (11.2%)	105 (13.3%)	162 (20.5%)	71 (9.0%)	
40-59 years	292	56 (19.2%)	55 (18.8%)	42 (14.4%)	32 (11.0%)	59 (20.0%)	48 (16.4%)	
> 60 years	100	14 (14.0%)	20 (20.0%)	14 (14.0%)	17 (17.0%)	27 (27.0%)	8 (8.0%)	
Sex								
Male	2248	567 (25.2%)	498 (22.2%)	259 (11.5%)	268 (11.9%)	438 (19.5%)	218 (9.7%)	0.827
Female	2181	548 (25.1%)	474 (21.7%)	261 (12.0%)	254 (11.6%)	452 (20.7%)	192 (8.8%)	
Diagnosis period								
1998–2004	1277	587 (46.0%)	9 (0.7%)	273 (21.4%)	3 (0.2%)	285 (22.3%)	120 (9.4%)	< 0.001
2005–2011	1565	486 (31.1%)	217 (13.9%)	231 (14.7%)	119 (7.6%)	365 (23.3%)	147 (9.4%)	
2012–2018	1587	42 (2.6%)	746 (47.0%)	16 (1.0%)	400 (25.2%)	240 (15.1%)	143 (9.0%)	
Race								
White	3619	930 (25.7%)	790 (21.8%)	427 (11.8%)	406 (11.2%)	738 (20.4%)	328 (9.1%)	0.176
Black	442	93 (21.0%)	105 (23.8%)	54 (12.2%)	67 (15.2%)	85 (19.2%)	38 (8.6%)	
American Indian/Alaska Native	36	11 (30.6%)	6 (16.7%)	5 (13.9%)	4 (11.1%)	8 (22.2%)	2 (5.6%)	
Asian or Pacific Islander	235	62 (26.4%)	49 (20.9%)	28 (11.9%)	33 (14.0%)	37 (15.7%)	26 (11.1%)	
Unknown	97	19 (19.6%)	22 (22.7%)	6 (6.2%)	12 (12.4%)	22 (22.7%)	16 (16.5%)	
Tumor size								
< 20 mm	401	81 (20.2%)	90 (22.4%)	35 (8.7%)	35 (8.7%)	93 (23.2%)	67 (16.7%)	< 0.001
20–40 mm	1309	302 (23.1%)	264 (20.2%)	178 (13.6%)	163 (12.5%)	252 (19.3%)	150 (11.5%)	
> 40 mm	1587	402 (25.3%)	466 (29.4%)	154 (9.7%)	217 (13.7%)	281 (17.7%)	67 (4.2%)	
Unknown	1132	330 (29.2%)	152 (13.4%)	153 (13.5%)	107 (9.5%)	264 (23.3%)	126 (11.1%)	
Tumor location								
Cerebellum	1753	598 (34.1%)	506 (28.9%)	111 (6.3%)	160 (9.1%)	326 (18.6%)	52 (3.0%)	< 0.001
Brainstem	542	72 (13.3%)	74 (13.7%)	115 (21.2%)	97 (17.9%)	104 (19.1%)	80 (14.8%)	
Cerebrum	385	43 (11.2%)	46 (11.9%)	61 (15.8%)	53 (13.8%)	72 (18.7%)	110 (28.6%)	
Frontal lobe	201	44 (21.9%)	41 (20.4%)	25 (12.4%)	22 (10.9%)	49 (24.4%)	20 (10.0%)	
Occipital lobe	58	26 (44.8%)	15 (25.9%)	3 (5.2%)	4 (6.9%)	10 (17.2%)	0 (0.0%)	
Overlapping lesions in the brain	132	34 (25.8%)	18 (13.6%)	22 (16.7%)	19 (14.4%)	21 (15.9%)	18 (13.6%)	
Parietal lobe	119	35 (29.4%)	29 (24.4%)	5 (4.2%)	10 (8.4%)	32 (26.9%)	8 (6.7%)	
Temporal lobe	239	55 (23.0%)	63 (26.4%)	36 (15.1%)	24 (10.0%)	52 (21.8%)	9 (3.8%)	
Ventricle	315	48 (15.2%)	54 (17.1%)	53 (16.8%)	45 (14.3%)	69 (21.9%)	46 (14.6%)	
Brain, NOS	685	160 (23.4%)	126 (18.4%)	89 (13.0%)	88 (12.8%)	155 (22.6%)	67 (9.8%)	
Radiotherapy								
No	4080	1085 (26.6%)	939 (23.0%)	425 (10.4%)	469 (11.5%)	829 (20.3%)	333 (8.2%)	< 0.001
Unknown	24	2 (8.3%)	3 (12.5%)	4 (16.7%)	2 (8.3%)	3 (12.5%)	10 (41.7%)	
Yes	325	28 (8.6%)	30 (9.2%)	91 (28.0%)	51 (15.7%)	58 (17.8%)	67 (20.6%)	
Chemotherapy								
Yes	502	26 (5.2%)	30 (6.0%)	120 (23.9%)	102 (20.3%)	102 (20.3%)	122 (24.3%)	< 0.001
No	3927	1089 (27.7%)	942 (24.0%)	400 (10.2%)	420 (10.7%)	788 (20.1%)	288 (7.3%)	
Vital status								
Dead	316	50 (15.8%)	29 (9.2%)	71 (22.5%)	35 (11.1%)	67 (21.2%)	64 (20.3%)	< 0.001
Alive	4113	1065 (25.9%)	943 (22.9%)	449 (10.9%)	487 (11.8%)	823 (20.0%)	346 (8.4%)	

Table 1. Patient baseline characteristics.

cerebellum tumors who underwent GTL, those with tumors located in the brainstem, cerebrum, and ventricles were more likely to undergo STR, biopsy, STL, or no surgery.

Different extent of resection were popular in different periods

We identified temporal trends in the selection of extent of resection across different periods. As depicted in Fig. 2, the distribution of extent of resection varied significantly across distinct time intervals. During the 1998–2004 period, lobectomy was the predominant surgical approach, with 46.0% of patients undergoing GTL and 21.0% undergoing STL, while fewer than 2.0% of patients underwent GTR or STR. In the 2005–2011 period, there was a noticeable shift, characterized by a gradual increase in the proportion of tumor excisions (including

	GTR	STL	STR	Biopsy	No surgery
Ref: GTL	OR (95% CI), *p*	OR (95% CI), *p*	OR (95% CI), *p*	OR (95% CI), *p*	OR (95% CI), *p*
Age group					
00–19 years	Reference				
20–39 years	0.95 (0.70–1.28), 0.731	1.03 (0.76–1.40), 0.859	1.35 (0.96–1.88), 0.083	1.04 (0.81–1.33), 0.764	1.05 (0.74–1.49), 0.788
40–59 years	1.04 (0.64–1.68), 0.878	1.53 (0.97–2.41), 0.070	1.36 (0.79–2.34), 0.265	1.27 (0.85–1.90), 0.250	2.33 (1.45–3.73), < 0.001
> 60 years	1.15 (0.50–2.64), 0.750	2.31 (1.02–5.19), 0.044	1.84 (0.78–4.37), 0.166	2.09 (1.04–4.18), 0.030	1.32 (0.50–3.47), 0.574
Diagnosis period					
1998–2004	Reference				
2005–2011	28.25 (14.33–55.71), < 0.001	0.98 (0.78–1.25), 0.896	49.53 (15.45-158.76), < 0.001	1.56 (1.27–1.92), < 0.001	1.54 (1.14–2.10), 0.006
2012–2018	1153.32 (555.54-2394.32), < 0.001	0.77 (0.42–1.42), 0.410	1964.27 (595.88-6475.10), < 0.001	12.08 (8.37–17.43), < 0.001	17.39 (11.24–26.90), < 0.001
Race					
White	Reference				
Black	1.11 (0.76–1.61), 0.590	1.34 (0.91–1.96), 0.141	1.39 (0.93–2.09), 0.112	1.07 (0.77–1.49), 0.681	1.15 (0.74–1.79), 0.546
American Indian/Alaska Native	0.31 (0.09–1.08), 0.066	1.06 (0.33–3.38), 0.927	0.59 (0.15–2.28), 0.443	0.80 (0.30–2.14), 0.655	0.57 (0.11–2.95), 0.506
Asian or Pacific Islander	0.83 (0.50–1.38), 0.471	0.91 (0.55–1.50), 0.704	1.03 (0.60–1.78), 0.906	0.72 (0.46–1.13), 0.154	1.13 (0.65–1.96), 0.667
Unknown	0.81 (0.38–1.74), 0.588	0.78 (0.30–2.03), 0.607	0.98 (0.42–2.29), 0.960	1.20 (0.62–2.30), 0.592	2.40 (1.13–5.10), 0.023
Tumor size					
< 20 mm	Reference				
20–40 mm	0.99 (0.65–1.50), 0.954	1.03 (0.65–1.64), 0.910	1.25 (0.76–2.08), 0.382	0.73 (0.51–1.05), 0.090	0.42 (0.27–0.65), < 0.001
> 40 mm	1.22 (0.81–1.83), 0.350	0.78 (0.49–1.26), 0.310	1.31 (0.79–2.15), 0.294	0.65 (0.45–0.93), 0.019	0.15 (0.09–0.24), < 0.001
Unknown	0.94 (0.61–1.47), 0.794	0.85 (0.53–1.36), 0.495	1.51 (0.89–2.55), 0.124	0.89 (0.62–1.28), 0.522	0.48 (0.31–0.76), 0.001
Tumor location					
Cerebellum	Reference				
Brainstem	1.17 (0.77–1.77), 0.473	5.79 (3.97–8.44), < 0.001	3.59 (2.35–5.49), < 0.001	2.12 (1.50-3.00), < 0.001	7.00 (4.43–11.06), 0.001
Brain, NOS	0.87 (0.63–1.22), 0.425	2.41 (1.71–3.40), < 0.001	1.51 (1.04–2.21), 0.032	1.49 (1.14–1.96), 0.004	3.46 (2.26–5.32), < 0.001
Cerebrum	1.32 (0.79–2.19), 0.292	4.89 (3.09–7.75), < 0.001	3.42 (2.04–5.73), < 0.001	2.51 (1.65–3.81), < 0.001	18.81 (11.57–30.59), < 0.001
Frontal lobe	1.04 (0.59–1.82), 0.894	2.44 (1.40–4.25), 0.002	1.40 (0.73–2.65), 0.310	1.65 (1.05–2.60), 0.031	3.15 (1.66–5.99), < 0.001
Occipital lobe	0.53 (0.21–1.38), 0.193	0.38 (0.10–1.42), 0.151	0.37 (0.10–1.32), 0.126	0.55 (0.24–1.22), 0.140	0.01 (0.00-6607.19), 0.459
Overlapping lesions in the brain	0.54 (0.26–1.13), 0.101	2.25 (1.22–4.16), 0.010	1.38 (0.66–2.89), 0.400	0.92 (0.51–1.66), 0.770	3.86 (1.90–7.85), < 0.001
Parietal lobe	1.04 (0.55–1.97), 0.901	0.62 (0.23–1.66), 0.345	1.08 (0.47–2.46), 0.856	1.50 (0.89–2.51), 0.129	1.89 (0.80–4.47), 0.149
Temporal lobe	1.29 (0.79–2.10), 0.307	3.15 (1.94–5.12), < 0.001	1.28 (0.70–2.34), 0.421	1.49 (0.98–2.28), 0.063	1.27 (0.58–2.80), 0.552
Ventricle	1.50 (0.91–2.47), 0.111	4.22 (2.67–6.69), < 0.001	2.72 (1.60–4.61), < 0.001	2.22 (1.47–3.35), < 0.001	6.88 (4.06–11.66), < 0.001

Table 2. Multivariate logistics regression analyses.

GTR and STR), though lobectomy (encompassing both GTL and STL) remained the most commonly selected procedure. By the 2012–2018 period, this trend had evolved significantly, with a marked rise in tumor excisions, evidenced by 47.0% of patients undergoing GTR and 25.0% undergoing STR. Conversely, the proportion of patients receiving lobectomy procedures (GTL at 3.0% and STL at 1.0%) had sharply declined.

The significant impact of age, tumor location, surgical extent, radiotherapy, and chemotherapy on patient survival rates

The results of the univariate Cox regression analysis demonstrated that age, tumor location, extent of resection, radiotherapy, and chemotherapy significantly impacted patient survival (Table 3). Subsequently, these significant variables identified in the univariate analysis—age, tumor location, extent of resection, radiotherapy, and chemotherapy—were incorporated into a multivariate Cox regression analysis to further elucidate their independent effects on survival. The multivariate analysis confirmed the strong influence of these factors on survival. When compared to the 0–19 years age group, patients aged 20–39 years (HR: 2.69, 95% CI 1.97–3.68, $p < 0.001$), 40–59 years (HR: 6.61, 95% CI 4.32–8.52, $p < 0.001$), and over 60 years (HR: 18.3, 95% CI 12.63–26.43, $p < 0.001$) demonstrated a progressively higher risk of mortality. Tumor location also significantly influenced survival outcomes, with cerebellum tumors associated with the most favorable prognosis.

In contrast, tumors in the cerebrum (HR: 2.37, 95% CI 1.55–3.62, $p < 0.001$), ventricles (HR: 2.15, 95% CI 1.40–3.32, $p < 0.001$), brainstem (HR: 2.07, 95% CI 1.41–3.03, $p < 0.001$), overlapping lesions in the brain (HR: 2.06, 95% CI 1.15–3.66, $p = 0.014$), and frontal lobe (HR: 2.05, 95% CI 1.26–3.34, $p = 0.004$) were associated with a significantly elevated risk of mortality compared to cerebellum tumors. In terms of extent of resection, patients who did not undergo surgery (HR: 2.19, 95% CI 1.46–3.28, $p < 0.001$) and those who had STR (HR:

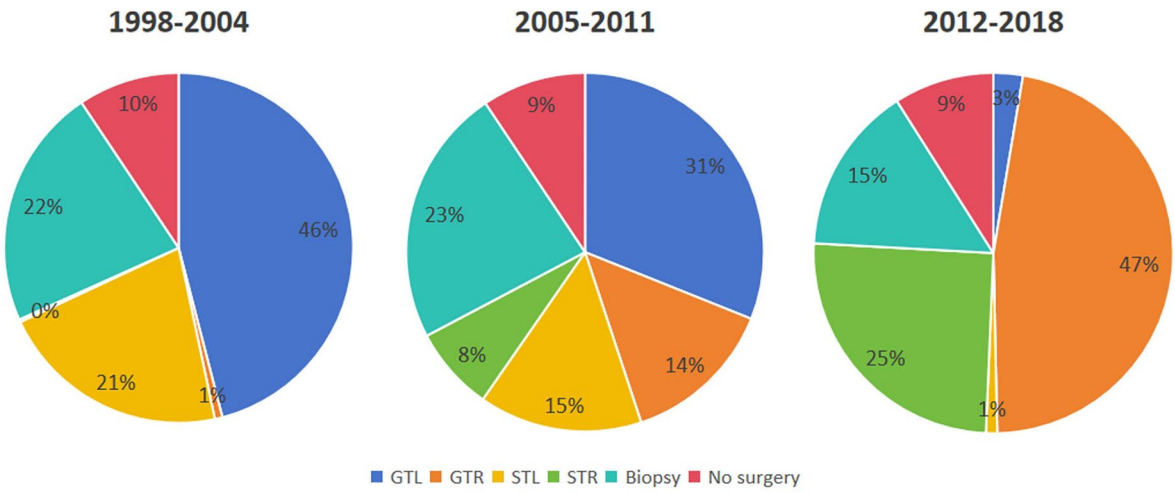

Fig. 2. Trends in extent of resection among patients undergoing surgery across different periods.

1.60, 95% CI 1.02–2.52, $p = 0.042$) faced a significantly increased mortality risk relative to those who underwent GTL. However, no statistically significant differences in survival were observed for patients who underwent GTR (HR: 1.17, 95% CI 0.73–1.86, $p = 0.500$), STL (HR: 1.46, 95% CI 0.99–2.15, $p = 0.056$), or biopsy (HR: 1.36, 95% CI 0.94–1.99, $p = 0.100$). Furthermore, patients who received radiotherapy exhibited a significantly higher mortality risk (HR: 3.10, 95% CI 2.35–4.09, $p < 0.001$), as did those who received chemotherapy (HR: 2.49, 95% CI 1.84–3.37, $p < 0.001$) (Table 3).

Patients with GTL and GTR have the highest survival rates

We conducted a comprehensive analysis using Kaplan–Meier survival curves to assess the influence of various extent of resection on patient survival, as illustrated in Fig. 3. We subsequently calculated the 5-year, 10-year, and 15-year survival rates corresponding to each extent of resection, which are detailed in Table 4. To rigorously evaluate the differences among the Kaplan–Meier curves, we employed log-rank tests, with the results summarized in Table 5. Notably, the analysis revealed no statistically significant differences in survival curves between GTR and GTL ($p = 0.18$), nor between STR and STL ($p = 0.97$). Overall, our findings indicate that both GTL and GTR are associated with superior survival outcomes compared to STL and STR.

Why do patients who receive chemotherapy and radiotherapy have worse survival rates

Cox regression analysis revealed that patients who received chemotherapy and radiotherapy exhibited poorer prognoses, a finding that piqued our interest due to its apparent contradiction to established expectations. Consequently, we intend to delve deeper into the underlying reasons for this anomalous observation. To begin our investigation, we classified patients based on their receipt of chemotherapy and radiotherapy and conducted a comparative analysis of their baseline characteristics. As illustrated in Table 6, a significant disparity was observed between patients who received chemotherapy or radiotherapy and those who did not, with notable differences in several key characteristics, including age, extent of resection, and tumor size ($p < 0.001$).

Given that patient age, tumor size, and surgical intervention (or extent of resection) are recognized as potential factors influencing patient survival, we undertook a further investigation to ascertain whether chemotherapy itself might adversely impact survival. Patients were stratified into two groups based on their receipt of chemotherapy. After addressing the discrepancies in baseline characteristics between those who received chemotherapy and those who did not, we proceeded to analyze the survival disparities between the two cohorts. To achieve a meaningful comparison, we employed propensity score matching (PSM) at 1:1 ratio. The matching variables included age, sex, diagnosis period, race, tumor size, tumor location, extent of resection, and the application of radiotherapy. The results, as summarized in Table 7, demonstrated that post-matching, there were no significant differences in any of the matching variables between the chemotherapy and non-chemotherapy groups. Subsequent Kaplan–Meier survival analysis following PSM, presented in Fig. 4a, revealed that patients who underwent chemotherapy experienced significantly poorer survival compared to their counterparts who did not receive chemotherapy ($p < 0.001$), thereby corroborating the initial findings observed prior to PSM.

In a similar vein, we sought to investigate whether the application of radiotherapy could be associated with a reduction in patient survival. Patients were stratified into two groups based on their receipt of radiotherapy. Following the adjustment for discrepancies in baseline characteristics between individuals who received radiotherapy and those who did not, we proceeded to analyze the survival rate variations between the two cohorts. To ensure a reliable comparison, the groups were matched using the propensity score matching (PSM)

Variable	N	Univariate analysis		Multivariate analysis	
		HR (95% CI)	p value	HR (95% CI)	p value
Age group					
00–19 years (Ref)	3245				
20–39 years	792	2.62 (1.99–3.47)	< 0.001	2.69 (1.97–3.68)	< 0.001
40–59 years	292	5.67 (4.17–7.71)	< 0.001	6.61 (4.32–8.52)	< 0.001
> 60 years	100	17.6 (12.6–24.6)	< 0.001	18.3(12.63–26.43)	< 0.001
Sex					
Female (Ref)	2181				
Male	2248	1.19 (0.96–1.49)	0.12		
Diagnosis period					
1998–2004 (Ref)	1277				
2005–2011	1565	0.84 (0.64–1.10)	0.196		
2012–2018	1587	1.06 (0.78–1.44)	0.72		
Race					
White (Ref)	3619				
Black	442	1.20 (0.85–1.70)	0.303		
American Indian/Alask Native	36	2.29 (0.94–5.54)	0.067		
Asian or Pacifics lander	235	1.04 (0.64–1.70)	0.883		
Unknown	97	0.17 (0.02–1.21)	0.076		
Tumor size					
< 20 mm (Ref)	401				
20–40 mm	1309	1.34 (0.84–2.15)	0.225		
> 40 mm	1587	1.24 (0.78–1.99)	0.365		
Unknown	1132	1.40 (0.87–2.25)	0.161		
Tumor location					
Cerebellum (Ref)	1753				
Brainstem	542	3.84 (2.71–5.44)	< 0.001	2.07 (1.41–3.03)	< 0.001
Brain, NOS	685	1.65 (1.10–2.48)	0.016	1.42 (0.91–2.21)	0.121
Cerebrum (not specified)	385	3.48 (2.36–5.14)	< 0.001	2.37 (1.55–3.62)	< 0.001
Frontal lobe	201	3.62 (2.26–5.82)	< 0.001	2.05 (1.26–3.34)	0.004
Occipital lobe	58	1.39 (0.44–4.43)	0.578	0.88 (0.27–2.84)	0.831
Overlapping lesions in the brain	132	4.25 (2.54–7.12)	< 0.001	2.06 (1.15–3.66)	0.014
Parietal lobe	119	2.77 (1.45–5.26)	0.002	1.86 (0.95–3.66)	0.073
Temporal lobe	239	1.37 (0.72–2.61)	0.334	0.91 (0.45–1.84)	0.782
Ventricle	315	3.80 (2.54–5.69)	< 0.001	2.15 (1.40–3.32)	< 0.001
Extent of resection					
GTL (Ref)	1115				
GTR	972	1.29 (0.81–2.05)	0.286	1.17 (0.73–1.86)	0.5
STL	520	3.19 (2.22–4.58)	< 0.001	1.46 (0.99–2.15)	0.056
STR	522	2.93 (1.89–4.56)	< 0.001	1.60 (1.02–2.52)	0. 042
Biopsy	890	2.07 (1.43–2.98)	< 0.001	1.36 (0.94–1.99)	0.100
No surgery	410	4.95 (3.41–7.18)	< 0.001	2.19 (1.46–3.28)	< 0.001
Radiotherapy					
No (Ref)	4080				
Yes	325	5.80 (4.56–7.38)	< 0.001	3.10 (2.35–4.09)	< 0.001
Unknown	24	1.73 (0.43–6.95)	0.442	1.03 (0.25–4.18)	0.971
Chemotherapy					
No (Ref)	3927				
Yes	502	2.68 (2.07–3.47)	< 0.001	2.49 (1.84–3.37)	< 0.001

Table 3. Univariate and multivariate Cox regression analysis.

methodology. The matching parameters encompassed age, sex, diagnosis period, race, tumor size, tumor location, extent of resection, and receipt of chemotherapy. The findings, detailed in Table 8, indicated that post-matching, there were no significant differences between the radiotherapy group and the non-radiotherapy group across all matching variables. Subsequent Kaplan–Meier survival analysis following PSM, illustrated in Fig. 4b, revealed that patients who underwent radiotherapy exhibited significantly poorer survival outcomes

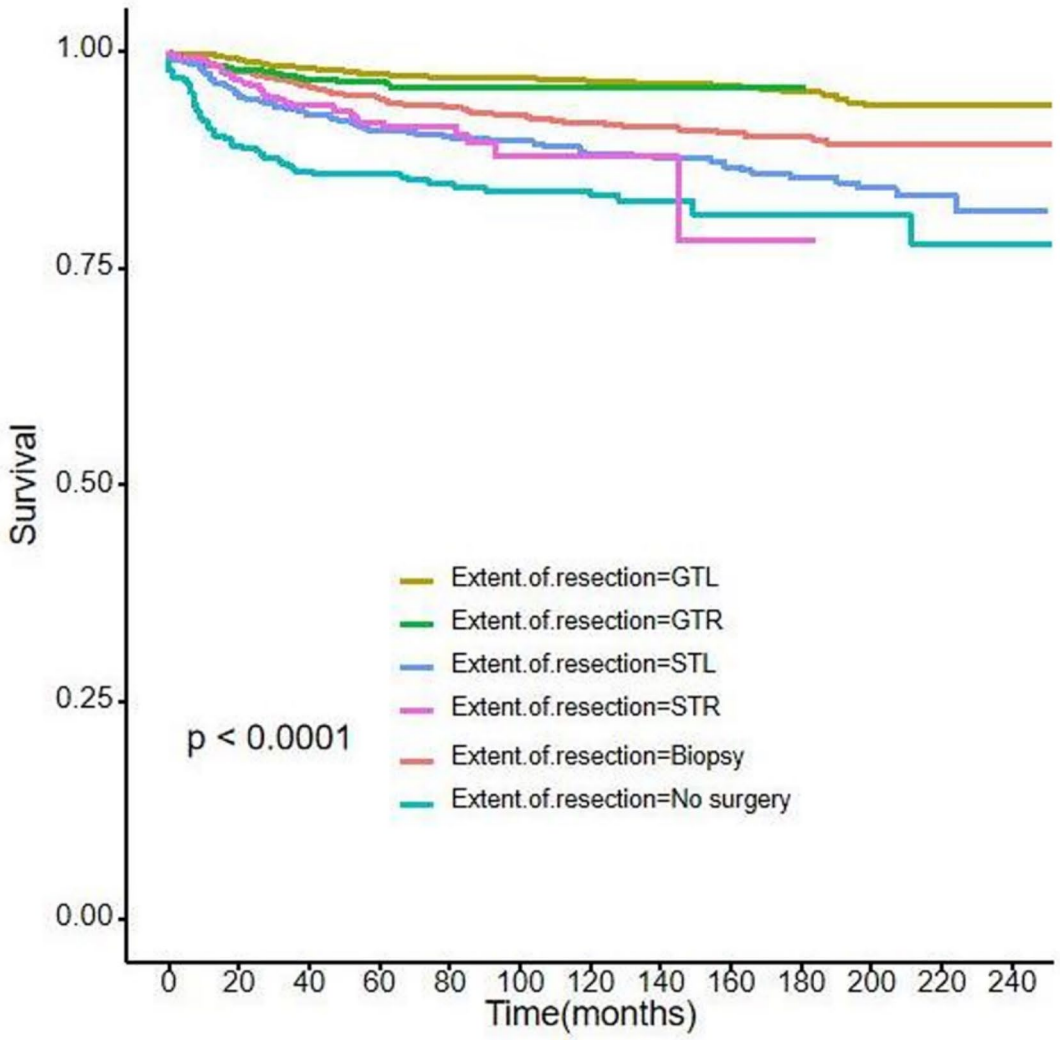

Fig. 3. Kaplan–Meier survival analysis of patients with various extent of resection.

	5-Year survival % (95% CI)	10-Year survival % (95% CI)	15-Year survival % (95% CI)
GTL	97.3 (96.4–98.3)	96.5 (95.5–97.6)	95.3 (93.9–96.7)
GTR	96.4 (95.1–97.8)	95.9 (94.3–97.4)	95.9 (94.3–97.4)
STL	90.9 (88.4–93.4)	88.3 (85.5–91.1)	85.4 (82.1–88.8)
STR	91.3 (88.4–94.4)	87.9 (83.1–92.9)	78.1 (61.6–99.1)
Biopsy	94.5 (93.0-96.1)	91.6 (89.5–93.7)	89.8 (87.3–92.4)
No surgery	85.9 (82.4–89.4)	83.4 (79.5–87.4)	81.3 (76.9–85.9)

Table 4. 5-year, 10-year, and 15-year survival rates for patients with various extent of resection.

compared to those who did not receive radiotherapy ($p < 0.0001$), thus reaffirming the trends observed prior to the application of PSM.

Discussion

Our findings indicate a significant correlation between advanced age and reduced survival, suggesting an increased risk of mortality as age progresses. This observation aligns with the research conducted by Yusuke Tomita et al., who reported consistent trends in age-adjusted incidence and mortality rates among elderly individuals, particularly those over 60 years of age diagnosed with PA[22]. Similarly, the study by Yang et al. reached comparable conclusions, utilizing competing risk analysis to demonstrate that, after adjusting for factors beyond age, the cumulative incidence of cancer-specific mortality was notably higher in the adult population[9]. As a

	GTR	STL	STR	Biopsy	No surgery
GTL	0.18	< 0.001	< 0.001	< 0.001	< 0.001
GTR		< 0.001	< 0.001	0.045	< 0.001
STL			0.97	0.012	0.021
STR				0.042	0.004
Biopsy					< 0.001

Table 5. Log-rank tests between different KM curves.

	Chemotherapy		Radiotherapy	
	Yes	No	Yes	No
Age group	$p < 0.001$		$p < 0.001$	
00–19 years	477(89.7%)	2798(71.3%)	169(52.0%)	3065(75.1%)
20–39 years	30(5.9%)	762(19.4%)	91(28.0%)	694(17.0%)
40–59 years	15(2.9%)	277(7.0%)	46(14.1%)	242(5.9%)
> 60 years	10(1.9%)	90(2.2%)	19(5.8%)	79(1.9%)
Tumor size	$p < 0.001$		$p = 0.860$	
< 20 mm	18(4.6%)	383(13.2%)	16(7.2%)	384(12.6%)
20–40 mm	155(40.0%)	1154(39.6%)	109(48.9%)	1190(38.9%)
> 40 mm	214(55.3%)	1373(47.2%)	98(43.9%)	1482(48.5%)
Surgery	$p < 0.001$		$p < 0.001$	
Yes	380(75.7%)	3639(92.7%)	258(79.4%)	3747(91.8%)
No	122(24.3%)	288(7.3%)	67(20.6%)	333(8.1%)

Table 6. Comparison of baseline characteristics between patients who received radiotherapy, chemotherapy, and those who did not.

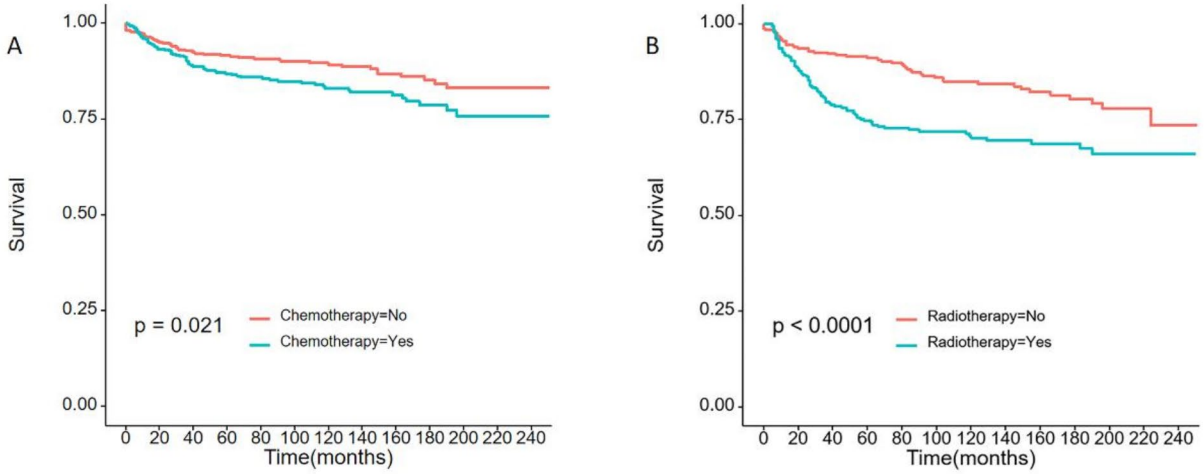

Fig. 4. Kaplan–Meier survival analysis of patients after PSM. (**a**) Kaplan–Meier survival analysis of patients after PSM who received chemotherapy compared to those who did not receive chemotherapy; (**b**) Kaplan–Meier survival analysis of patients after PSM who received radiotherapy compared to those who did not receive radiotherapy.

predominantly low-grade tumor that is most commonly observed in pediatric patients, PA typically presents with symptoms during childhood; however, a minority of cases may manifest in adulthood, often leading to a first-time diagnosis[19]. This phenomenon may help explain the lower incidence of PA in adult patients relative to pediatric cohorts. Despite its rarity in adults, PA is characterized by a relatively high recurrence rate. Case series and systematic reviews conducted by Kamila M. Bond et al. support this assertion, indicating that while PA is uncommon in adults, its occurrence is associated with a poorer prognosis, as adult patients demonstrate a higher likelihood of recurrence following subtotal resection compared to their pediatric counterparts. This finding underscores the critical importance of striving for gross total resection whenever feasible[23].

	Overall	Chemotherapy		*p* value
		No	Yes	
N	1004	502	502	
Age group (%)				
00–19 years	897 (89.3)	450 (89.6)	447 (89.0)	0.99
20–39 years	58 (5.8)	28 (5.6)	30 (6.0)	
40–59 years	29 (2.9)	14 (2.8)	15 (3.0)	
> 60 years	20 (2.0)	10 (2.0)	10 (2.0)	
Sex				
Male	501 (49.9)	246 (49.0)	255 (50.8)	0.614
Female	503 (50.1)	256 (51.0)	247 (49.2)	
Year of diagnosis				
1998–2004	269 (26.8)	139 (27.7)	130 (25.9)	0.802
2005–2011	356 (35.5)	177 (35.3)	179 (35.7)	
2012–2018	379 (37.7)	186 (37.1)	193 (38.4)	
Race				
White	816 (81.3)	413 (82.3)	403 (80.3)	0.645
Black	109 (10.9)	52 (10.4)	57 (11.4)	
American Indian/Alaska Native	2 (0.2)	0 (0.0)	2 (0.4)	
Asian or Pacific Islander	61 (6.1)	29 (5.8)	32 (6.4)	
Unknown	16 (1.6)	8 (1.6)	8 (1.6)	
Tumor size (%)				
< 20 mm	34 (3.4)	16 (3.2)	18 (3.6)	0.542
20–40 mm	322 (32.1)	167 (33.3)	155 (30.9)	
> 40 mm	407 (40.5)	193 (38.4)	214 (42.6)	
Unknown	241 (24.0)	126 (25.1)	115 (22.9)	
Tumor location				
Cerebellum	86 (8.6)	39 (7.8)	47 (9.4)	0.974
Brain stem	213 (21.2)	104 (20.7)	109 (21.7)	
Cerebrum	218 (21.7)	109 (21.7)	109 (21.7)	
Frontal lobe	42 (4.2)	22 (4.4)	20 (4.0)	
Occipital lobe	5 (0.5)	3 (0.6)	2 (0.4)	
Overlapping lesions in the brain	50 (5.0)	22 (4.4)	28 (5.6)	
Parietal lobe	6 (0.6)	3 (0.6)	3 (0.6)	
Temporal lobe	42 (4.2)	23 (4.6)	19 (3.8)	
Ventricle	118 (11.8)	60 (12.0)	58 (11.6)	
Brain, NOS	224 (22.3)	117 (23.3)	107 (21.3)	
Extent of resection				
GTL	54 (5.4)	28 (5.6)	26 (5.2)	0.509
GTR	55 (5.5)	25 (5.0)	30 (6.0)	
STL	255 (25.4)	135 (26.9)	120 (23.9)	
STR	219 (21.8)	117 (23.3)	102 (20.3)	
Biopsy	195 (19.4)	93 (18.5)	102 (20.3)	
No surgery	226 (22.5)	104 (20.7)	122 (24.3)	
Radiotherapy				
Yes	185 (18.4)	91 (18.1)	94 (18.7)	0.502
No	812 (80.9)	409 (81.5)	403 (80.3)	
Unknown	7 (0.7)	2 (0.4)	5 (1.0)	

Table 7. Baseline characteristics of patients who received chemotherapy and those who did not after PSM.

Further investigations indicate that PA in adult patients exhibits characteristics indicative of a non-benign tumor, marked by a notable propensity for recurrence[24,25]. Although data from the Surveillance, Epidemiology, and End Results (SEER) program does not incorporate details regarding recurrence, it is well-established that cancer recurrence often correlates with a poorer prognosis, thereby potentially exacerbating the unfavorable prognostic outlook noted in adult patients. Research by Jason A. Ellis et al. reinforces this perspective, shedding light on the clinical trajectory of adult patients, in which tumor recurrence and malignant transformation may

	Overall	Radiotherapy		*p* value
		No	Yes	
N	634	317	317	
Age group				
00–19 years	343 (54.1)	174 (54.9)	169 (53.3)	0.797
20–39 years	177 (27.9)	89 (28.1)	88 (27.8)	
40–59 years	87 (13.7)	43 (13.6)	44 (13.9)	
> 60 years	27 (4.3)	11 (3.5)	16 (5.0)	
Sex				
Male	324 (51.1)	164 (51.7)	160 (50.5)	0.812
Female	310 (48.9)	153 (48.3)	157 (49.5)	
Year of diagnosis				
1998–2004	242 (38.2)	125 (39.4)	117 (36.9)	0.251
2005–2011	236 (37.2)	123 (38.8)	113 (35.6)	
2012–2018	156 (24.6)	69 (21.8)	87 (27.4)	
Race				
White	526 (83.0)	266 (83.9)	260 (82.0)	0.519
Black	60 (9.5)	26 (8.2)	34 (10.7)	
American Indian/Alaska Native	4 (0.6)	1 (0.3)	3 (0.9)	
Asian or Pacific Islander	40 (6.3)	21 (6.6)	19 (6.0)	
Unknown	4 (0.6)	3 (0.9)	1 (0.3)	
Tumor size in mm				
< 20	31 (4.9)	15 (4.7)	16 (5.0)	0.833
20–40	211 (33.3)	103 (32.5)	108 (34.1)	
> 40	185 (29.2)	90 (28.4)	95 (30.0)	
Unknown	207 (32.6)	109 (34.4)	98 (30.9)	
Tumor location				
Cerebellum	104 (16.4)	49 (15.5)	55 (17.4)	0.994
Brain stem	163 (25.7)	81 (25.6)	82 (25.9)	
Cerebrum	91 (14.4)	47 (14.8)	44 (13.9)	
Frontal lobe	28 (4.4)	12 (3.8)	16 (5.0)	
Occipital lobe	14 (2.2)	7 (2.2)	7 (2.2)	
Overlapping lesions in the brain	30 (4.7)	15 (4.7)	15 (4.7)	
Parietal lobe	14 (2.2)	7 (2.2)	7 (2.2)	
Temporal lobe	23 (3.6)	13 (4.1)	10 (3.2)	
Ventricle	65 (10.3)	32 (10.1)	33 (10.4)	
Brain, NOS	102 (16.1)	54 (17.0)	48 (15.1)	
Extent of resection				
GTL	55 (8.7)	27 (8.5)	28 (8.8)	0.741
GTR	51 (8.0)	21 (6.6)	30 (9.5)	
STL	191 (30.1)	102 (32.2)	89 (28.1)	
STR	99 (15.6)	48 (15.1)	51 (16.1)	
Biopsy	111 (17.5)	54 (17.0)	57 (18.0)	
No surgery	127 (20.0)	65 (20.5)	62 (19.6)	
Chemotherapy				
Yes	162 (25.6)	75 (23.7)	87 (27.4)	0.317
No	472 (74.4)	242 (76.3)	230 (72.6)	

Table 8. Baseline characteristics of patients who received radiotherapy and those who did not after PSM.

manifest following the initial surgical intervention in a subset of individuals. Consequently, rigorous clinical surveillance and imaging follow-up are essential for adults diagnosed with PA, particularly during the first four years post-resection[26]. In contrast, studies focusing on pediatric PA patients suggest that those undergoing gross total resection may require less frequent imaging follow-up. Recommendations indicate that a regimen of six postoperative MRI scans may suffice, given that pediatric patients who achieve gross total resection generally demonstrate excellent event-free survival (EFS) and overall survival. Additionally, these patients typically exhibit slow disease progression following recurrence, often remaining asymptomatic[27]. This finding advocates for a

considered reduction in unnecessary imaging follow-up for pediatric patients, thereby alleviating financial burdens on families while optimizing the allocation and utilization of medical resources.

Based on the findings reported by Joo Whan Kim et al., achieving gross total resection of PA located in the cerebrum and cerebellum appears to be relatively attainable[28]. However, the decision-making process surrounding surgical intervention, the extent of resection, and subsequent postoperative prognosis is influenced by various critical factors. Our study outcomes reveal that tumors situated in the cerebrum exhibit the most dismal prognosis, followed by those in the ventricles and brainstem, with progressively favorable prognoses observed in overlapping brain lesions, as well as lesions in the frontal, occipital, parietal, temporal lobes, and cerebellum. Importantly, multivariate logistic regression analyses indicate that patients with tumors located in the brainstem, cerebrum, and ventricles are more likely to pursue STR, biopsy, STL, or refraining from surgery altogether, in contrast to their counterparts with cerebellum tumors. This inclination may be attributed to the increased risk of neurological deficits and potentially life-threatening complications that accompany extensive resection of brainstem tumors[29]. In particular, extensive resection within the cerebrum may precipitate functional impairments, memory deficits, and enduring language expression disorders[30], while analogous procedures targeting tumors in the ventricles are often associated with substantial intraoperative blood loss, significantly compromising postoperative quality of life[31]. As a consequence, individuals harboring tumors in these high-risk regions (brainstem, cerebrum, and ventricles) tend to favor less invasive and more conservative treatment strategies.

Standard treatment protocols for gliomas typically incorporate radiotherapy and chemotherapy due to their established efficacy in eradicating malignant cells and inhibiting tumor progression. However, it is imperative to recognize that each therapeutic intervention for PA, a generally benign neoplasm, carries inherent risks of late complications that may substantially compromise patients' quality of life[32]. Our analysis reveals that both radiotherapy and chemotherapy may adversely affect survival rates in PA patients, irrespective of whether surgical intervention is undertaken (data not shown). This observation aligns with findings reported by Matthew W. Parsons et al.[33]. The observed decline in survival among patients undergoing radiotherapy may be attributed to the severe side effects associated with radiation exposure, which include endocrine dysfunctions, hearing loss, vasculopathy[34], and the potential for radiotherapy to catalyze the malignant transformation of PA. Notably, certain studies have delineated radiotherapy as a critical contributor to the malignant transformation of PA[35], particularly within the pediatric population[36]. Similarly, the poorer prognostic outcomes in patients undergoing chemotherapy may be linked to the inherent sensitivity of PA to chemotherapeutic agents, which can precipitate the emergence of multidrug-resistant tumor cell populations[37,38].While the SEER database does not provide granular details regarding the specific chemotherapeutic and radiotherapeutic regimens employed—merely categorizing patients as having received or not received such treatments—single-center retrospective cohort studies have indicated that a significant proportion of PA patients treated with Bevacizumab demonstrate favorable clinical responses[39]. Consequently, the observed decline in prognosis among patients receiving chemotherapy may be associated with the administration of suboptimal pharmacological agents during treatment. Although our findings, in conjunction with previous research, suggest that both radiotherapy and chemotherapy may culminate in unfavorable outcomes, the underlying mechanisms remain inadequately understood and necessitate further investigation to elucidate the complex interplay between these treatment modalities and their impact on patient prognosis.

Kaplan–Meier survival analysis and Log-rank tests revealed significant differences in survival among patients with varying extent of resection. Specifically, patients undergoing GTR and GTL demonstrated markedly better survival compared to those who received biopsy, STR, or STL, with the no surgery cohort exhibiting the poorest survival rates. Notably, there was no statistically significant difference in survival between the GTL and GTR groups, nor between the STL and STR cohorts. In the realm of glioma research, the pursuit of optimal complete tumor resection is a widely adopted paradigm. However, there is a paucity of detailed investigations specifically examining the distinctions between STL and STR, which accounts for our inability to identify pertinent literature on these procedures. Consequently, our analysis predominantly focuses on a more comprehensive exploration of GTL and GTR. Prior studies have consistently demonstrated that gross total resection is superior to subtotal resection[8], corroborating our own findings. Nonetheless, these previous investigations did not directly compare survival curves between GTR and GTL, a gap that our study addresses by illustrating the absence of a significant survival difference between GTL and GTR. Both GTR and GTL are classified as supramaximal resections, designed to maximize the excision of the FLAIR signal, indicative of tumor infiltration, in order to mitigate the risk of tumor recurrence[10]. While GTL may signify a more extensive supramaximal resection, its application in glioma patients carries potential risks, including seizures, personality changes[40]. Furthermore, certain scholars contend that for tumors that are amenable to complete resection, additional lobectomy may be unnecessary. They suggest that such an intervention could potentially lead to a reduction in overall survival duration for patients[18].

Our analysis suggests that GTL does not exhibit higher early postoperative mortality rates, likely attributable to advancements in microsurgical techniques; however, it does not demonstrate improved long-term prognosis compared to GTR. While previous studies have indicated similar survival rates between GTL and GTR in the management of glioblastoma[18], there has yet to be any investigation distinguishing between GTL and GTR specifically in the treatment of PA. Existing population-based studies related to PA, such as the research conducted by Yang et al., have classified resection extents into STR, GTR/ TR, biopsy, and unknown categories[9]. In contrast, our study further refines this classification by delineating the resection extents into GTL, GTR, STL, STR, biopsy, and no surgery. To the best of our knowledge, this is the first report demonstrating that in the context of surgical treatment for PA, GTL and GTR yield essentially equivalent survival rates. Consequently, we advocate for prioritizing GTR over GTL, given its marginally superior long-term survival, reduced postoperative complications, and enhanced quality of life for patients. Therefore, we recommend that patients should prioritize

GTR whenever clinically feasible. Moreover, we observed a noticeable decline in the prevalence of lobectomy procedures alongside a corresponding increase in tumor resection practices over time. This trend suggests that complete tumor resection without the necessity of lobectomy is becoming increasingly achievable owing to advancements in medical technology. The integration of a growing array of innovative techniques in brain tumor surgery, such as preoperative imaging assessments, intraoperative ultrasound modalities, and 5-ALA imaging agents, provides neurosurgeons with diverse options to optimize the extent of gross total resection of tumors[41,42]. Furthermore, emerging research indicates that the presence of eosinophilic Rosenthal fibers (RFs) and eosinophilic granular bodies can facilitate the delineation of PA margins, thereby enhancing the potential for complete neurosurgical resection and ultimately improving patient prognosis[43].

In addition to the potential biases and inaccuracies inherent in the data, this study is subject to several notable limitations. Given that the focus is on a benign tumor characterized by generally high long-term survival rates, a significant number of patients were lost to follow-up, which may compromise the robustness of our analysis. Furthermore, the SEER database lacks specific clinical and molecular outcome data, thereby constraining our ability to conduct more intricate investigations into the molecular aspects of PA. It is important to note that optic nerve PA were excluded from this study due to the substantial differences in surgical treatment approaches between optic and intracranial PA; thus, our analysis is confined exclusively to brain PA. Additionally, a considerable portion of patients (15.5%) had tumors located in unspecified regions of the brain, and a significant subset of patients (25.6%) presented with undetermined tumor sizes. Furthermore, the availability of detailed information regarding adjuvant therapies, such as radiotherapy and chemotherapy, was limited. These factors collectively contribute to the potential influence on the analytical outcomes.

Radiosurgery represents a viable therapeutic alternative for the management of residual or recurrent volumetric disease in PA, providing long-term local tumor control[32]. While the primary approach to PA treatment remains complete surgical resection, certain tumor locations may present significant challenges that hinder total resection. In such cases, the application of radiosurgery, particularly Gamma Knife procedures, becomes a pertinent consideration. Initial studies have demonstrated the effectiveness of Gamma Knife radiosurgery for tumors that are inaccessible via conventional surgical approaches[44].Regrettably, the SEER database utilized in this study does not provide a distinct categorization for radiosurgery; rather, it encompasses this treatment modality under the broader umbrella of radiation therapy. This limitation significantly restricts our capacity to perform a comprehensive analysis of the specific impact of radiosurgery on treatment outcomes for patients with PA.

Conclusion

In conclusion, there was no significant difference in PA patients' survival between GTR and GTL, so GTR with less damage was preferred. The application of radiotherapy and chemotherapy can reduce overall survival of patients with PA.

Gliomas can be classified into infiltrative and non-infiltrative types based on their growth patterns. Infiltrative gliomas exhibit a growth pattern akin to the distribution of tree roots within soil, making it exceedingly challenging to delineate tumor boundaries during surgical intervention. Common imaging modalities used to define tumor margins often underestimate the extent of tumor infiltration, which can consequently lead to recurrence after surgery. Therefore, it is recommended that such tumors be subjected to supra total/supramaximal resection. In contrast, the focus of this study is on PA, a non-infiltrative tumor characterized by well-defined edges. Given this clarity in delineation, gross total resection based on imaging-defined boundaries theoretically enables the achievement of gross total resection of tumor. This may elucidate why, in our study centered on PA, there were no statistically significant differences in survival between the GTR and GTL. Furthermore, GTR likely minimizes damage to the surrounding normal brain tissue, a factor contribute to the slightly superior long-term survival observed in patients undergoing GTR compared to those undergoing GTL.

Data availability

The datasets generated or analyzed during this study are available from the corresponding author on reasonable request. SEER database data can be directly accessed and obtained from seer.cancer.gov.

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Author contributions

JS, SG, ZC and PY was responsible for conception, design, quality control of this study, reviewed, and edited the manuscript. YH, JY, QT, YM, HZ and GH performed the study selection, data extraction, statistical analyses, and were major contributors in writing the manuscript and contributed in classification criteria discussion. CG, GD and PY participated in studies selection and statistical analyses. All authors have read and approved the final version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

Data for this study were obtained from the Surveillance, Epidemiology, and End Results (SEER) public user database. As a public database, SEER database can be accessed by anyone. The patient information utilized in this study contains de-identifiable information. Therefore, this study has received approval exemption from the ethics committee of Xinxiang Medical University.

Additional information

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