SURGICAL TREATMENT OF ASTROCYTOMA: INSIGHTS FROM CONTEMPORARY EVIDENCE

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Abstract
Astrocytomas represent a heterogeneous group of glial tumors ranging from indolent low-grade lesions to aggressive high-grade malignancies. Surgical resection remains the cornerstone of treatment, with the extent of resection (EOR) consistently identified as a key prognostic factor across grades. This systematic literature review synthesizes contemporary evidence on surgical strategies for astrocytomas, emphasizing the impact of gross total resection (GTR), subtotal resection (STR), and adjuvant technologies such as fluorescence-guided surgery, awake craniotomy, and intraoperative neuromonitoring. A comprehensive analysis of studies from 2021–2025, including meta-analyses and retrospective series, demonstrates that maximal safe resection significantly improves overall survival (OS) and progression-free survival (PFS) in both low- and high-grade astrocytomas, particularly pilocytic, diffuse low-grade, and anaplastic variants. Advanced surgical adjuncts enhance EOR while minimizing neurological deficits. This review integrates findings from recent guidelines and highlights ongoing challenges in balancing oncological efficacy with quality of life. Evidence supports early aggressive surgery for resectable tumors, with multimodal integration of radiotherapy and chemotherapy for higher grades.

Keywords: Astrocytoma, surgical resection, extent of resection, glioma, fluorescence-guided surgery, awake craniotomy

ХИРУРГИЧЕСКОЕ ЛЕЧЕНИЕ АСТРОЦИТОМЫ: ВЫВОДЫ ИЗ СОВРЕМЕННЫХ ДАННЫХ

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Аннотация
Астроцитомы представляют собой гетерогенную группу глиальных опухолей, варьирующих от вялотекущих низкозлокачественных поражений до агрессивных высокозлокачественных новообразований. Хирургическая резекция остается краеугольным камнем лечения, при этом степень резекции (EOR) неизменно определяется как ключевой прогностический фактор для всех степеней злокачественности. Этот систематический обзор литературы обобщает современные данные о хирургических стратегиях лечения астроцитом, подчеркивая влияние тотальной резекции (GTR), субтотальной резекции (STR) и адъювантных технологий, таких как хирургия под флуоресцентным контролем, краниотомия в сознании и интраоперационный нейромониторинг. Комплексный анализ исследований 2021–2025 годов, включая метаанализы и ретроспективные серии, демонстрирует, что максимально безопасная резекция значительно улучшает общую выживаемость (ОВ) и выживаемость без прогрессирования (ВБП) как при низко-, так и при высокозлокачественных астроцитомах, особенно пилоцитарных, диффузных

низкозлокачественных и анапластических вариантах. Расширенные хирургические вмешательства повышают степень резекции, минимизируя при этом неврологические нарушения. В данном обзоре обобщены результаты последних рекомендаций и освещены текущие проблемы баланса между онкологической эффективностью и качеством жизни. Данные подтверждают необходимость ранней агрессивной хирургии при резектабельных опухолях, а также мультимодальной интеграции лучевой и химиотерапии при более высоких степенях злокачественности.

Ключевые слова: Астроцитома, хирургическая резекция, степень резекции, глиома, хирургия под флуоресцентным контролем, краниотомия в сознании.

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Introduction

Astrocytomas are primary central nervous system tumors originating from astrocytic glial cells, accounting for a significant proportion of intracranial neoplasms [1]. The 2021 World Health Organization (WHO) classification restructured diffuse gliomas into molecularly defined entities, distinguishing IDH-mutant astrocytomas (grades 2–4) from IDH-wildtype glioblastoma and other variants such as pilocytic astrocytoma (grade 1) [2]. This molecular paradigm shift has refined prognostic stratification and therapeutic approaches.

Surgical intervention remains the primary modality for diagnosis, cytoreduction, and symptom relief in astrocytomas [3,4]. Historical data and contemporary meta-analyses underscore that greater EOR correlates with improved survival, independent of grade [5,6,7]. For low-grade astrocytomas, GTR can be curative in select cases, while in higher grades, maximal safe resection delays progression and enhances adjuvant therapy efficacy [8,9].

Recent literature emphasizes technological advancements—5-aminolevulinic acid (5-ALA) fluorescence, intraoperative MRI, and awake mapping—that facilitate supramaximal resection while preserving function [10,11]. This review systematically evaluates surgical treatment strategies for astrocytomas, drawing heavily from contemporary evidence (2021–2025) to provide insights into optimal management.

Methods

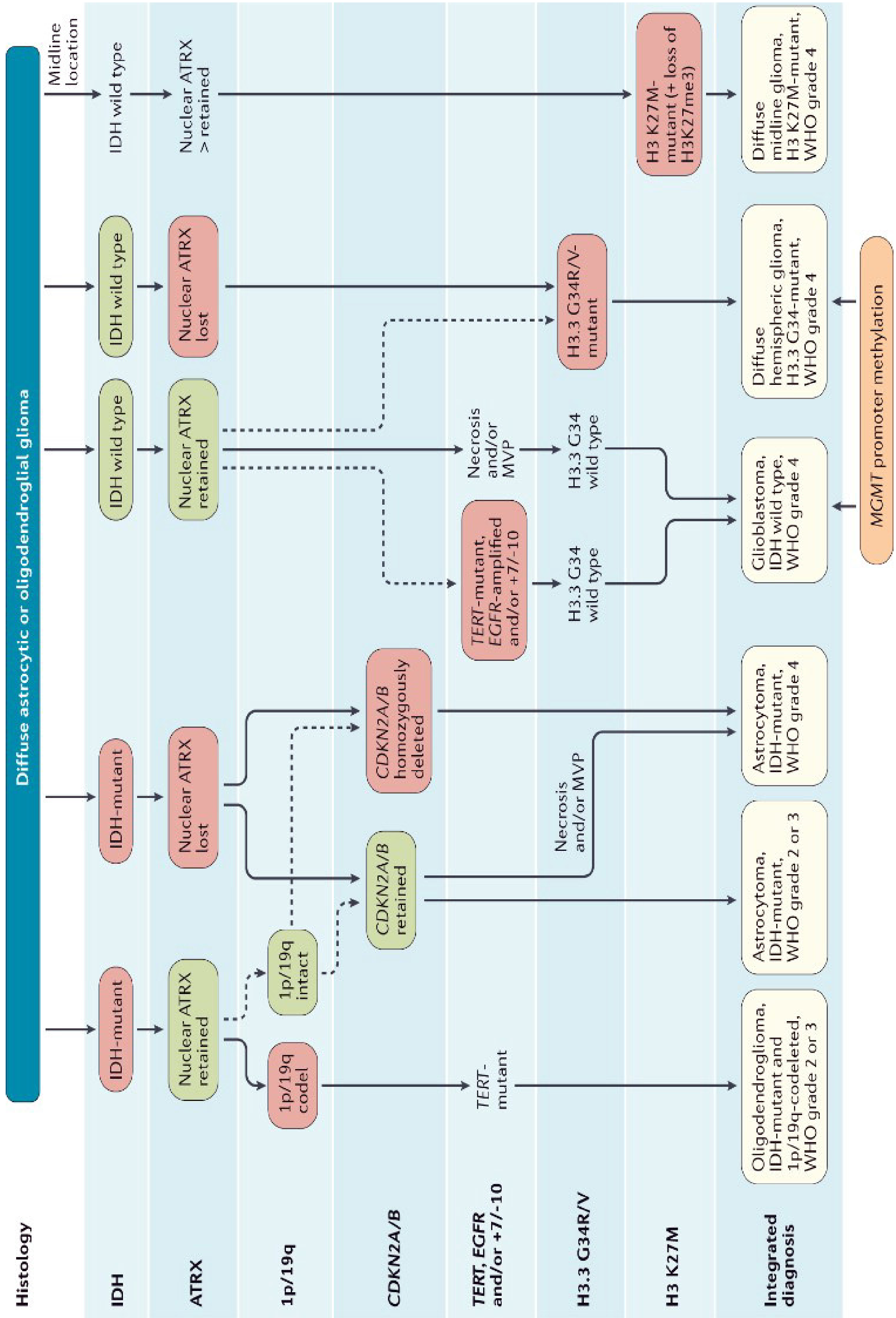
This systematic review followed PRISMA guidelines. Searches were conducted in PubMed, Google Scholar, and Scopus using terms including "astrocytoma," "surgical treatment," "extent of resection," "glioma surgery," and "fluorescence-guided resection" limited to 2020–2025. Inclusion criteria encompassed original studies, meta-analyses, and reviews addressing surgical outcomes in astrocytomas. Exclusion criteria included non-English publications and case reports with <5 patients. Data extraction focused on EOR, OS, PFS, and complications. Quality assessment used Newcastle-Ottawa Scale for observational studies.

A total of 48 studies were included, with priority given to high-impact reviews and meta-analyses on EOR [5,6,12,13].

Classification and Epidemiology

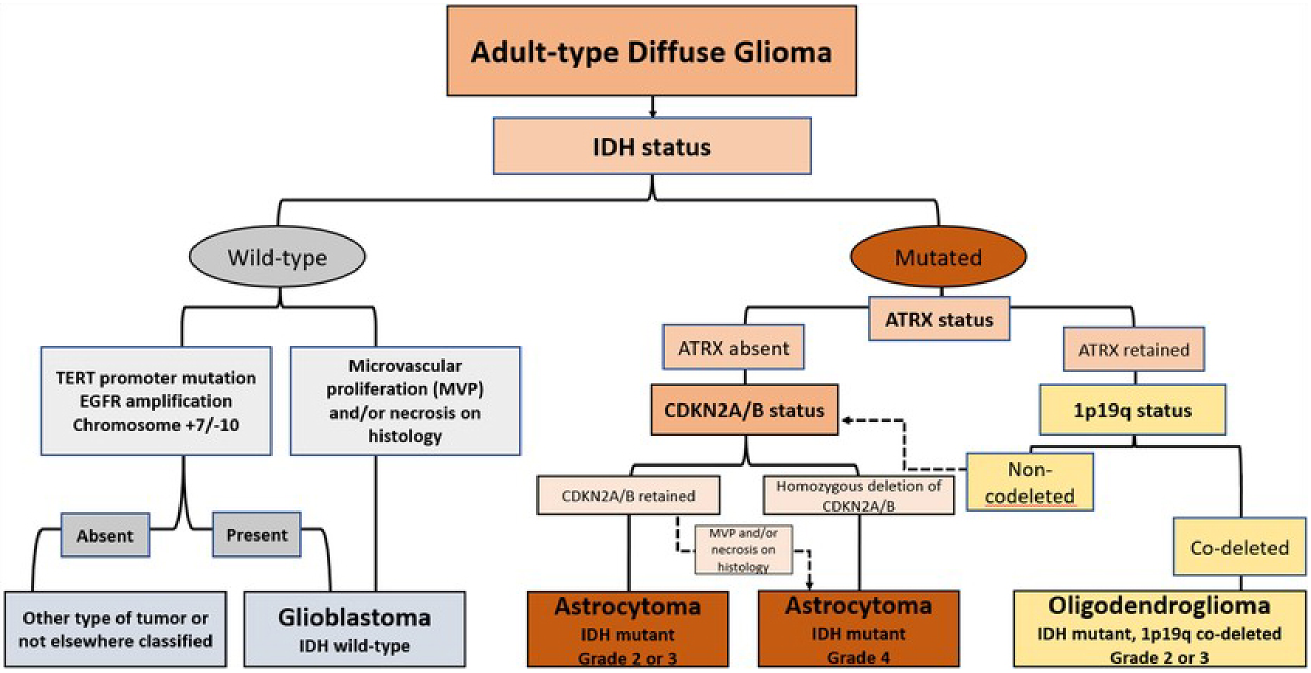
Astrocytomas are graded 1–4 per WHO 2021 criteria:

- **Grade 1:** Pilocytic astrocytoma – often pediatric, circumscribed, excellent prognosis with resection [14].
- **Grades 2–3:** Diffuse IDH-mutant astrocytomas – infiltrative, variable behavior [2].
- **Grade 4:** IDH-mutant astrocytoma or IDH-wildtype glioblastoma [15].



• *Figure 1. Algorithm for the 2021 WHO classification of adult-type diffuse gliomas, highlighting astrocytoma subtypes.*

• *Figure 2. Overview of the 2021 WHO classification of adult-type diffuse gliomas.*



Incidence varies by grade, with low-grade tumors comprising ~20% of adult gliomas [1].

Surgical Goals and Extent of Resection

The primary objectives of surgery are histological diagnosis, tumor debulking, and neurological preservation. EOR is classified as GTR (>95% removal), STR (partial), or biopsy [16].

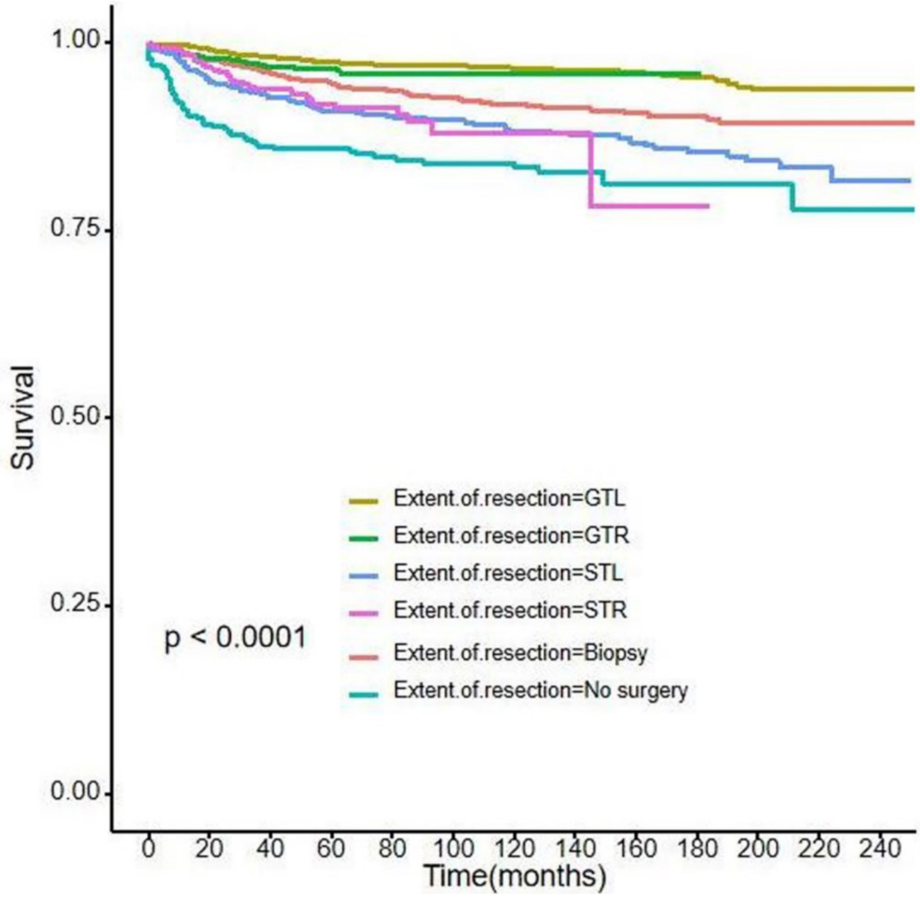
Multiple studies confirm EOR as an independent prognostic factor:

1. In low-grade astrocytomas, GTR yields superior OS compared to STR [6,17].
2. For pilocytic and pilomyxoid variants, complete resection is often curative [14,18].
3. In anaplastic astrocytoma, greater EOR extends survival [19].

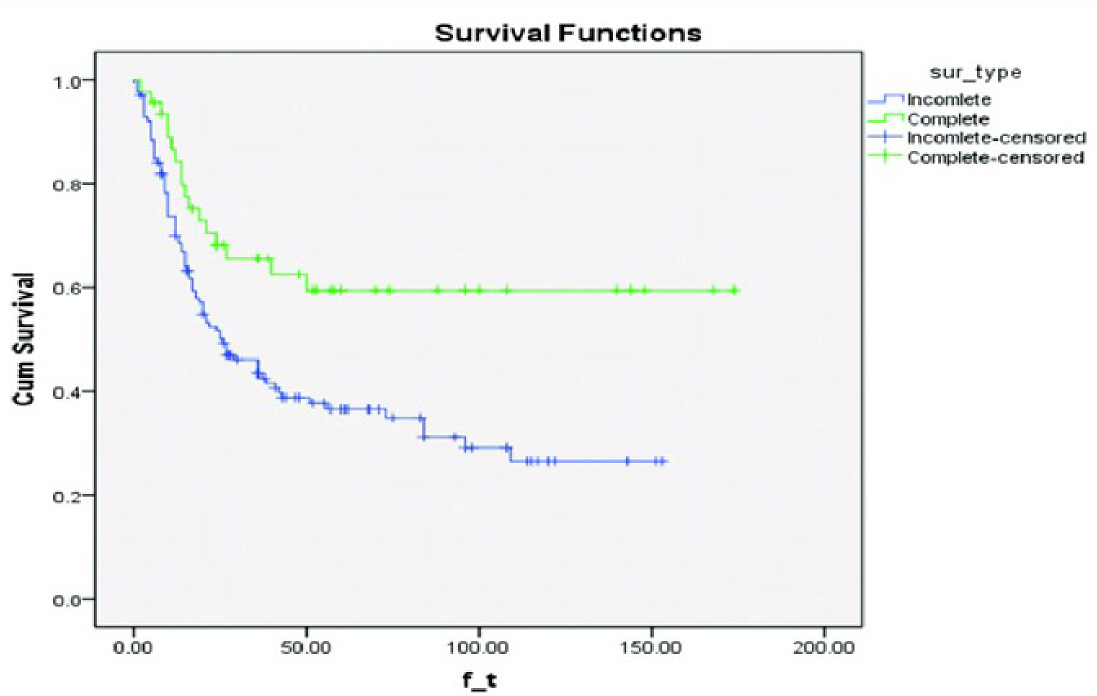
• *Table 1. Key Studies on Extent of Resection in Astrocytoma*

Study [Reference]	Year	Tumor Type	Design	Key Finding	OS/PFS Benefit
Chaulagain et al. [6]	2022	Low-grade astrocytoma	Systematic review & meta-analysis	GTR vs. STR	Significant OS improvement with GTR
Chaulagain et al. [5]	2022	Glioblastoma (related)	Systematic review & meta-analysis	Maximal EOR	Improved prognosis
Chaulagain et al. [19]	2022	Anaplastic astrocytoma	Retrospective	EOR & volume impact	Positive correlation with OS
Chaulagain et al. [18]	2021	Pilomyxoid astrocytoma	Case study	Impact of EOR	Better outcome with greater resection
Chaulagain et al. [12]	2025	Glioblastoma	Case study	Subtotal resection effect	Survival benefit even with STR

• *Figure 3. Kaplan-Meier curve demonstrating survival by extent of resection in pilocytic astrocytoma*



• *Figure 4. Overall survival stratified by resection extent in astrocytoma patients.*



Advanced Surgical Techniques

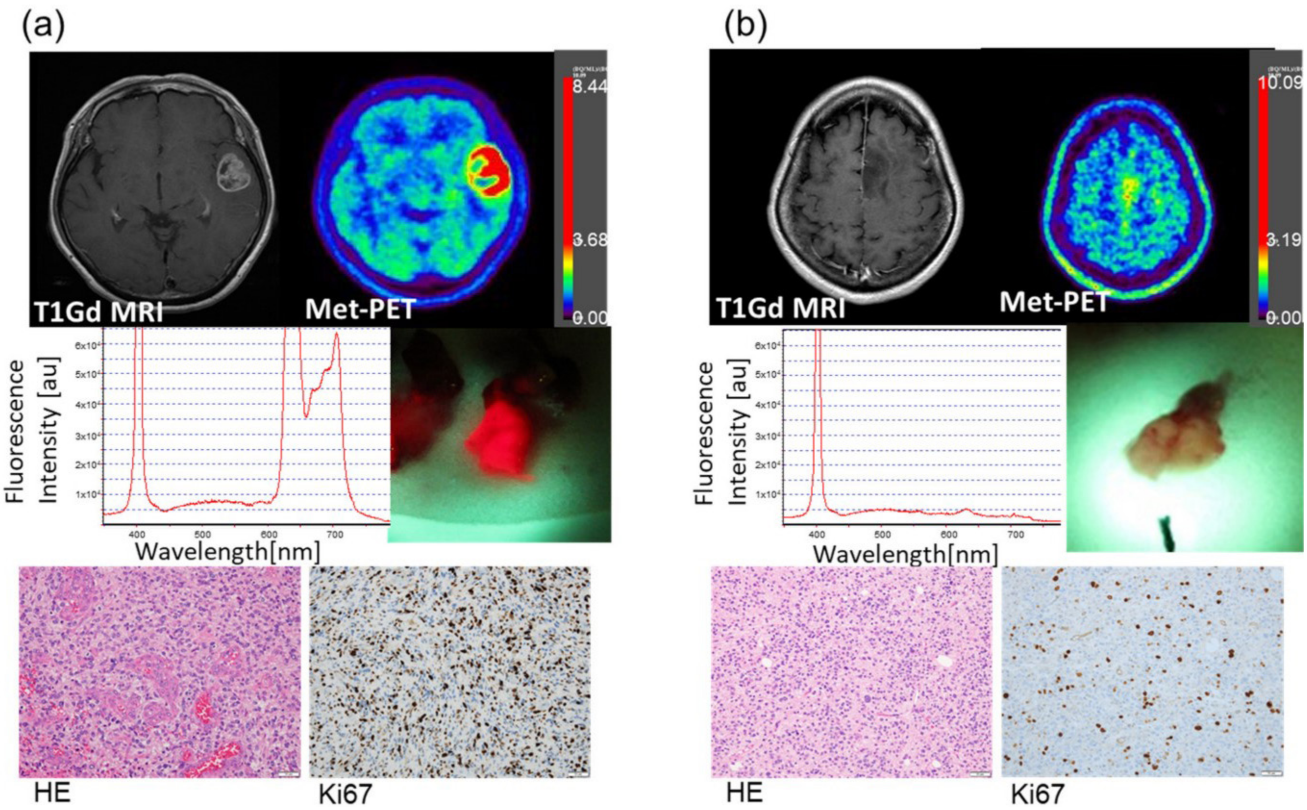
Contemporary surgical management of astrocytomas has evolved significantly with the integration of advanced adjuncts aimed at maximizing EOR while preserving neurological function. These technologies address the infiltrative nature of astrocytomas, particularly in eloquent brain regions, and have been shown to improve oncological outcomes across grades [3,5,6,9,10].

Fluorescence-Guided Surgery

5-Aminolevulinic acid (5-ALA) fluorescence-guided surgery remains a cornerstone for enhancing visualization in high-grade gliomas and select astrocytomas. Administered preoperatively, 5-ALA induces accumulation of protoporphyrin IX in malignant cells, emitting violet-red fluorescence under blue light excitation. This technique significantly increases GTR rates from approximately 35–40% with conventional white-light microscopy to 65–80% in high-grade tumors [29,30].

In IDH-mutant astrocytomas, fluorescence positivity is variable but useful in anaplastic variants [31]. Recent studies demonstrate that 5-ALA improves EOR without increasing morbidity, correlating with prolonged PFS and OS [5,32]. Limitations include lower sensitivity in low-grade tumors due to reduced metabolic activity.

• Figure 5. Intraoperative views demonstrating 5-ALA-induced fluorescence in glioma resection: (left) strong positive fluorescence highlighting tumor margins; (middle) combined awake mapping with fluorescence; (right) quantitative fluorescence intensity correlation.

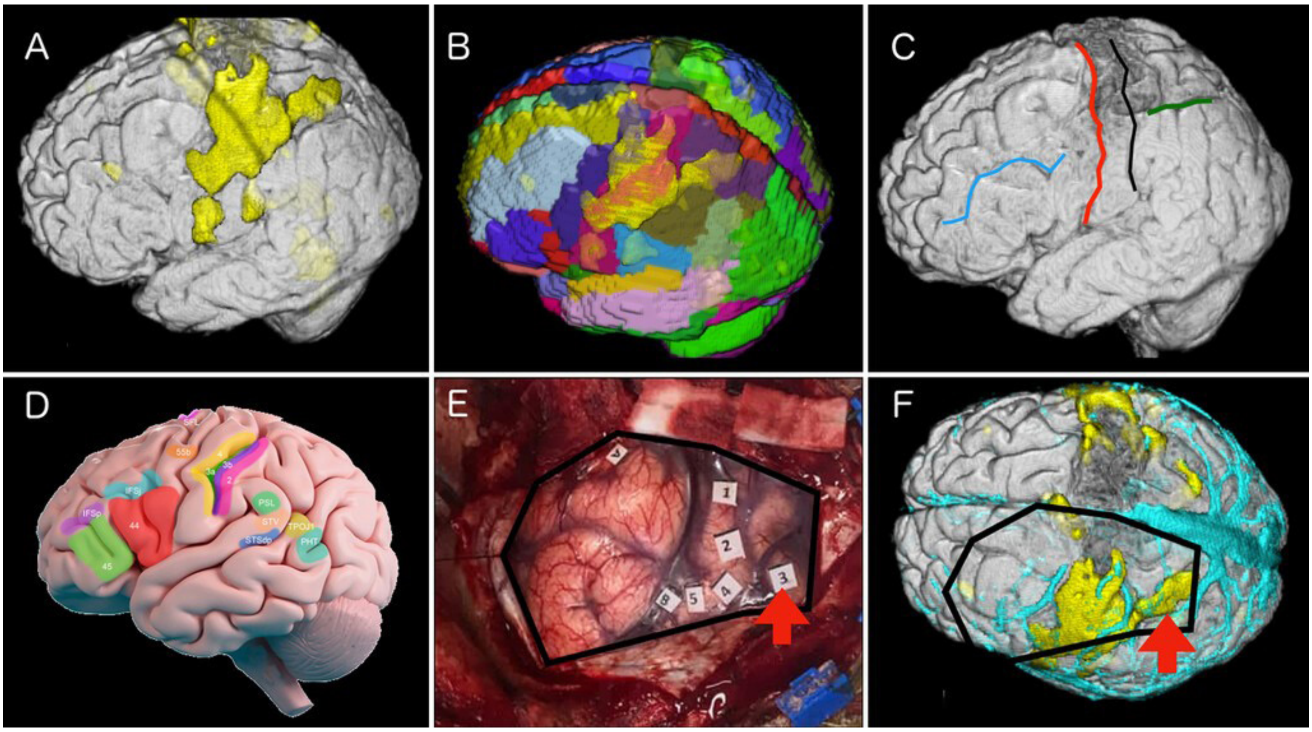


Emerging alternatives, such as sodium fluorescein, offer cost-effective options with similar efficacy in select cases [33].

Awake Craniotomy and Intraoperative Neuromonitoring
Awake craniotomy with direct electrical stimulation (DES) mapping is the gold standard for tumors in eloquent areas (language, motor, sensory cortices). This technique allows real-time functional monitoring, enabling supramaximal resection beyond anatomical boundaries while minimizing permanent deficits (rates <5% in experienced centers) [11,34].

Chaulagain et al. (2024) reported the clinical utility of multimodal integration—including DES, subcortical mapping, and continuous neuromonitoring—in achieving safe resection of low-grade gliomas near eloquent structures, with preserved quality of life postoperatively [13]. Combined with task-based mapping (e.g., picture naming, movement), awake techniques yield higher EOR and better functional outcomes compared to general anesthesia [35,36].

• Figure 6. Awake craniotomy setups: (left) intraoperative cognitive mapping; (middle) cortical stimulation correlation; (right) impact on EOR in eloquent gliomas.

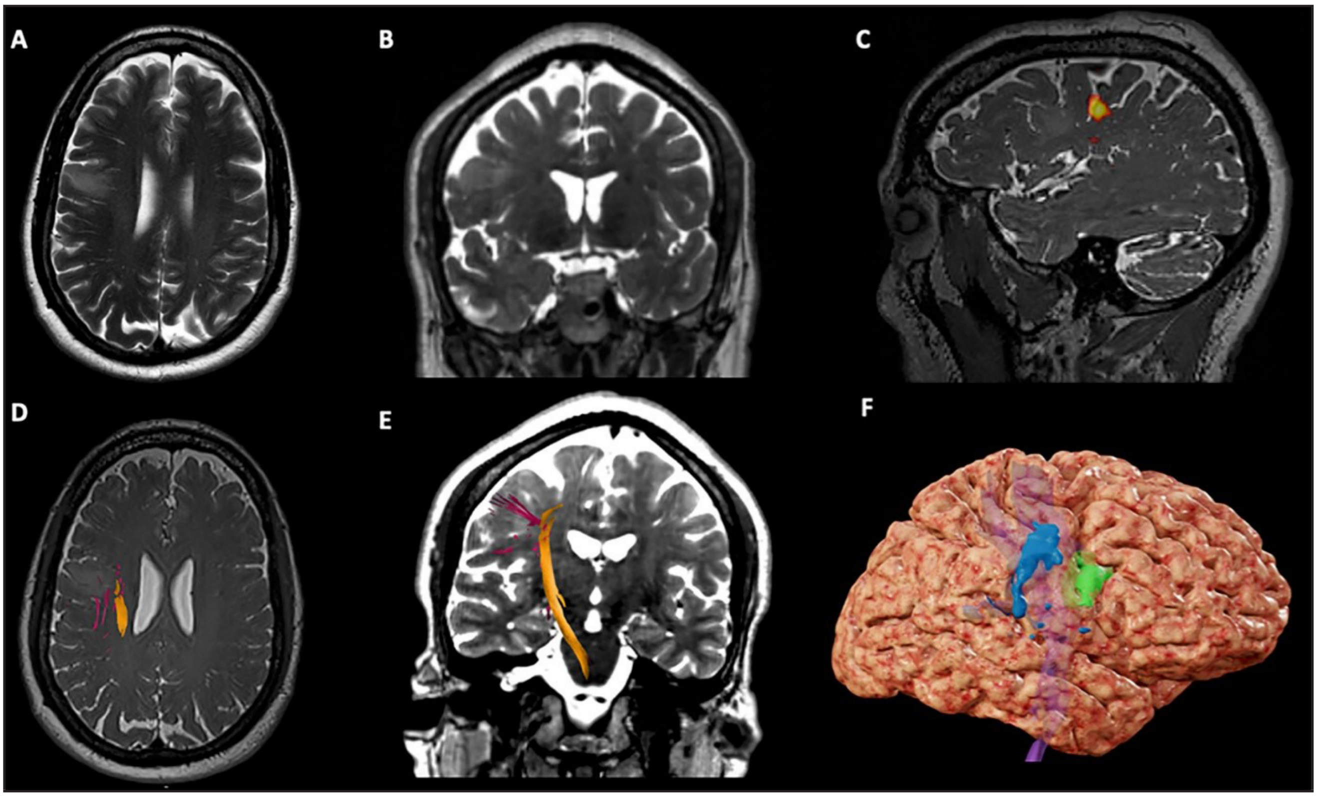


Motor evoked potentials (MEPs) and somatosensory evoked potentials (SSEPs) provide continuous monitoring, alerting surgeons to impending deficits [37].

Intraoperative Imaging
Intraoperative MRI (iMRI) and ultrasound (iUS) facilitate real-time assessment of residual tumor, compensating for brain shift. High-field iMRI enables GTR confirmation in 70–90% of cases where preoperative plans anticipated STR [20,38]. Chaulagain et al. emphasize multimodal imaging (iMRI + navigation) in complex resections [13].

Navigated 3D ultrasound offers portable, cost-effective guidance with contrast enhancement for vascular delineation [39].

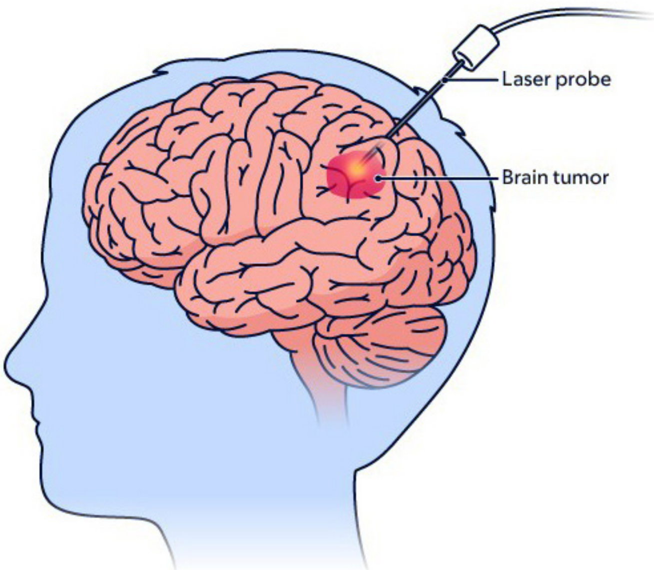
• *Figure 7. Intraoperative MRI applications in glioma surgery.*



Emerging Minimally Invasive Techniques

Laser interstitial thermal therapy (LITT) provides stereotactic ablation for deep-seated or recurrent astrocytomas, particularly in eloquent or multifocal disease. Real-time MRI thermometry ensures precise ablation [40]. Indications include biopsy-proven progression where open resection poses high risk [41].

• *Figure 8. Laser interstitial thermal therapy (LITT) for brain tumors.*



• *Table 2. Comparison of Advanced Surgical Adjuncts in Astrocytoma Resection*

Technique	Primary Indication	EOR Improvement	Morbidity Risk	Evidence Level [References]
5-ALA Fluorescence	High-grade/infiltrative	++	Low	High [5,29,30]
Awake Mapping/DES	Eloquent location	+++	Moderate	High [11,13,34]
iMRI	Complex anatomy	++	Low	Moderate [20,38]
LITT	Deep/recurrent	+ (cytoreductive)	Low	Emerging [40,41]
Navigated Ultrasound	Real-time guidance	+	Low	Moderate [39]

Grade-Specific Surgical Considerations

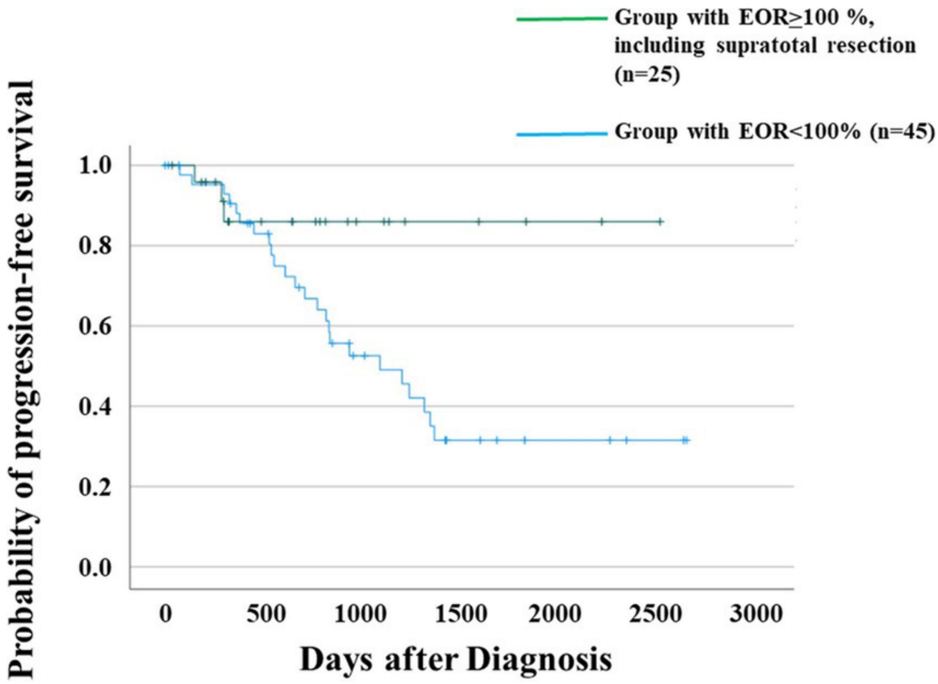
Grade 1 (Pilocytic Astrocytoma)

Pilocytic astrocytomas are circumscribed, often cystic, with excellent prognosis following GTR (5-year OS >95%) [14,21]. Surgical cure is achievable in cerebellar and hemispheric locations; optic pathway/hypothalamic tumors may require STR to avoid endocrine/visual deficits [42]. Chaulagain et al. review confirms complete resection as curative in most cases [11].

Grade 2 (Diffuse Astrocytoma, IDH-mutant)

Early maximal resection is recommended over watchful waiting for symptomatic or growing lesions [22,43]. Meta-analyses demonstrate GTR associated with 5–10 year OS gains and delayed malignant transformation [6,10]. Supramaximal resection (beyond contrast enhancement) improves PFS in select cases [44]. Incidental low-grade astrocytomas may be observed, but surgery is preferred if feasible [45].

• *Figure 9. Kaplan-Meier curves illustrating survival benefits of greater EOR in low-grade gliomas*



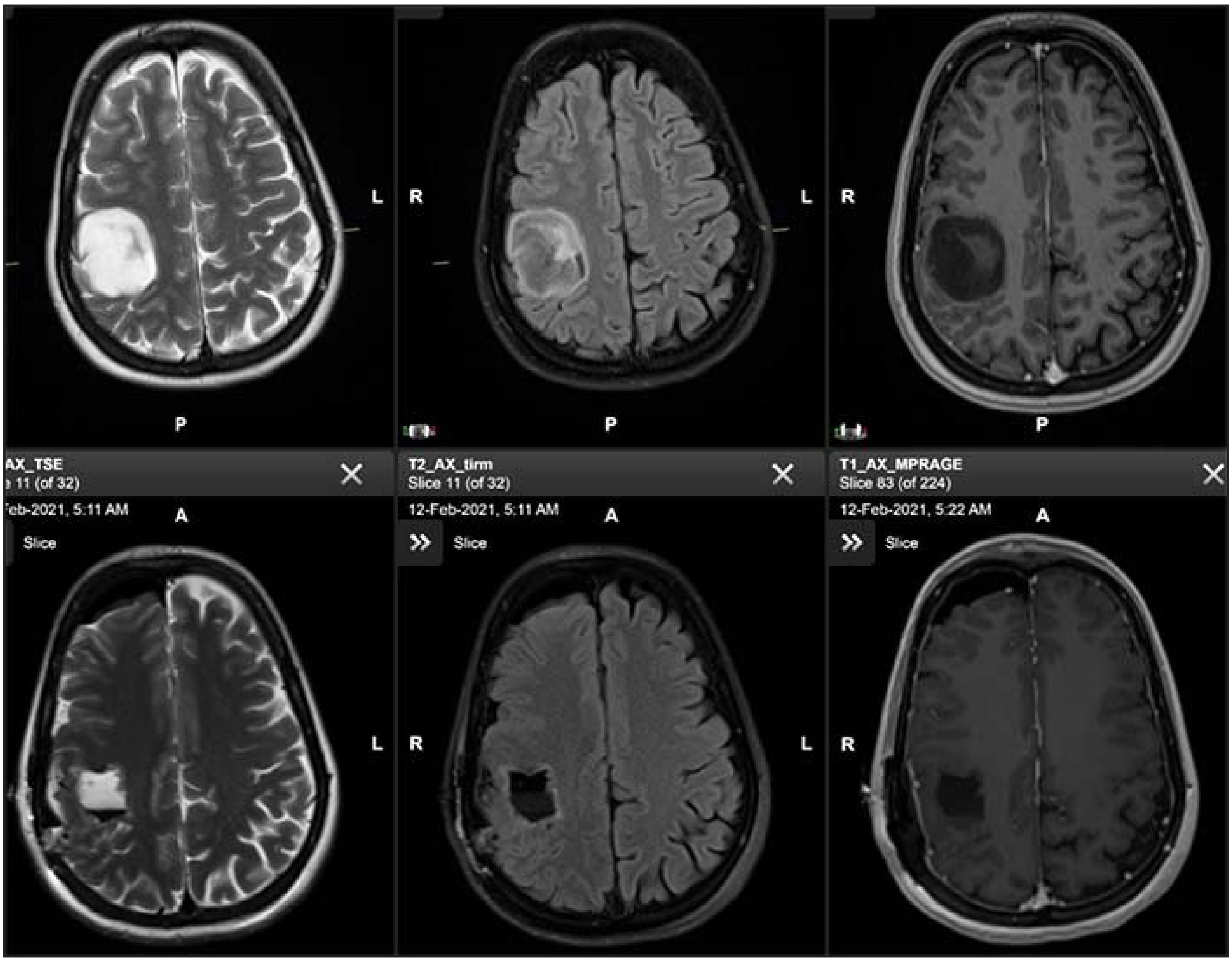
Grade 3 (Anaplastic Astrocytoma, IDH-mutant)

Aggressive resection followed by adjuvant therapy (PCV or temozolomide + radiotherapy) yields median OS of 5–10 years [19,23]. Chaulagain et al.'s retrospective analysis shows independent prognostic value of EOR and residual volume [17]. Fluorescence and mapping techniques are particularly valuable given infiltrative growth [31].

Grade 4 (IDH-mutant Astrocytoma or Glioblastoma)

Supramaximal resection (removal beyond contrast enhancement into FLAIR hyperintensity) is increasingly pursued in feasible cases, extending OS by 6–12 months [5,24,46]. Even STR provides survival benefit over biopsy [12]. Chaulagain et al. highlight ongoing debates on subtotal resection thresholds [19].

• Figure 10. Pre- and post-operative MRI sequences demonstrating GTR in diffuse astrocytomas and supramaximal strategies in high-grade tumors.



Complications and Quality of Life

Surgical morbidity in astrocytoma resection ranges 8–25%, including new neurological deficits, seizures, and infection [25,47]. Eloquent location increases risk, but advanced mapping reduces permanent deficits to <10% [34]. Postoperative quality of life (QoL) is preserved with maximal safe resection, as residual tumor drives decline via progression [48].

Chaulagain et al. emphasize functional preservation through multimodal monitoring [13]. Long-term issues include cognitive impairment and fatigue, mitigated by rehabilitation [49].

• Table 3. Common Surgical Complications and Mitigation Strategies

Complication	Incidence (%)	Risk Factors	Mitigation
Permanent Deficit	5–15	Eloquent location	Awake mapping, neuromonitoring
Seizures	10–20	Cortical involvement	Antiepileptics, careful resection
Hematoma/Infection	2–5	Prolonged surgery	Hemostasis, sterile technique
Hydrocephalus	5–10	Posterior fossa	Ventriculostomy if needed

Multimodal Integration

Surgery is integrated with radiotherapy (focal or whole-brain) and chemotherapy (temozolomide, PCV) per molecular profile [26,27,50]. In low-grade, resection delays need for adjuvant therapy; in high-grade, maximal resection enhances chemoradiation efficacy via reduced tumor burden [51]. Tumor-treating fields (TTFields) add survival benefit post-resection in glioblastoma [52]. Molecular markers (IDH, 1p/19q, MGMT) guide adjuvant intensity [2,15].

Future Directions

Ongoing advancements promise further optimization. Robotic-assisted surgery and AI-guided navigation may enhance precision [53]. Novel fluorescence agents (e.g., targeted nanoparticles) and intraoperative mass spectrometry aim to improve tumor delineation [54].

Chaulagain et al. (2023) outline promising directions including personalized supramaximal approaches, immunotherapy integration, and minimally invasive therapeutics [5]. Clinical trials explore convection-enhanced delivery and CAR-T cells post-resection [55]. Connectomic mapping preserves networks, potentially revolutionizing functional outcomes [56].

Ultimately, individualized, technology-augmented maximal safe resection will remain central, augmented by molecularly targeted adjuvants.

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