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# BRAIN TUMOR: CLASSIFICATION, PATHOPHYSIOLOGY, AND THERAPEUTIC APPROACHES

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## 1. ABSTRACT

Brain tumors represent a significant public health challenge and are classified as either primary (originating in the brain) or secondary (metastatic) malignancies. This comprehensive review examines the epidemiology, classification, clinical manifestations, diagnostic modalities, and contemporary therapeutic strategies for brain tumors. Emphasis is placed on the pathophysiology of glial, neuronal, and metastatic tumors, as well as the multifactorial genetic and environmental factors contributing to tumorigenesis. The review highlights emerging treatment approaches including targeted molecular therapy, immunotherapy, and precision medicine that offer improved outcomes for patients with both benign and malignant brain tumors. Additionally, it addresses the challenges in diagnosis, the role of molecular biomarkers, and the psychosocial implications of brain tumor management. A multidisciplinary approach integrating neurosurgery, neuro-oncology, radiation oncology, and supportive care is essential for optimizing patient outcomes and quality of life. Recent advances in neuroimaging, molecular profiling, and personalized treatment strategies are reshaping the landscape of brain tumor management and offering hope for improved prognosis and reduced mortality.

**2. KEYWORDS:** Brain tumor, glioblastoma, meningioma, astrocytoma, oligodendroglioma, brain cancer, CNS lymphoma, medulloblastoma, neurofibromatosis, tumor classification, WHO grading, neuroimaging, MRI, CT scan, radiation therapy, chemotherapy, targeted therapy, immunotherapy, molecular biomarkers, IDH mutation, MGMT methylation, tumor microenvironment, blood-brain barrier, temozolomide, precision medicine, neuro-oncology, seizure management, increased intracranial pressure.

## 3. INTRODUCTION

Brain tumors are abnormal growths of cells within the brain that can originate from brain tissue (primary tumors) or spread from cancers in other parts of the body (secondary or metastatic tumors). The World Health Organization (WHO) classifies brain tumors based on histological characteristics, genetic alterations, and molecular profile, with malignancy grades ranging from benign (Grade I) to highly aggressive (Grade IV). Primary brain tumors account for approximately 1.4% of all human cancers but represent a disproportionate disease burden due to their high morbidity and mortality rates. Unlike most organ systems, the brain is protected by the blood-brain barrier (BBB), a specialized endothelial layer that restricts drug penetration and poses significant therapeutic challenges for pharmacological interventions.

The incidence of primary brain tumors varies globally, with approximately 250,000 to 400,000 new cases diagnosed annually worldwide. Gliomas, which arise from glial cells, represent the most common primary brain tumors, accounting for approximately 50% of all intracranial neoplasms. Glioblastoma (Grade IV astrocytoma) is the most aggressive and common malignant brain tumor, with median overall survival rates historically ranging from 12 to 15 months despite multimodal therapy. Secondary brain tumors, or brain metastases, are far more common than primary tumors, particularly in patients with history of lung, breast, melanoma, or colorectal cancers. The complex heterogeneity of brain tumors, both histologically and molecularly, necessitates an individualized and multidisciplinary approach to diagnosis, treatment planning, and management.

Brain tumors present unique clinical challenges due to their location within the central nervous system (CNS), their propensity for infiltration into vital neural structures, and the vulnerability of patients to severe neurological complications. Patients may experience seizures, cognitive dysfunction, motor weakness, visual disturbances, and endocrine abnormalities. The psychological and social impact of brain tumor diagnosis extends beyond the patient to family members and caregivers, who must navigate complex treatment decisions and manage potential long-term neurological sequelae. Recent advances in

molecular profiling, neuroimaging technology, and therapeutic strategies have begun to improve outcomes, particularly through the identification of prognostically significant mutations and the development of targeted and immunological therapies.

## 4. Epidemiology and Risk Factors

### 4.1 Incidence and Prevalence

The incidence of primary brain tumors is estimated at 5-10 per 100,000 population annually in developed countries, with variations based on age, geographic location, and socioeconomic factors. Age distribution shows a bimodal pattern, with peaks in childhood (particularly ages 5-9 years) and in older adults (ages 65-74 years). Malignant brain tumors have a slightly higher incidence in males, with a male-to-female ratio of approximately 1.3:1, though some benign tumors such as meningiomas show a female predominance.

### 4.2 Genetic Risk Factors

Several hereditary syndromes significantly increase the risk of brain tumor development. Neurofibromatosis type 1 (NF1) and type 2 (NF2) are autosomal dominant disorders caused by mutations in tumor suppressor genes, with NF2 patients having a particularly high risk for bilateral vestibular schwannomas and meningiomas. Li-Fraumeni syndrome, associated with TP53 mutations, predisposes individuals to multiple malignancies including brain tumors. Hereditary nonpolyposis colorectal cancer (HNPCC) and Cowden syndrome also carry elevated risks. Familial adenomatous polyposis (FAP) patients have an increased incidence of medulloblastomas and supratentorial primitive neuroectodermal tumors (PNETs).

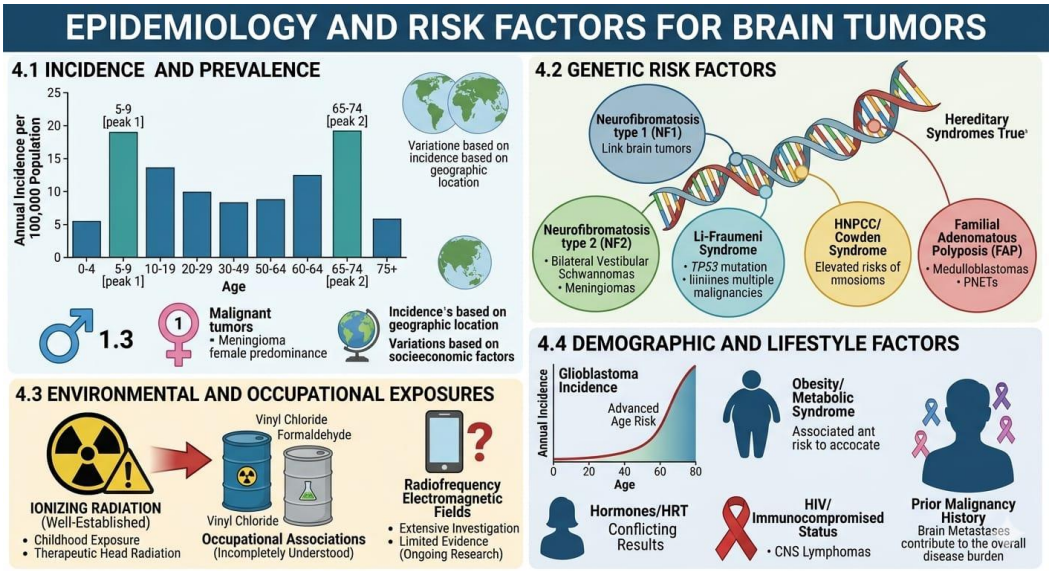
### 4.3 Environmental and Occupational Exposures

Ionizing radiation is the only well-established environmental risk factor for brain tumor development. This risk is particularly pronounced in individuals exposed during childhood, including those receiving therapeutic head radiation for prior malignancies or benign conditions. Occupational exposures to certain chemicals, such as vinyl chloride and formaldehyde, have been epidemiologically associated with increased brain tumor risk, though the causal relationships remain incompletely understood. Exposure to radiofrequency electromagnetic fields from mobile phones has been investigated extensively, with recent international agency classifications noting limited evidence for human carcinogenicity, though this remains an area of ongoing research.

### 4.4 Demographic and Lifestyle Factors

Advanced age remains a significant risk factor, with glioblastoma incidence increasing substantially in individuals over 60 years. Obesity and metabolic syndrome have been

associated with increased brain tumor risk in some studies. The role of hormonal factors, particularly hormone replacement therapy in postmenopausal women, has been evaluated with conflicting results. Certain infections, such as human immunodeficiency virus (HIV), particularly in severely immunocompromised patients, increase the risk of CNS lymphomas. Prior malignancy history, especially with potential for brain metastases, significantly elevates the overall burden of brain tumor disease in cancer survivors.




## 5. Classification and Pathological Characteristics

### 5.1 WHO Classification System

The WHO classification system for tumors of the central nervous system (CNS) is the gold standard for brain tumor categorization and has been revised multiple times to incorporate molecular and genetic findings. The 2021 WHO classification emphasizes integrated diagnostic criteria that combine histology with molecular alterations. Tumors are classified hierarchically by anatomical origin (e.g., glioma, meningioma, nerve sheath tumor) and then by histological grade (I-IV), with Grade I representing benign, slow-growing lesions and Grade IV indicating highly malignant, rapidly progressive tumors.

### 5.2 Gliomas

Astrocytomas originate from astrocyte cells and represent the most common glial tumor. Diffuse astrocytomas (Grade II-III) are infiltrating tumors that gradually progress toward higher grades, while Grade IV astrocytomas (glioblastomas) are characterized by rapid growth, necrosis, and vascular proliferation. IDH1/IDH2 mutations distinguish secondary glioblastomas (which develop from lower-grade precursor tumors) from primary

glioblastomas (which arise de novo), with secondary glioblastomas generally having a better prognosis.

Oligodendrogliomas originate from oligodendrocyte cells and comprise 5-10% of gliomas. Grade II oligodendrogliomas with concurrent 1p/19q codeletion are associated with more favorable prognosis and superior chemotherapy response. The presence of IDH mutation is strongly associated with better outcomes and improved survival compared to IDH wild-type tumors.

Mixed gliomas containing both astrocytic and oligodendroglial components are increasingly subclassified based on their molecular profile. The distinction between pure oligodendroglioma and mixed oligoastrocytoma has been largely abandoned in favor of molecular-based classification, with tumors stratified by IDH and 1p/19q status.

Ependymomas arise from ependymal cells lining the ventricular system and are relatively rare, comprising 2-3% of adult gliomas but accounting for a higher proportion of pediatric tumors. These tumors range from Grade I (myxopapillary ependymomas) to Grade III (anaplastic ependymomas), with molecular subgroups increasingly recognized as having distinct prognostic significance.

**5.3 Non-Glial Tumors**

Meningiomas arise from the dura mater and arachnoid mater and represent approximately 30% of primary brain tumors. The majority (80%) are benign (Grade I), but atypical (Grade II) and malignant (Grade III) variants exist with worse outcomes. NF2 mutations are found in a subset of meningiomas, while TERT promoter mutations and TP53 mutations are associated with higher-grade tumors.

Acoustic neuromas (vestibular schwannomas) are benign Grade I nerve sheath tumors that arise from the vestibular division of the eighth cranial nerve. They are strongly associated with neurofibromatosis type 2 in younger patients and bilateral tumors.

Central nervous system lymphomas (CNS-L), predominantly non-Hodgkin lymphomas of B-cell origin, are increasing in incidence, particularly in immunocompromised populations. Primary CNS lymphomas carry worse prognosis than systemic lymphomas with similar histology.

**5.4 Pediatric Tumors**

Medulloblastomas are the most common malignant brain tumors in children, arising from the cerebellar vermis. Molecular subgroups including WNT-activated, SHH-activated, Group 3, and Group 4 tumors show distinct clinical features and treatment responses. Molecular profiling is increasingly used to stratify patients for risk-adapted therapy.

Pilocytic astrocytomas (Grade I) are relatively benign tumors predominantly occurring in children and young adults, often in the optic pathway or cerebellum. These tumors generally have excellent prognosis with surgery alone in many cases, though radiation and chemotherapy may be required for progressive tumors.

## 6. Molecular Pathogenesis and Genetic Alterations

### 6.1 Key Molecular Markers

The molecular basis of brain tumor development involves accumulation of genetic and epigenetic alterations. IDH mutations (isocitrate dehydrogenase 1 and 2) are found in approximately 70-80% of lower-grade gliomas and secondary glioblastomas but are rare in primary glioblastomas. IDH mutant tumors are associated with better overall survival and improved treatment response.

MGMT methylation status (methylation of the O6-methylguanine-DNA methyltransferase promoter) is a strong predictive marker for temozolomide chemotherapy response in glioblastomas. Patients with methylated MGMT promoters show superior progression-free and overall survival with concurrent and adjuvant temozolomide compared to those with unmethylated status.

TP53 mutations occur in approximately 30-50% of high-grade gliomas and are associated with worse prognosis. These mutations impair tumor suppressor function and reduce treatment responsiveness.

PTEN loss is frequently observed in primary glioblastomas and is associated with aggressive phenotype and poor prognosis. PTEN loss activates the PI3K/AKT pathway, promoting cellular proliferation and survival.

EGFR amplification and mutation occur in approximately 40% of glioblastomas, particularly primary tumors. EGFR-mutant tumors may be candidates for targeted therapy approaches.

### 6.2 Gene Expression Subtypes

Comprehensive genomic analyses have identified distinct molecular subtypes of glioblastomas with prognostic and predictive significance. Classical subtype glioblastomas show EGFR amplification and exhibit the most aggressive behavior. Mesenchymal subtype glioblastomas show frequent NF1 loss and TP53 mutations and are associated with higher invasion and worse outcomes. Proneural subtype glioblastomas are characterized by IDH mutations, G-CIMP (CpG island methylator phenotype), and generally carry better prognosis. Neural subtype glioblastomas show expression of markers associated with normal neural function and have intermediate outcomes.

## 7. Clinical Presentation and Diagnostic Approaches

### 7.1 Clinical Manifestations

Brain tumor symptoms vary depending on tumor location, size, growth rate, and degree of edema. Headaches are the most common presenting symptom, occurring in 40-50% of patients, though often nonspecific in character. Seizures occur in 20-40% of patients depending on tumor type and location, with cortical tumors having higher seizure risk. Focal neurological deficits including motor weakness, sensory loss, visual field defects, and speech difficulties depend on tumor anatomical location. Cognitive changes, memory impairment, personality changes, and psychiatric symptoms may develop, particularly with frontal or temporal lobe involvement.

Increased intracranial pressure (ICP) from tumor mass effect or obstruction of cerebrospinal fluid (CSF) flow causes headaches, vomiting (particularly morning vomiting), papilledema on fundoscopy, and altered mental status. Hormonal dysfunction may manifest with pituitary adenomas, causing amenorrhea, galactorrhea, Cushing's syndrome, or acromegaly. Symptoms of hydrocephalus include headache, gait disturbance, and cognitive decline.

### 7.2 Neuroimaging

Magnetic resonance imaging (MRI) is the gold standard for brain tumor evaluation. T1-weighted images with gadolinium contrast demonstrate tumor enhancement and contrast-leaking patterns. T2-weighted and fluid-attenuated inversion recovery (FLAIR) sequences demonstrate tumor edema. Diffusion-weighted imaging (DWI) may show restricted diffusion in high-grade gliomas and lymphomas. Perfusion imaging and MR spectroscopy provide information about tumor vascularity and metabolic profile.

Computed tomography (CT) is useful for detecting calcifications, bone involvement, and acute complications like hemorrhage, though it has inferior soft tissue resolution compared to MRI.

Positron emission tomography (PET) with fluorodeoxyglucose (FDG) and other tracers can supplement MRI in assessing tumor activity, though availability varies.

Functional MRI (fMRI) and diffusion tensor imaging (DTI)** assist in surgical planning by identifying eloquent cortex and white matter tracts, allowing maximization of resection while minimizing neurological morbidity.

### 7.3 Histopathological Diagnosis and Biopsy

Definitive diagnosis requires histopathological examination of tumor tissue obtained through biopsy or surgical resection. Stereotactic needle biopsy is minimally invasive, though carries

risks of sampling error, particularly in heterogeneous tumors. Open surgical biopsy provides larger tissue samples but requires craniotomy. Frameless stereotactic biopsy offers improved accuracy using neuronavigation guidance.

Intraoperative neuromonitoring including electrocorticography (ECoG) and motor/sensory evoked potentials assists in real-time assessment of neurological function during resection.

### 7.4 Molecular Testing

Contemporary neuropathology practice includes molecular testing for prognostically and therapeutically significant alterations. Next-generation sequencing (NGS) panels enable comprehensive mutation analysis. Fluorescence in situ hybridization (FISH) identifies chromosomal alterations including 1p/19q codeletion and EGFR amplification. Methylation profiling provides molecular classification and prognostic stratification. Immunohistochemistry (IHC) for IDH1 R132H mutation and other markers guides classification.

## 8. Current Treatment Strategies

### 8.1 Surgical Management

Maximal safe resection is the primary treatment goal for most operable brain tumors, as extent of resection strongly correlates with overall survival. Preoperative imaging including fMRI and DTI guides surgical planning to identify tumor-eloquent cortex relationships. Intraoperative neuronavigation using frameless stereotactic systems provides real-time anatomical guidance. Intraoperative monitoring of motor and sensory evoked potentials and electrocorticography enables real-time assessment of neurological function during resection.

Awake craniotomy under local anesthesia allows direct cortical stimulation mapping to identify eloquent cortex and optimize extent of resection while preserving neurological function. Fluorescence-guided surgery using 5-aminolevulinic acid (5-ALA) in high-grade gliomas enhances visualization of tumor tissue due to increased fluorescence, potentially improving extent of resection.

Repeat resection at tumor progression may be considered in selected patients with recurrent gliomas, though prognostic benefit remains debated.

### 8.2 Radiation Therapy

External beam radiation therapy (EBRT) is standard adjuvant treatment for most malignant brain tumors. Conventional fractionated radiotherapy delivers 30 Gy in 10 fractions (for high-

grade gliomas) to 54-59.4 Gy in 30-33 fractions. Hypofractionated radiotherapy uses fewer, larger daily fractions and shows equivalent efficacy to conventional fractionation in glioblastoma while improving convenience.

Intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) allow conformal dose delivery to the target volume while sparing surrounding normal brain tissue, reducing neurotoxicity.

Stereotactic radiosurgery (SRS) delivers a high dose of radiation in one or few fractions to small, well-defined targets. It is particularly useful for brain metastases, recurrent tumors, and as boost therapy.

Proton beam therapy offers theoretical dosimetric advantages due to Bragg peak characteristics, reducing dose to normal tissues distal to the target, though clinical benefit remains under investigation.

### 8.3 Chemotherapy

Temozolomide (TMZ) is the primary chemotherapeutic agent for high-grade gliomas. The Stupp protocol, combining maximal resection, concurrent TMZ with radiotherapy, followed by adjuvant TMZ, improved median overall survival in glioblastoma from 12.1 months to 14.6 months. Dosing is typically 75 mg/m²/day during radiotherapy, followed by 150-200 mg/m² daily for 5 days in 28-day cycles.

Nitrosoureas including carmustine (BCNU) as wafers implanted at surgery and lomustine (CCNU) have limited roles in contemporary practice. Procarbazine, lomustine, and vincristine (PCV) chemotherapy is used for lower-grade gliomas and some recurrent high-grade gliomas.

Bevacizumab, a vascular endothelial growth factor (VEGF) inhibitor, is used for recurrent glioblastoma, showing improved progression-free survival though limited overall survival benefit. Irinotecan combined with bevacizumab is an alternative salvage regimen.

The blood-brain barrier significantly limits chemotherapy penetration into brain tumors, with many agents achieving inadequate CNS concentrations. Osmotic disruption of the BBB, convection-enhanced delivery, and encapsulation in nanoparticles represent emerging strategies to improve drug delivery.

### 8.4 Supportive Care

Seizure management is essential, with approximately 20-40% of brain tumor patients experiencing seizures. Prophylactic antiepileptic drugs are not routinely recommended;

however, treatment is indicated for breakthrough seizures. Corticosteroids (typically dexamethasone or methylprednisolone) reduce cerebral edema and intracranial pressure, providing symptomatic relief, though prolonged use is associated with significant toxicity.

Deep vein thrombosis (DVT) and pulmonary embolism (PE) prophylaxis with anticoagulation is important, as cancer patients have substantially elevated thromboembolic risk.

**Summary of Treatment Strategies**

| Strategy | Key Modalities | Primary Goals |
|---|---|---|
| **Surgical** | Safe maximal resection, fMRI, DTI, 5-ALA fluorescence | Cytoreduction while preserving eloquent cortex. |
| **Radiation** | EBRT, IMRT, VMAT, SRS, Proton Beam | Adjuvant treatment to eliminate residual cells; conformal delivery. |
| **Chemotherapy** | Temozolomide (Stupp Protocol), Bevacizumab | Systemic control; overcoming the blood-brain barrier. |
| **Supportive** | Seizure management, Corticosteroids, VTE prophylaxis | Symptom management and prevention of complications. |

## 9. Emerging and Targeted Therapies

### 9.1 Targeted Molecular Therapy

IDH inhibitors such as ivosidenib (AG-120) and enasidenib (AG-221) target mutant IDH1 and IDH2 enzymes respectively. These agents are showing promise in IDH-mutant gliomas and other CNS malignancies.

EGFR inhibitors including gefitinib and erlotinib show activity in EGFR-amplified glioblastomas, though resistance development remains problematic.

BRAF inhibitors such as vemurafenib and dabrafenib target BRAF V600E mutations found in pilocytic astrocytomas and some other pediatric tumors, showing excellent response rates.

Crizotinib and other ALK inhibitors are active in tumors with ALK alterations, including some brainstem gliomas.

PTEN loss-directed therapies remain an area of active investigation, with dual PI3K/mTOR inhibitors and other pathway inhibitors under study.

### 9.2 Immunotherapy

Checkpoint inhibitors targeting PD-1/PD-L1 and CTLA-4 have been investigated in glioblastoma and other CNS malignancies. Recent trials exploring nivolumab and ipilimumab combinations show promise, particularly when combined with radiotherapy or chemotherapy.

CAR-T cell therapy engineered to target tumor-associated antigens such as EphA2 or IL-13Rα2 are in early clinical development for glioblastomas and other CNS tumors.

Dendritic cell vaccines pulsed with tumor lysates or personalized neoantigen peptides represent another immunotherapeutic approach under active investigation.

Tumor-infiltrating lymphocyte (TIL) therapy and other adoptive cell therapies are being developed for CNS malignancies.

### 9.3 Combination Approaches

Combining conventional therapies with novel targeted and immunological agents is yielding improved outcomes. Radiotherapy plus checkpoint inhibitors enhance immune activation while avoiding excessive neurotoxicity. Chemotherapy plus targeted agents address tumor heterogeneity by targeting multiple pathways simultaneously.

## 10. Challenges in Brain Tumor Management

### 10.1 Blood-Brain Barrier Penetration

The blood-brain barrier, composed of specialized endothelial cells with tight junctions, prevents most chemotherapeutic agents from achieving therapeutic CNS concentrations. Active efflux pumps including P-glycoprotein further reduce drug accumulation. Strategies to overcome BBB limitations include lipophilic drug formulations, BBB-permeable prodrugs, nanoparticle-based delivery systems, and temporarily disrupting barrier integrity through osmotic or ultrasonic means.

### 10.2 Tumor Heterogeneity and Clonal Evolution

Spatial and temporal tumor heterogeneity, with distinct molecular and phenotypic characteristics in different tumor regions and at different timepoints, complicates treatment selection and contributes to treatment resistance. Intratumoral heterogeneity in IDH and TP53 mutation status, hypoxic regions, and immune infiltration creates a heterogeneous tumor microenvironment that limits response to single-agent therapies.

### 10.3 Neurotoxicity and Leukoencephalopathy

Radiation-induced neurotoxicity, including radiation necrosis, leukoencephalopathy, cognitive decline, and secondary malignancy risk, accumulates with higher doses. Chemotherapy-related cognitive impairment ("chemo brain" or "cancer-related cognitive impairment") affects quality of life in long-term survivors. Balancing tumor control with minimization of treatment toxicity remains challenging.

### 10.4 Treatment Resistance and Recurrence

Intrinsic and acquired resistance to chemotherapy, radiation, and targeted therapies limits durable disease control. Mechanisms include genetic mutations conferring drug resistance, phenotypic switching, and selection of treatment-resistant clones. Recurrent glioblastomas show marked genomic evolution with acquisition of novel mutations and altered immune microenvironment.

### 10.5 Psychosocial and Quality-of-Life Issues

Brain tumor diagnosis carries significant psychological burden for patients and families. Cognitive and neurological sequelae impact employment, social relationships, and independence. Depression and anxiety are common, requiring integrated psychiatric and psychological support. Financial toxicity from extended treatment and rehabilitation contributes to health disparities.

## 11. Prognostic Factors and Outcomes

Median overall survival varies dramatically by tumor type and molecular characteristics. Glioblastoma (Grade IV astrocytoma) has median overall survival of 14-16 months with current standard therapy, though ranges from 6-12 months for older patients or those with unfavorable molecular features to 24+ months for younger patients with favorable molecular profiles (IDH mutation, MGMT methylation). Grade III gliomas have median overall survival of 2-5 years. Grade II gliomas have median overall survival of 5-15 years.

Favorable prognostic factors include young age, good performance status, gross total resection, IDH mutations, MGMT methylation, and absence of TP53 mutations. Unfavorable prognostic factors include advanced age, poor performance status, incomplete resection, EGFR amplification, and homozygous PTEN loss.

## 12. CONCLUSION

Brain tumors represent a diverse group of malignancies with significant morbidity and mortality affecting patients across all age groups. Recent advances in molecular profiling, neuroimaging technology, and therapeutic strategies have improved our understanding of tumor biology and expanded treatment options. The WHO integrated diagnostic classification combining histology with molecular characteristics now guides clinical management and prognostication. Maximal safe resection combined with radiation therapy and chemotherapy remains the foundation of treatment for malignant gliomas, though emerging targeted

therapies and immunological approaches offer promise for improved outcomes, particularly in molecularly-defined subgroups.

Despite these advances, substantial challenges remain in overcoming the blood-brain barrier, managing treatment-related neurotoxicity, addressing tumor heterogeneity and treatment resistance, and providing equitable access to novel therapies. Precision medicine approaches incorporating molecular profiling, patient-derived tumor models, and functional biomarkers will increasingly enable individualized treatment selection. Integration of digital health tools for symptom monitoring and adherence tracking can improve care delivery and quality of life.

The multidisciplinary management of brain tumors requires close collaboration between neurosurgeons, neuro-oncologists, radiation oncologists, neuroradiologists, pathologists, and supportive care specialists. Involvement of patients and families in treatment decision-making, with attention to goals of care and functional prognosis, ensures management aligned with patient values and preferences. Continued investment in basic and translational research to understand tumor biology, identify new therapeutic targets, and develop improved delivery mechanisms for CNS-penetrant drugs is essential.

Future directions include expansion of immunotherapy approaches, development of more selective and CNS-penetrant targeted agents, application of artificial intelligence to diagnostic imaging and treatment planning, and investigation of liquid biomarkers for early detection and treatment monitoring. Investment in clinical trials testing novel agents and combinations, particularly in underrepresented populations, will expand treatment options and reduce health disparities. Through continued innovation, research, and multidisciplinary collaboration, we can work toward improving outcomes and quality of life for patients with brain tumors worldwide.

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