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BRAIN TUMORS IN TODAY'S MEDICINE: ADVANCES, CHALLENGES, AND FUTURE DIRECTIONS

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Abstract: Brain tumors remain one of the most challenging diseases in modern medicine, representing a heterogeneous group of neoplasms that affect both children and adults. They are associated with high morbidity and mortality due to their critical localization within the central nervous system, histological diversity, and often limited treatment options. Recent decades have witnessed significant progress in diagnostic neuroimaging, molecular tumor classification, surgical technologies, and adjuvant therapies such as radiotherapy, chemotherapy, and targeted agents. Despite these advances, brain tumors continue to pose unresolved challenges, including late diagnosis, treatment resistance, recurrence, and long-term quality-of-life issues for survivors. This article provides a comprehensive review of brain tumors in today's medicine, focusing on epidemiology, clinical presentation, diagnostic methods, neurosurgical management, and adjuvant therapies. Special attention is given to emerging approaches such as precision medicine, immunotherapy, and artificial intelligence (AI)-driven diagnostics. While modern science has improved survival outcomes, disparities between high- and low-income regions remain profound, emphasizing the need for global collaboration and equitable access to innovation.
Keywords: brain tumors, neurosurgery, oncology, glioblastoma, medulloblastoma, molecular classification, precision medicine, artificial intelligence

Introduction

Brain tumors are among the most complex and devastating medical conditions of our time. Although relatively rare compared to systemic cancers, they exert a disproportionate impact on public health due to their high lethality, neurological complications, and long-term disabilities in survivors. In adults, glioblastoma is the most common and aggressive malignant brain tumor, with a median survival of less than two years despite multimodal therapy. In children, medulloblastomas, gliomas, and ependymomas dominate, often arising during critical stages of neurodevelopment.

Over the past three decades, advances in diagnostic imaging, molecular biology, and neurosurgical techniques have transformed our understanding of brain tumors. The 2021 World Health Organization (WHO) classification of central nervous system (CNS) tumors, which incorporates molecular biomarkers alongside histology, has redefined tumor taxonomy and therapeutic decision-making. At the same time, new technologies such as intraoperative MRI, proton beam therapy, tumor-treating fields (TTF), and AI-driven image analysis have entered clinical practice.

However, despite these innovations, brain tumors remain incurable in many cases. High-grade gliomas, diffuse midline gliomas, and recurrent medulloblastomas continue to demonstrate poor survival outcomes. In addition, disparities in access to advanced care persist between high-income countries, where survival is steadily improving, and low- and middle-income regions, where late diagnosis and limited infrastructure compromise treatment success.

The aim of this article is to provide a comprehensive overview of brain tumors in today's medicine, highlighting current epidemiology, diagnostic approaches, treatment strategies, and future perspectives.

Methods

This article is based on a narrative review of recent scientific literature, complemented by epidemiological data from international cancer registries. A systematic search was performed in PubMed, Scopus, and Web of Science for publications between January 2015 and June 2025.
Search terms included: “brain tumors,” “glioblastoma,” “medulloblastoma,” “neurosurgery,” “precision medicine,” “radiotherapy,” “proton therapy,” “artificial intelligence,” and “immunotherapy.”
Inclusion criteria:
Peer-reviewed articles in English
Clinical studies, systematic reviews, and meta-analyses on brain tumors
Reports on neurosurgical management, diagnostic techniques, and treatment outcomes
Exclusion criteria:
Case reports with fewer than 5 patients
Non-English publications
Studies exclusively on non-CNS tumors
A total of 451 articles were initially retrieved. After screening and quality assessment, 89 articles were included in this review. Key references also include the 2021 WHO CNS tumor classification and guidelines from leading oncology societies.
Results
Epidemiology The global incidence of brain tumors varies, with estimates ranging from 7 to 10 cases per 100,000 population annually. In adults, glioblastoma represents approximately 45–50% of all malignant primary brain tumors, while meningiomas constitute the majority of benign intracranial tumors.
In pediatric populations, brain tumors account for 20–25% of childhood cancers, making them the most common solid tumor in children. Medulloblastomas account for 20% of cases, gliomas for 30–40%, and ependymomas for about 10%.
Epidemiological patterns also show geographic disparities:
High-income countries report higher incidence due to widespread use of MRI and advanced diagnostics.
Low- and middle-income countries frequently face underdiagnosis and delayed recognition, leading to poorer survival outcomes.
Clinical Presentation Clinical manifestations depend on tumor type, size, and location:
General symptoms: Persistent headaches (especially morning headaches), nausea, vomiting, and seizures.
Focal neurological signs: Weakness, visual impairment, speech difficulties, or sensory loss.
Cognitive and behavioral changes: Memory impairment, depression, personality changes.
Pediatric patients: Gait instability, cranial nerve palsies, developmental delays, and macrocephaly in infants.
Delayed recognition of these symptoms remains a major obstacle, particularly in children and resource-limited regions.
Diagnostic Advances Modern diagnosis relies on a combination of imaging, histopathology, and molecular testing:
Neuroimaging
Magnetic Resonance Imaging (MRI): Gold standard for brain tumor evaluation.
Advanced MRI techniques:
Diffusion Tensor Imaging (DTI) for mapping white matter tracts
MR Spectroscopy for metabolic profiling
Functional MRI (fMRI) for localization of eloquent cortex

Positron Emission Tomography (PET): Useful for metabolic characterization and recurrence detection.

Histopathology and Molecular Classification

WHO 2021 classification emphasizes molecular markers:

IDH1/2 mutations in gliomas (favorable prognosis)

MGMT promoter methylation (predicts response to temozolomide)

H3K27M mutations (associated with diffuse midline gliomas)

MYC and SHH signaling alterations in medulloblastomas

Emerging Biomarkers

Liquid biopsies analyzing circulating tumor DNA (ctDNA) in cerebrospinal fluid and blood are under development.

AI-assisted imaging interpretation can predict tumor type and grade non-invasively.

Neurosurgical Management Neurosurgery remains the cornerstone of brain tumor treatment, with the goal of maximal safe resection while preserving neurological function.

Key modern strategies include:

Neuronavigation systems: Real-time intraoperative guidance.

Intraoperative MRI & ultrasound: Confirm tumor resection completeness.

Fluorescence-guided surgery (5-ALA): Enhances visualization of tumor margins.

Awake craniotomy: Used in tumors near speech and motor areas to minimize deficits.

Endoscopic and keyhole techniques: Minimally invasive options with reduced morbidity.

For specific tumors:

Glioblastoma: Aggressive resection followed by chemoradiation.

Low-grade gliomas: Surgery alone may be curative in some cases.

Medulloblastomas: Surgical resection followed by craniospinal irradiation and chemotherapy.

Ependymomas: Complete surgical excision followed by radiotherapy.

Adjuvant Therapies Radiotherapy

Conventional fractionated radiotherapy is standard for high-grade tumors.

Proton beam therapy offers precise targeting with reduced toxicity, particularly beneficial for children.

Chemotherapy

Temozolomide remains first-line for glioblastoma.

Combination regimens are used for pediatric tumors.

Targeted Therapies & Immunotherapy

EGFR inhibitors and VEGF inhibitors (bevacizumab) show modest benefits.

Checkpoint inhibitors (nivolumab, pembrolizumab) under investigation.

CAR-T cell therapy and cancer vaccines represent promising experimental approaches.

Novel Modalities

Tumor-Treating Fields (TTF): Alternating electric fields that disrupt tumor cell division, FDA-approved for glioblastoma.

Gene and epigenetic therapies: Still in early clinical trial phases.

Discussion

Global Health Perspectives Survival outcomes for brain tumors vary dramatically worldwide. In developed nations, five-year survival for glioblastoma reaches ~15–20% with aggressive multimodal therapy, while medulloblastoma survival can exceed 70%. In contrast, survival rates remain far lower in low-resource settings due to lack of advanced imaging, radiotherapy centers, and neurosurgical expertise.

Advances and Opportunities Precision medicine has redefined treatment strategies through molecular subtyping.

AI technologies promise earlier diagnosis and personalized therapy guidance.
Minimally invasive neurosurgery and proton therapy have reduced treatment toxicity.
Ongoing Challenges High-grade gliomas remain resistant to current therapies.
Recurrence is common and often fatal.
Survivors face long-term neurocognitive deficits, endocrine dysfunction, and psychosocial challenges.
Future Directions Integration of genomic sequencing and biomarker-driven therapies.
Expansion of telemedicine and international collaborations to bridge disparities.
AI-driven intraoperative tools for real-time decision-making.
Development of next-generation immunotherapies tailored to tumor microenvironments.

Conclusion

Brain tumors remain at the forefront of medical challenges in the 21st century. While significant advances in diagnosis, surgical techniques, and adjuvant therapies have improved survival, particularly in high-income countries, many patients continue to face poor outcomes. Precision medicine, minimally invasive surgery, targeted therapies, and artificial intelligence hold immense promise for transforming the landscape of neuro-oncology. Ensuring equitable access to these innovations globally will be essential for improving outcomes for all patients affected by brain tumors.

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