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Brain tumor, a major concern to the society. itscauses, signs and symptoms, diagnosis, treatment, and complications

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Abstract
Brain tumors constitute a major public health concern, posing significant threats to individuals and communities worldwide. These abnormal growths within the brain, whether benign or malignant, can severely impact cognitive function, quality of life, and overall survival. Characterized by the rapid proliferation of abnormal brain cells, brain tumors often lead to critical impairment of neurological function and present with diverse sizes, textures, and locations. They are notably among the most aggressive malignancies, particularly affecting children and young adults, where they are a leading cause of cancer-related mortality. The increasing incidence of brain tumors underscores the urgent need for enhanced awareness, early detection, and effective management strategies among healthcare practitioners. Clinical manifestations largely depend on tumor location and intracranial pressure levels. While recent advances in neuroimaging, molecular profiling, and targeted therapies have significantly improved diagnostic precision and personalized treatment options, the complexity of brain tumors—owing to their intricate anatomical positioning and biological heterogeneity—continues to present considerable challenges. Overcoming these obstacles requires ongoing research, innovative surgical techniques, and multidisciplinary collaboration to improve outcomes for affected patients.

Keywords: Abnormal, benign, cognitive, proliferation, intracranial

Introduction

Brain tumours are abnormal growths or masses of cells that arise within or around brain tissue. They are broadly classified as either primary tumours, originating in the brain, or secondary (metastatic) tumours, which spread to the brain from cancers located elsewhere in the body. Among primary brain tumours, gliomas are the most common and can occur in both adults and children. Brain tumours are further categorised as benign (slow-growing and typically non-cancerous, with well-defined borders) or malignant (cancerous, fast-growing, and capable of invading surrounding tissues).

Examples of benign brain tumours include chordomas, which typically originate at the base of the skull or lower spine, and meningiomas, the most prevalent type of primary brain tumour, developing within the meninges—the protective layers covering the brain and spinal cord. Although most meningiomas are benign, rare malignant forms exist. In contrast, malignant tumours such as glioblastoma (GBM)—the most aggressive form of astrocytoma—originate from astrocytes, a type of glial cell. Astrocytoma's, the most common type of glioma, are frequently located within the cerebrum.

Globally, approximately 350,000 new cases of brain tumours are diagnosed annually, with a five-year survival rate of only 36%, according to a 2021 study. Furthermore, the UK Cancer Research Organisation estimates that only 3% of brain cancers are preventable, a significantly lower proportion compared to most other cancer types.

The human brain is a highly complex and developed organ that functions as the control centre for all bodily activities, facilitating cognitive processes, communication, and emotional expression. It is composed of three primary components: cerebrospinal fluid (CSF), white matter (WM), and grey matter (GM). Grey matter, consisting of neurons and glial cells, regulates brain activity, while white matter, composed of myelinated axons, connects different brain regions. The corpus callosum, a dense band of white matter fibres, links the brain's left and right hemispheres. Due to the rigid and volume-limited structure of the human skull, any abnormal growth within the brain can significantly impact neurological function and may lead to metastasis, further compromising vital bodily systems.

Early detection of brain cancer is critical for effective treatment planning and remains a key priority in healthcare. Diagnostic approaches can be invasive, such as surgical biopsies for histopathological examination, or non-invasive, using imaging techniques like computed tomography (CT) and magnetic resonance imaging (MRI). These modalities enable radiologists to detect and localise brain abnormalities with greater accuracy.

This review paper is organised as follows: Section 2 discusses the causes of brain tumours; Section 3 outlines the signs and symptoms; Section 4 examines diagnostic methods; Section 5 explores treatment options; Section 6 addresses complications associated with brain tumours; and finally, Section 7 presents a concluding discussion, highlighting the societal significance of brain tumours as a major health concern.

Historical Background

The study and understanding of brain tumors have evolved significantly over centuries, mirroring the broader advances in medicine and technology. Early descriptions of brain tumors date back to ancient civilizations, with Egyptian and Greek physicians, including Hippocrates (460–370 BC),

documenting cases of cranial swelling and neurological symptoms suggestive of intracranial masses. However, due to limited diagnostic capabilities, such conditions were poorly understood and often attributed to supernatural causes.

The real turning point in brain tumor research came during the Renaissance period, as anatomical studies by pioneers like Andreas Vesalius (1514–1564) deepened human knowledge of the brain's structure. By the 19th century, with the advent of pathology as a scientific discipline, physicians like Rudolf Virchow began classifying tumors based on their histological characteristics. Virchow's introduction of the concept of "glioma" provided the foundation for modern neuropathology.

The first successful surgical removal of a brain tumor was performed by Dr. Rickman Godlee in 1884 in London, marking a monumental advancement in neurosurgery. However, without the aid of anesthesia, antibiotics, or imaging technologies, early surgeries were highly risky. The development of X-ray imaging by Wilhelm Röntgen in 1895, and later the introduction of computed tomography (CT) in the 1970s and magnetic resonance imaging (MRI) in the 1980s, revolutionized the ability to diagnose brain tumors accurately and non-invasively.

Research into the causes of brain tumors has expanded significantly in the 20th and 21st centuries. While some genetic and environmental factors have been identified, the exact etiology of many brain tumors remains unclear. Advances in molecular biology and genetics have uncovered specific mutations and pathways involved in tumor development, enabling targeted therapy approaches.

Despite technological and medical advancements, brain tumors remain a major concern for society due to their complex nature, high mortality rates, and the profound impact they have on patients' quality of life. Brain tumors can arise in individuals of any age, including children, and they often present with subtle signs and symptoms, making early diagnosis challenging. Treatments, although increasingly sophisticated, including surgery, radiotherapy, chemotherapy, and newer immunotherapy techniques, are often associated with significant complications and side effects.

Today, brain tumor research is an interdisciplinary field involving neurology, oncology, radiology, genetics, and immunology. Public health campaigns have also emphasized raising awareness about brain tumors, their symptoms, and the importance of early diagnosis. Yet, despite these efforts, brain tumors continue to pose a major societal challenge, necessitating ongoing research, improved therapeutic strategies, and better supportive care for affected individuals.

Causes of Brain Tumor

The precise etiology of primary brain tumors remains largely unknown, despite advancements in recent studies and artificial intelligence-driven literature reviews. It is generally accepted that brain tumors arise from the uncontrolled proliferation of abnormal cells within the brain, leading to the formation of a mass or growth. Although the fundamental mechanisms underlying tumor initiation and progression remain poorly understood, several environmental and genetic factors have been identified as potential contributors to the risk of developing brain tumors. These include:

- **Exposure to High Levels of Ionizing Radiation**

Exposure to significant doses of ionizing radiation has been firmly associated with an increased risk of brain tumor development. Individuals who have undergone radiotherapy for the treatment of other cancers, or those who have been exposed to nuclear fallout, face a heightened risk. Ionizing radiation is known to cause direct DNA damage, which may contribute to oncogenic mutations within brain tissue.

- **Advancing Age**

Age is a well-recognized risk factor in the development of brain tumors. The likelihood of developing a brain tumor increases significantly with advancing age, particularly in individuals over the age of 65. This trend is believed to be due to the cumulative effect of genetic mutations over time and the natural decline in cellular repair mechanisms as part of the aging process.

- **Gender Predisposition**

Gender differences also play a role in brain tumor epidemiology. Overall, men are more likely to develop brain tumors compared to women. However, it is important to note that certain specific types of brain tumors, such as meningiomas, occur more frequently in women. These gender-specific patterns suggest that hormonal and genetic factors may influence tumor susceptibility.

- **Familial History and Genetic Factors**

Approximately 5–10% of brain tumors are linked to inherited genetic conditions. Disorders such as neurofibromatosis types 1 and 2, Li-Fraumeni syndrome, and von Hippel-Lindau disease predispose individuals to tumor formation within the central nervous system. The presence of these hereditary syndromes emphasizes the importance of genetic counseling and testing for individuals with a strong family history of brain tumors.

- **Immunodeficiency Disorders**

A compromised immune system has been associated with an elevated risk of certain types of brain tumors, particularly primary central nervous system lymphomas. Conditions such as acquired immunodeficiency syndrome (AIDS) and the use of immunosuppressive therapies following organ transplantation can significantly impair immune surveillance, thereby facilitating tumorigenesis in the brain and spinal cord.

- **Ethnic Predisposition**

Epidemiological studies have indicated that individuals of Caucasian descent are at a comparatively higher risk of developing brain tumors compared to individuals from other ethnic backgrounds. While the reasons behind these ethnic differences are not fully understood, they may reflect a complex interplay of genetic susceptibility and environmental exposures.

Sign and Symptoms of Brain Tumor

A review published on January 30, 2006 [9], by S. H. Wilne, R. C. Ferris, A. Nathwani, and C. R. Kennedy identified several key signs and symptoms associated with brain

tumours, noting their prevalence within the affected population. Understanding these symptoms is critical for early detection and effective clinical intervention.

- **Headache**

Headache is the most commonly reported symptom, affecting approximately 41% of individuals diagnosed with brain tumours. These headaches are often persistent, may worsen over time, and can be more severe in the morning. They may also be resistant to standard pain-relief medications and could intensify with changes in body position, coughing, or exertion.

- **Vomiting**

Vomiting, reported in around 12% of cases, is typically unrelated to food intake and often occurs in the morning. It may be associated with raised intracranial pressure, and when persistent, it warrants further neurological evaluation.

- **Unsteadiness**

Unsteadiness or balance difficulties were observed in 11% of patients. These symptoms may manifest as clumsiness, difficulty walking in a straight line, or a general feeling of dizziness, and are often indicative of tumours affecting the cerebellum or brainstem.

- **Visual Disturbances**

Visual impairments, including blurred vision, double vision (diplopia), or even partial or complete loss of vision, are common presentations. These disturbances often result from increased intracranial pressure or direct compression of visual pathways by the tumour.

Educational or Behavioural Difficulties

Educational decline and behavioural changes, particularly notable in paediatric cases, affect approximately 10% of individuals. These changes may present as decreased academic performance, altered social interactions, mood swings, or new-onset behavioural problems.

- **Seizures**

Seizures, reported in 9% of cases, may be the initial manifestation of a brain tumour. These can range from focal seizures, affecting one part of the body, to generalized seizures involving loss of consciousness and convulsions. New-onset seizures in individuals without a prior history of epilepsy should prompt urgent neuroimaging.

- **Memory Impairment**

Memory impairment can manifest as short-term memory loss or a broader cognitive decline. Patients may experience difficulty recalling recent events, maintaining conversations, or learning new information, particularly when tumours affect the temporal lobes or other memory-associated brain regions.

- **Difficulties with Speech and Language**

Language and speech difficulties are common and may include trouble finding the right words (anomia), difficulties in articulating thoughts, or problems understanding spoken and written language. These symptoms often reflect involvement of language-dominant regions such as Broca's or Wernicke's areas.

- **Psychological Symptoms**

Psychological manifestations, such as anxiety, depression, irritability, or emotional instability, can occur secondary to brain tumours. These changes might be due to direct tumour effects on emotional centres or the psychological burden of the illness itself.

- **Sensory and Motor Impairments**

Tumours affecting sensory or motor pathways can lead to tingling, numbness, or stiffness, typically localized to one side of the body. Motor deficits might present as weakness, poor coordination, or abnormal reflexes, depending on the tumour's anatomical location.

- **Hearing Loss**

Partial or complete hearing loss may arise if the tumour impinges on auditory pathways or cranial nerves. Patients may report difficulty understanding conversations, especially in noisy environments, or complete deafness in one ear.

- **Sleep Disturbances**

Sleep disturbances, including insomnia or disrupted sleep patterns, are also reported among individuals with brain tumours. These disturbances could result from the tumour's impact on brain structures regulating sleep or from associated stress and discomfort.

Diagnosis of Brain Tumors

In recent years, significant advancements in medical tomography and sophisticated image processing techniques have markedly improved the diagnosis of brain tumors. The increasing integration of computer-aided diagnosis systems, especially those based on Magnetic Resonance Imaging (MRI), has led to notable progress in the early detection, accurate segmentation, and precise classification of brain tumors. As highlighted in a review by Reham Kaifi (2023) [5], the diagnostic process generally comprises three essential stages: detection, segmentation, and classification, each facilitated by advancements in imaging technology and computational analysis.

Radiological Diagnosis

Radiological evaluation forms the cornerstone of brain tumor diagnosis, leveraging both static and dynamic imaging modalities to gain comprehensive anatomical and functional insights.

1. Static Imaging

Static imaging techniques, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), are non-invasive methods that provide highly detailed anatomical representations of intracranial structures.

a. CT Scan

A CT scan employs ionizing radiation and thin bands of X-rays to produce cross-sectional images of brain tissue. It is particularly useful post-surgical intervention to verify the accuracy of biopsy sites and to evaluate the extent of tumor resection. CT imaging is often the first-line investigation in acute clinical settings due to its rapid acquisition time and efficacy in detecting hemorrhage, calcifications, and bone involvement.

b. Magnetic Resonance Imaging (MRI)

MRI utilizes powerful magnetic fields and radiofrequency pulses to generate high-resolution images of the brain. The administration of gadolinium-based contrast agents enhances the differentiation between tumor tissue and surrounding edema, making MRI the gold standard in brain tumor imaging. Advanced MRI techniques provide superior soft-tissue contrast compared to CT, facilitating more accurate tumor characterization.

2. Dynamic Imaging

Dynamic imaging techniques offer critical information regarding the metabolic and physiological properties of brain tumors and adjacent tissues.

a. Positron Emission Tomography (PET) Scan

PET scans involve the use of cyclotrons and radioactive isotopes to visualize metabolic activity within the brain. This modality provides valuable data about tumor metabolism, distinguishing between benign and malignant lesions, and evaluating tumor recurrence.

b. Single Photon Emission Computed Tomography (SPECT) Scan

An evolution of PET imaging, SPECT scans use isotopes that do not require a cyclotron. SPECT is particularly useful in assessing cerebral blood flow and determining precise tumor localization.

c. Magnetic Resonance Spectroscopy (MRS)

MRS complements static MRI by measuring the metabolic activity of brain tumors. It provides information on the chemical composition of tissues, aiding in distinguishing tumor types and grades.

d. Functional Magnetic Resonance Imaging (fMRI)

fMRI employs echo-planar imaging technology within conventional MRI scanners to map cerebral blood flow at the capillary level. It is instrumental in evaluating the functional impact of tumors on brain activity, assisting in surgical planning to preserve critical functional areas.

Computed Integration Imaging

Modern computing technologies enable the integration of imaging data from CT, MRI, PET, and SPECT to create two- and three-dimensional reconstructions of cranial planes. This multimodal image integration enhances diagnostic precision, facilitating better treatment planning and surgical navigation.

Biopsy

When imaging studies are inconclusive or when histological confirmation is required, a biopsy is performed. This procedure involves drilling a small hole in the skull to extract a tissue sample for microscopic examination by a pathologist. Biopsies are crucial for determining the tumor type, grade, and molecular characteristics, guiding subsequent therapeutic strategies.

Laboratory Diagnosis

Laboratory investigations complement radiological and histopathological findings, offering valuable diagnostic information:

- **Perimetry:** Evaluates visual fields to assess tumors located near the optic chiasm.
- **Electroencephalography (EEG):** Monitors brain electrical activity and detects seizure foci, although it has limited sensitivity in tumor screening.
- **Lumbar Puncture:** Analyzes cerebrospinal fluid (CSF) to detect tumor dissemination or associated infections.
- **Audiometry and Vestibular Testing:** Essential for diagnosing tumors situated at the cerebellopontine angle, such as vestibular schwannomas.
- **Endocrine Testing:** Investigates hormonal abnormalities caused by tumors affecting the pituitary gland and hypothalamus.

Clinical Diagnosis

Clinical assessment remains a fundamental aspect of brain tumor diagnosis and includes:

- **Medical History:** Gathering a comprehensive history of the patient's symptoms, their onset, progression, and associated factors.
- **Neurological Examination**: Evaluating reflexes, motor strength, sensory function, coordination, and cognitive abilities to localize neurological deficits.
- **Ophthalmological Examination**: Assessing the optic discs for papilledema and other signs of increased intracranial pressure due to tumor mass effect.

Treatment of Brain Tumors

The treatment of brain tumors has significantly evolved over recent years, primarily driven by advancements in medical technology and research. According to a review published by Soichi Oya in September 2023, surgical removal remains a cornerstone approach in enhancing patient survival and quality of life. However, the appropriate treatment strategy varies depending on the tumor’s type, size, and location. The primary treatment modalities include surgical intervention, chemotherapy, particle therapy, and laser therapy.

Surgical Intervention

Surgical removal, also known as craniotomy, is the most common and often the first-line approach for treating brain tumors. The primary objective of surgical intervention is to excise the tumor entirely. However, complete removal is not always feasible, especially when the tumor is located near or within critical brain structures. In such scenarios, neurosurgeons aim to extract as much of the tumor as is safely possible to minimize neurological damage while improving the patient's prognosis. Advances in intraoperative imaging and surgical navigation technologies have significantly increased the precision of tumor resections, thereby enhancing outcomes and reducing operative risks.

Chemotherapy

Chemotherapy involves the administration of drugs, either orally or intravenously, designed to destroy tumor cells. The effectiveness of chemotherapy varies widely depending on the type of brain tumor being treated. Some tumors are highly responsive to chemotherapeutic agents, while others

show limited sensitivity. Commonly observed side effects include nausea, vomiting, and hair loss, with severity influenced by the specific medication and dosage employed. Chemotherapy is often used in combination with other treatment modalities to maximize efficacy and manage tumor growth.

Particle Therapy

Particle therapy represents an advanced form of radiation therapy increasingly utilized for brain tumor treatment, particularly when surgical options are limited. According to a review published by Dr. Meetu Jain on January 10, 2025 [6], particle therapy employs charged particles—such as protons or heavier ions—to target tumor tissues precisely. This method allows for maximal radiation dosing to the tumor while sparing surrounding healthy brain tissue, thereby minimizing collateral damage. Particle therapy has shown high efficacy in treating various types of brain tumors, including gliomas and metastatic brain tumors. The precision and reduced side effect profile make it a highly promising treatment modality.

Laser Therapy Applications

Recent technological advancements have led to the development of laser therapy as a non-invasive option for brain tumor management. This technique uses highly focused laser beams to shrink or inhibit tumor growth without the need for open surgery. Laser therapy is painless and offers a viable alternative for patients who may not be suitable candidates for conventional surgical procedures due to tumor location, patient health status, or other contraindications. The ability to minimize collateral damage while effectively targeting tumor tissue positions laser therapy as an innovative and promising option in the evolving landscape of brain tumor treatment.

Complications of Brain Tumors

Patients diagnosed with brain tumors often experience a wide range of complications, which can significantly affect their quality of life and overall prognosis. According to a review published by Jinyoung Park and Yoon Ghil Park in November 2022 [2], brain tumor complications are diverse and multifaceted, including both direct neurological impairments and secondary psychological effects. Below are some of the most common complications observed in patients with brain tumors:

1. **Seizures:** Seizures are one of the most common complications in patients with brain tumors, occurring in a significant proportion of individuals across different types of tumors. Seizures are reported in approximately 20%–40% of patients with high-grade tumors, 50%–85% of those with low-grade tumors, and 15%–20% of those with brain metastases. The presence of seizures in brain tumor patients often requires careful management, as they can complicate rehabilitation and treatment efforts.

2. **Cognitive Dysfunction:** Cognitive dysfunction, including attentional deficits, memory impairment, and overall cognitive decline, frequently occurs in patients with brain tumors. These cognitive changes can significantly hinder rehabilitation efforts. In cases where chemotherapy has been administered, cognitive decline is primarily associated with elevated cytokines, DNA damage, and neurotoxic effects on brain white matter. Moreover, secondary factors such as fatigue, depression, and psychosomatic symptoms may also exacerbate cognitive dysfunction. Research indicates that 50%–90% of patients who survive more than six months after radiation therapy experience radiation-induced cognitive dysfunction, further complicating long-term recovery.

3. **Headache:** Headaches are a prevalent symptom in patients with brain tumors, affecting approximately 50% of these individuals. Among these, tension headaches are the most common, occurring in around 78% of affected patients. These headaches can significantly impede rehabilitation efforts and reduce motivation, making appropriate management essential to improving patients' overall well-being.

4. **Mood Disorders:** The diagnosis of a brain tumor can lead to the development of mood disorders, with major depressive disorder affecting up to 42% of patients at the time of diagnosis. This depression can worsen over time, particularly in patients experiencing cognitive and functional impairments, which further reduces their quality of life. Addressing mood disorders is critical in the comprehensive care of brain tumor patients to enhance both their emotional and functional recovery.

5. **Other Complications:** Brain tumor patients may also face a variety of other complications, including pain, physical weakness, infections, memory disorders, and communication difficulties. These issues can range from mild to severe and require a multidisciplinary approach to treatment and management.

6. **Ischemia:** Ischemia is another serious complication that can arise in patients with brain tumors. The surrounding edema or the tumor mass itself can exert pressure on blood vessels, restricting blood flow to the affected brain regions. This reduction in blood supply can lead to tissue damage and neurological dysfunction, further complicating the clinical management of brain tumors.

7. **Hemorrhage:** Hemorrhage, or bleeding within the brain, may occur as a result of the rupture of blood vessels within the tumor. This can lead to bleeding within the brain tissue, which can cause further neurological damage and requires immediate medical intervention to prevent exacerbating the patient's condition.

Brain tumors are a major concern to society due to their significant impact on public health, both at the individual and societal levels. In India, the prevalence of brain tumors is rising, with increasing awareness and advancements in diagnostic technologies bringing to light a growing number of cases. Despite these advances, the limited availability of specialized medical resources in rural areas and the high cost of treatment continue to be significant barriers, especially in a developing nation. The global burden of brain tumors is similarly alarming, with an estimated 300,000 new cases each year worldwide. Brain tumors can lead to debilitating symptoms and a reduced quality of life, particularly when diagnosed late, making early detection

and effective treatment essential. The complexities of brain tumors also pose challenges to medical research, requiring extensive studies on their causes, prevention, and the development of effective therapies. Factors such as lifestyle, genetics, and environmental exposures contribute to the increasing incidence of brain tumors, further highlighting the need for enhanced public awareness, improved healthcare infrastructure, and global collaborations to tackle this issue. Addressing brain tumors through early detection, improved healthcare access, and better treatment options is a pressing challenge for society at large.

Conclusion

Brain tumors remain a significant medical challenge, posing substantial concerns to both individual patients and society as a whole. Their complexity and unpredictability, combined with their impact on neurological health, make them a crucial area of research and healthcare attention. The causes of brain tumors are multifactorial, encompassing genetic, environmental, and lifestyle factors, but much remains to be understood. In countries like India, where healthcare disparities exist, early diagnosis and timely intervention are often hindered by factors such as lack of awareness, insufficient healthcare infrastructure, and financial constraints.

The signs and symptoms of brain tumors, though varied, require prompt recognition, as early-stage intervention can drastically improve outcomes. Diagnosis often involves advanced imaging techniques like MRI and CT scans, but accessibility to these diagnostic tools can be limited in rural or underdeveloped regions, further complicating early detection.

Treatment options, including surgery, radiation therapy, and chemotherapy, have evolved over the years, yet access to cutting-edge medical care remains unequal, especially in developing nations. India, with its large population and diversity, faces unique challenges in providing equitable and effective treatment for brain tumor patients. The global world, too, grapples with the growing incidence of brain tumors, necessitating international collaboration for research, healthcare advancements, and awareness campaigns.

The complications associated with brain tumors, including neurological deficits, cognitive impairments, and emotional challenges, extend beyond the physical realm, affecting the quality of life of patients and their families. In India, these complications often lead to significant social and economic burdens, underlining the need for improved support systems and rehabilitation services.

Ultimately, addressing the challenges of brain tumors requires a holistic approach involving better healthcare access, increased public awareness, investment in medical research, and a global effort to reduce the burden of this devastating disease. The collaboration between governmental bodies, healthcare providers, and global organizations is critical in ensuring that advancements in diagnosis, treatment, and care are accessible to all, regardless of geographic or economic barriers. By fostering such efforts, both India and the global community can make meaningful strides in combating brain tumors and alleviating the impact on affected individuals and society at large.

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