Contrast Enhanced Mri in the Evaluation of Intracranial Meningiomas

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***Abstract*—Meningiomas are the most common primary non-glial tumors of the central nervous system, arising from the meninges that envelop the brain and spinal cord, and while they are typically benign and slow-growing, a subset may behave aggressively or rarely become malignant. They account for 16–20% of all intracranial tumors and demonstrate an annual incidence of approximately 6 per 100,000 individuals, occurring about twice as frequently in women and most often diagnosed after the fifth decade of life, frequently as incidental findings. Symptomatic meningiomas manifest through compression or invasion of adjacent brain, spinal cord, or vascular structures, resulting in a broad spectrum of neurological deficits such as headaches, seizures, visual disturbances, hearing loss, balance problems, motor weakness, or sensory impairment. Although their etiology is often idiopathic, recognized risk factors include prior cranial irradiation, genetic syndromes such as neurofibromatosis type 2, and possibly head trauma, with a small proportion occurring in atypical extracranial locations. Magnetic resonance imaging (MRI) is the diagnostic modality of choice due to its superior tissue contrast, ability to differentiate intra- and extra-axial lesions, and characteristic radiological features, including iso- to hypointensity on T1, hyperintensity on T2 and FLAIR, restricted diffusion on DWI, avid homogeneous enhancement post-gadolinium administration, well-defined margins, and the classic dural tail sign. Nonetheless, atypical imaging appearances and overlapping features with other neoplastic or non-neoplastic entities can pose diagnostic challenges. Meningiomas may arise from virtually any dural surface, with common sites including the parasagittal region, cerebral convexity, sphenoid wing, middle cranial fossa, olfactory groove, and cerebellopontine angle, while rarer sites include the optic nerve sheath, choroid plexus, sella turcica, spine, or even extracranial regions such as the temporal bone, mandible, or mediastinum. Management strategies depend on tumor size, growth rate, location, and symptomatology, ranging from careful observation in small, asymptomatic cases to surgical resection as the mainstay of treatment, with adjunctive options such as radiotherapy or, in select cases, targeted pharmacological therapy employed to control progression or recurrence.**

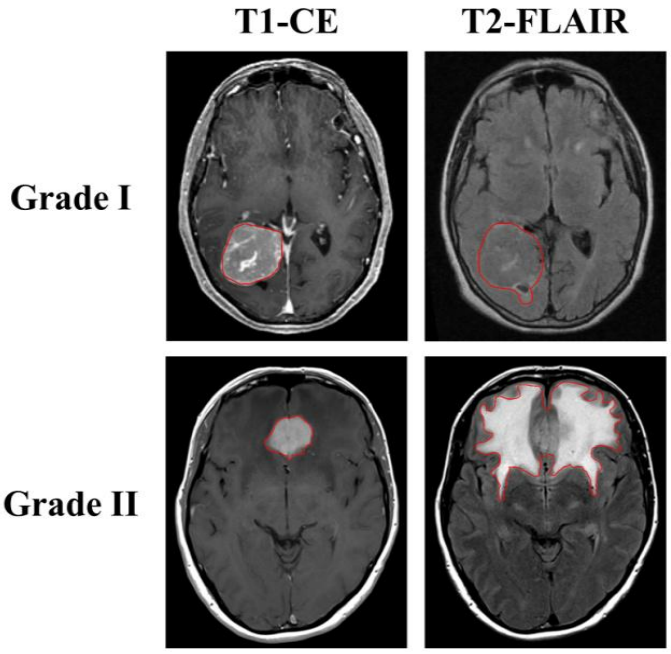
***Index Terms*—Meningioma, Diagnosis, Magnetic resonance imaging, Spectroscopy, Diffusion tensor imaging**

I. INTRODUCTION

Meningiomas are primary brain tumors that develop from the meninges, the protective layers covering the brain and spinal cord, and while they are generally slow-growing and most often benign, a subset may display aggressive behavior and in rare instances become malignant. They represent the most common type of primary brain tumor in adults and are classified into different histological subtypes based on their microscopic appearance, with their location varying along the meninges. As they enlarge, meningiomas can compress adjacent brain or spinal cord structures, leading to neurological manifestations that depend on the tumor's size and site of involvement. Patients may present with a wide range of symptoms, including persistent headaches, seizures, visual disturbances, hearing impairment, balance difficulties, limb weakness, or sensory loss. Diagnosis is usually established through neuroimaging techniques such as MRI or CT scans, which provide information about the tumor's size, location, and radiological characteristics.

Management strategies are tailored to the individual case and may involve careful observation in patients with small, slow-growing, and asymptomatic tumors, while larger or symptomatic meningiomas often require surgical resection, with adjuvant options like radiation therapy or, in select cases, targeted drug therapy considered to control growth or recurrence.

Meningiomas are the most common non-glial tumours of the central nervous system (CNS), accounting for between 16 and 20 % of all intracranial tumours . Magnetic resonance imaging (MRI) is the modality of choice for the investigation of meningiomas, providing superior contrast differentiation and usually the ability to differentiate between intra- and extra-axial lesions.There are a number of characteristic imaging features of meningiomas on magnetic resonance imaging (MRI) that allow an accurate diagnosis, however there are a number of atypical features that may be diagnostically challenging. Furthermore, a number of other neoplastic and non-neoplastic conditions may mimic meningiomas.



II. EPIDEMOLOGY

Meningiomas have an annual incidence of approximately 6 cases per 100,000 individuals and occur about twice as frequently in women compared to men. They are most commonly diagnosed after the fifth decade of life and are often detected incidentally, as many remain asymptomatic, with a reported prevalence of 2–3% in the elderly population. When symptoms do develop, they are typically the result of compression of surrounding neural structures, direct invasion of brain tissue, reactive changes, or obstruction of cerebrospinal fluid (CSF) pathways and vascular structures, leading to a wide spectrum of clinical manifestations. Although the majority of meningiomas arise spontaneously and without a clearly defined cause, several risk factors have been recognized, including prior exposure to cranial irradiation and genetic predispositions such as neurofibromatosis type 2, where patients often present with multiple tumors. A possible association with head trauma has also been suggested, though the causal relationship in this context remains uncertain.

III. CLINICAL OVERVIEW OF MENINGIOMAS

Meningiomas are tumors that originate from the meninges, which are the layers of tissue covering the brain and spinal cord. These tumors are typically slow-growing and are usually benign (non-cancerous) in nature. However, some meningiomas can exhibit more aggressive behavior and rare cases can be malignant (cancerous). Meningiomas are the most common type of primary brain tumor in adults. They

are often classified based on their appearance under a microscope and can have various subtypes. These tumors can arise from different locations along the meninges and can press against the brain or spinal cord as they grow, potentially causing neurological symptoms depending on their size and location.

Common symptoms of meningiomas include headaches, seizures, changes in vision, hearing loss, balance problems, weakness, and numbness in the limbs, among others. The severity of symptoms depends on the tumor's location and size.

Meningiomas are typically diagnosed through imaging techniques such as MRI and CT scans, which can show the location, size, and characteristics of the tumor. Treatment options include observation (for slow-growing and asymptomatic tumors), surgical removal, radiation therapy, and in some cases, targeted drug therapy.

MRI appearance of Meningiomas

The appearance of a meningioma on MRI can vary depending on factors such as the tumor's location, size, subtype, and other characteristics. Here are the key observed features in the MRI of meningiomas:

T1-Weighted Images:

Meningiomas typically appear iso- to hypointense on T1-weighted images. This means they often have similar or slightly lower signal intensity compared to the adjacent brain tissue. The exact appearance can vary based on factors like tumor composition and the presence of calcifications.

T2-Weighted Images:

On T2-weighted images, meningiomas often appear hyperintense. This hyperintensity is due to the relatively high-water content in these tumors. The tumor's appearance can sometimes be heterogeneous, with areas of varying signal intensity.

FLAIR Images:

In Fluid-Attenuated Inversion Recovery (FLAIR) images, meningiomas generally present as hyperintense lesions, emphasizing their relatively high-water content.

DWI Images:

In Diffusion-Weighted Imaging (DWI), meningiomas typically appear hyperintense, indicating restricted diffusion due to their cellular structure. This heightened signal contrasts with the surrounding brain tissue.

Post-Contrast Images (Gadolinium-Enhanced Images):

One of the distinctive features of meningiomas is their avid uptake of contrast material (gadolinium) on MRI. After the administration of contrast, meningiomas typically enhance strongly and uniformly. The degree of enhancement can provide information about the tumor's vascularity and characteristics.

Tumor Margins:

Meningiomas often have well-defined margins, which can help differentiate them from other types of brain tumors. This clear demarcation between the tumor and surrounding brain tissue is one of the features that make them distinguishable on MRI.

Dural Tail:

A characteristic feature associated with many meningiomas is the "dural tail." This is an area of enhancement extending from the tumor into the adjacent dura mater (the outermost layer of the meninges). The dural tail is thought to be caused by reactive changes in the adjacent dura due to the tumor.

IV. LESIONS AND LOCATIONS

Meningiomas can arise from virtually any site along the external surfaces of the brain as well as within the ventricular system, where they originate from stromal arachnoid cells of the choroid plexus. The most frequent sites of occurrence include the parasagittal region of the cerebral convexity, the lateral convexity of the hemispheres, the sphenoid wing, the middle cranial fossa, and the olfactory groove. When located at the skull base, these tumors may extend through natural foramina into adjacent structures, such as the orbit or along the course of the trigeminal nerve. In the posterior fossa, meningiomas are the second most common mass lesion of the cerebellopontine angle after vestibular schwannomas. Less frequent sites include the optic nerve sheath, accounting for about 0.4–1.3% of cases, and the choroid plexus, where they occur in approximately 0.5–3% of cases, most commonly within the trigone of the lateral ventricle in adults. They may also occur in the region of the sella turcica. Around 10% of meningiomas are spinal in origin, while a very small proportion, approximately 1%, arise entirely outside the dura and may be purely extracalvarial, calvarial, or calvarial

with extracalvarial extension. Reported extracranial sites include the temporal bone, mandible, mediastinum, and even the lung. The pathogenesis of these rare ectopic meningiomas is thought to involve meningocytes or arachnoid cap cells becoming trapped within cranial sutures during brain remodeling at birth, their displacement following trauma, or meningothelial differentiation from multipotential mesenchymal precursors.

V. CONCLUSION

MRI has a promising role in predicting meningioma grade prior to resection, which can directly impact patients' management protocols regarding surgical planning and complications.

Meningiomas are the most frequently encountered extra-axial tumors of the central nervous system and are known for their wide spectrum of imaging appearances. On MRI, they can exhibit both typical and atypical features, making their diagnosis sometimes challenging. A thorough understanding of these imaging characteristics is crucial for radiologists, as meningiomas can closely resemble several other intracranial lesions. Recognizing the diverse manifestations of meningiomas on imaging enables accurate differentiation from their mimics, ensuring proper diagnosis and management.

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