CHAPTER 2

CLASSIFICATIONS OF BRAIN TUMOR

2.1 INTRODUCTION

This chapter begins with an outline of brain anatomy and the magnetic resonance imaging in brain tumors. Section 2.4 gives a definition of brain tumor and its associated components. In Section 2.5 brain tumors classification will be given and Section 2.6 will present the characteristics of most brain tumors. Sections 2.7 and 2.8 describes the classification of tumors based on their location and their radiologic appearance. Finally, conclusions are given in Section 2.9.

2.2 BRAIN ANATOMY

The nervous system is commonly divided into the central nervous system (CNS) and the peripheral nervous system. The CNS is made up of the brain, its cranial nerves and the spinal cord (Elain Marieb 2000). In this section the brief study of cell structures and anatomical components of the brain are presented. The brain consists mainly of two tissue types: gray matter (GM) and white matter (WM) as shown in Figure 2.1. Gray matter is made of neuronal and glial cells, also known as neuroglia or glia that control brain activity, while the cortex is a coat of gray matter that covers the brain and the basal nuclei are the gray matter nuclei located deep within the white matter. The basal nuclei include: caudate nucleus, putamen, pallidum and claustrum as shown in Figure 2.1. White matter fibers are myelinated axons
which connect the cerebral cortex with other brain regions. The corpus callosum, a thick band of white matter fibers, connects the left and right hemispheres of the brain (Elain Marieb 2000).

The cerebrospinal fluid (CSF) is also found within the brain and in the spinal cord that surrounds the brain and the spinal cord. The CSF consists of glucose, salts, enzymes and white blood cells. This fluid circulates through channels (ventricles) around the spinal cord and the brain to protect them from injury (Woolsey 2003). Between the skull and the brain there is another tissue, which is called the meanings. The meanings consist of three layers that protect the brain and spinal cord.

Anatomically the brain is composed of the cerebrum, the cerebellum and the brainstem as shown in Figure 2.2. The cerebrum, which forms the major part of the brain, is divided into two major parts by the longitudinal fissure: the right and left cerebral hemispheres. Each hemisphere is divided into 4 lobes or areas: the frontal lobe in the front of the brain, the parietal lobe behind the frontal lobe, the temporal lobe on each side of the brain and the occipital lobe at the back of the brain as illustrated in Figure 2.2 (Elain Marieb 2000).

The cerebellum is located at the back of the brain below the occipital lobes. It is separated from the cerebrum by tentorium (fold of dura). Like the cerebrum, it has a thin outer cortex of gray matter, internal white matter and small, deeply situated masses of gray matter. The brainstem is the lower extension of the brain, located in front of the cerebellum and connected to the spinal cord. It consists of gray matter surrounded by white matter fiber tracts. It has three structures: the midbrain, pons and medulla oblongata. The midbrain is located below the hypothalamus, the pons serves as a bridge between the medulla and midbrain, and the medulla is interconnected with the spinal cord as shown in Figure 2.2.
The ventricular system that provides the CSF is separated into four cavities called ventricles, which are linked by a sequence of holes called to as foramen, and tubes. Two ventricles enclosed in the cerebral hemispheres are called the lateral ventricles (first and second) and in touch with the third ventricle. The third ventricle is in the center of the brain, and its walls are made up of the thalamus and hypothalamus. The third ventricle connects with the fourth ventricle through a long tube (Woolsey 2003).

**Figure 2.1** Some brain structures illustrated on a schematic drawing (left) and on a slice of a MR image (right) (reproduced from (Elain Marieb 2000)).

**Figure 2.2** Anatomy of the brain (reproduced from (Elain Marieb 2000))
2.3 MAGNETIC RESONANCE IMAGING OF BRAIN TUMORS

For the treatment of patients with brain tumors, imaging of the brain is often indicated at different stages and usually has a significant role in each of them. Several stages of management may be considered:

- Detection or confirmation that a structural abnormality is present,
- Localization and assessment of the extent of any abnormality,
- Characterization of the abnormality,
- Assessment of the nature of a tumor,
- Facilitation of additional diagnosis procedures, and planning for surgery or other types of therapy,
- Intra operative control of rejection progress,
- Monitoring of response to therapy.

A variety of imaging techniques are used to study brain tumors, including Computed tomography (CT), Magnetic resonance (MR) imaging, Single photon emission computed tomographic (SPECT) imaging, Positron emission tomographic (PET) scanning, and Cerebral angiography. At this moment, CT and MR imaging are the most widely used techniques, because of their widespread availability and their ability to produce high resolution images of normal anatomic structures and pathological tissues.

CT is the fastest modality, making it the preferred examination for imaging critically ill or medically unstable patients. SPECT and PET imaging serve smaller roles, although their ability to provide information on tissue biology and physiology can be greatly helpful. PET scanning is also used to evaluate tumor grade.
2.3.1 Advantages and Limitations of MRI

MRI is the most frequently used neuroimaging technique for the evaluation and follow up review of patients with brain tumors for many reasons. It does not use ionizing radiation like CT, SPECT, and PET studies. Its contrast resolution is higher than the other techniques, making it preferable for detecting small lesions and isodense lesions on unenhanced CT. Also, it is more sensitive than CT to detect lesion enhancement. The ability of MRI devices to generate images in the sagittal, axial and coronal planes provides better localization of a lesion in the 3D space of the brain and allows structures involved by the tumor to be more clearly delineated. Finally, MR imaging eliminates the beam-hardening artifact produced by the skull base on CT, making it better for evaluating lesions in the posterior fossa and in the inferior frontal and temporal lobes. In addition to these well-known advantages, the development of MR spectroscopy, MR diffusion imaging, and MR perfusion imaging now permits evaluation of tumor biophysicsology with MR scanners. The acquisition of both functional and anatomical information about the tumor during the same scan may be the most important benefit of MR imaging (Ricci 2001).

There are numerous restrictions to MR imaging that must be acknowledged. Possibly the most important is a lack of specificity. Multiple pathologic lesions show hypointense on T1-weighted (T1w) images and hyperintense on T2-weighted (T2w) images. The MRI differential diagnosis for intracranial neoplasms includes infarcts, demyelinating lesions, radiation necrosis, infections, and other inflammatory processes. Although, enhancement does not always correspond to histologic tumor grade, in general, higher grade tumors will frequently show enhancement on MR imaging. However, an exception to this rule is seen in a very slow-growing tumor such as Juvenile pilocytic astrocytoma (JPA), which will frequently
show contrast enhancement areas within the tumor. Similarly, some higher grade tumors will not enhance. Hence, even if MR features of a lesion can be useful, but from time to time histologic confirmation is necessary to set up a diagnosis. MR imaging is also not able to distinguish the edge of a tumor, or determine the full extent of disease. Viable tumor cells are known to exist beyond the borders of abnormal contrast enhancement. Imaging abnormalities seen following treatment are sometimes nonspecific. Radiation injury, including radiation necrosis, is virtually in differentiable from tumor regrowth. Hence, MRI alone cannot be applied to determine whether tumor is present or not following such a therapy. In spite of these limitations, MRI remains the standard imaging method in neurooncology.

2.3.2 MRI Principle

Magnetic resonance imaging (MRI), Nuclear magnetic resonance imaging (NMRI), or Magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize detailed internal structures. MRI makes use of the property of Nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body.

An MRI machine uses a powerful magnetism field to align the nuclear magnetic moment of some atom in the body, and radio frequency fields to systematically alter the alignment of this magnetization. This causes the nuclei to produce a rotating magnetic field detectable by the scanner and this information is recorded to construct an image of the scanned area of the body. Strong magnetic field gradients cause nuclei at different locations to rotate at different speeds. The 3-D spatial information can be obtained by providing gradients in each direction.
The body is largely composed of body water. Each water molecule has two hydrogen atomic nuclei or proton. When a person is inside the powerful magnetic field of the scanner, the magnetic dipole moment of some of these protons becomes aligned with the direction of the field. A radio frequency transmitter is briefly turned on, producing a further varying electromagnetic field. The photons of this field have just the right energy, known as the resonance frequency to be absorbed and flip the spin (physics) of the aligned protons in the body. The frequency at which the protons resonate depends on the strength of the applied magnetic field. After the field is turned off, those protons which absorbed energy revert back to the original lower-energy spin-down state. Now a hydrogen dipole has two spins, one high spin and one low. In low spin both dipole and field are in parallel direction and in high spin case it is anti parallel. They release the difference in energy as a photon, and the released photons are detected by the scanner as an electromagnetic signal, similar to radio waves. As a result of conservation of energy the resonant frequency also dictates the frequency of the released photons. The photons released when the field is removed have energy and therefore a frequency in which depends upon the energy absorbed while the field was active. It is this relationship between field-strength and frequency that allows the use of nuclear magnetic resonance for imaging. An image can be constructed because the protons in different tissues return to their equilibrium state at different rates, which is a difference that can be detected. More information about the physics of MRI can be found in (Hornak 2010).

2.3.3 MRI Modalities

The changeable activities of protons within different tissues direct to differences in tissue look. The quantity of signal created by definite tissue types is calculated by their number of mobile hydrogen protons, the speed at which they are moving, and the tissue’s T1 and T2 relaxation times
(Armstrong 2004, Lee 2004). T1 is the time required for the protons within the tissue to go back to their original state of magnetization and T2 is the time required for the protons perturbed into coherent oscillation by the radiofrequency pulse to drop this coherence. As T1 and T2 relaxation times are time dependent, the timing of the RF pulse and the evaluation of the radiated RF energy alter the appearance of the image. There are further timing also used during imaging, they are, the repetition time (TR) describes the time between consecutive applications of RF pulse sequences and the echo time (TE) describes the delay before the RF energy radiated by the tissue in question is measured. The pulse sequence, which is described by the TR and TE and indicates the technique used to administer the RF energy, can be chosen to maximize the effect of differences in T1 or T2. This gives rise to the description of an MRI image as T1 or T2 weighted.

The standard MRI pulse sequence for anatomic and pathologic detail is a spin echo sequence. T1-weighted images (short TR, short TE) provide better anatomic detail, while T2 weighted images (long TR, long TE), which are more sensitive to water content, are more sensitive to pathology. The intermediate or proton density images (long TR, short TE) provide improved contrast between lesions and cerebrospinal fluid.

Fluid-attenuated inversion recovery (FLAIR) image is another pulse sequence that is helpful in detecting low contrast lesions. With FLAIR (long T1, long TR, and variable TE), the CSF signal is cancelled, activating pathology adjacent to the CSF to be seen more noticeably, i.e. FLAIR sequence produces heavily T2-weighted and CSF-cancelled MR image. Much information confirms the supremacy of the FLAIR sequence over conventional spin-echo (SE) sequences with respect to disease (Saleh 2004). This method has assumed a vital role in routine brain imaging because of its presumed ability to improve the visibility of brain lesions compared with that
of proton density weighted and of T2-weighted spin-echo sequences. FLAIR images augment the detection accuracy for non enhanced tumor in compare T1 and T2-weighted images.

To highlight the regions of abnormality, paramagnetic contrast agents like gadolinium, may be injected during MRI acquisitions. After injection, the gadolinium remains in the vascular system of the brain, except where the blood-brain barrier has been interrupted. A several processes can disrupt the blood-brain barrier, ranging from head trauma to brain tumors (Armstrong 2004). Certain structures within the brain like the pituitary gland, pineal gland, pituitary infundibulum, choroids plexus, and veins, in which the blood-brain barrier is not intact, normally display contrast enhancement. Thus, contrast enhanced T1-weighted (CE-T1w) images provide anatomic details of the brain and distinguish tumor from edema. Figure 2.3 includes an example of T1-weighted, contrast enhanced T1-weighted, FLAIR, and T2-weighted images of a high grade glioma.

![MRI images](image)

**Figure 2.3** MRI of brain. (a) T1-weighted image without contrast enhancement. (b) T1-weighted image with contrast enhancement. (c) T2-weighted image. (d) FLAIR image (Armstrong 2004).

MRI is evolving rapidly and newer imaging sequences, such as echoplanar MRI, are being developed, reducing scan times and improving the information obtained from the images (Wen 2001). Echoplanar MRI can scan images in less than 100 milliseconds and provides information on tumor
diffusion and perfusion. Diffusion weighted MR imaging permits the 
assessment of the mobility of water molecules and may be useful in helping to 
distinguish tumor from edema, cystic changes, and normal white matter.

Magnetic resonance spectroscopy (MRS) is a non-invasive method 
which permits the investigation of tumor metabolism and gives information 
on the composition and spatial distribution of cellular metabolites. There is 
presently a great interest in evaluating the worth of MRS for non-invasive 
diagnosis of tumors, determining tumor grade, and distinguishing tumor from 
radiation effects (Wen 2001).

Functional Magnetic Resonance Imaging (fMRI) is used to 
visualize brain function by recording changes in the chemical composition of 
areas of the brain caused by changes in blood flow that occur over intervals of 
seconds to minutes. This technique, which provides both an anatomic and 
functional view of the brain, is currently being used for surgical planning for 
the removal of lesions that impinge on visual or speech areas of the brain 
(Armstrong 2004).

MR angiography (MRA) displays the blood vessels in the brain in a 
non-invasive manner. It is mostly used in preference to conventional 
angiography, although angiography has better resolution and is still necessary in certain situations (Wen 2001).

This review concludes that the contrast enhanced-T1weighted (CE-
T1w) and FLAIR images are enough for segmentation of the most of brain 
tumors. Hence in the proposed methods for brain tumor segmentation in 
Chapters 4-7, the CE-T1w and FLAIR images are the inputs of the system.
2.4 **BRAIN TUMOR AND ITS APPEARANCE IN MRI**

A brain tumor is an intracranial mass formed by an uncontrolled growth of cells either usually found in the brain such as neurons, glial cells, lymphatic tissue, blood vessels, pineal gland and pituitary, skull, or spread from cancers primarily positioned in other organs. Brain tumors are classified based on the type of tissue involved, the location of the tumor, whether it is benign or malignant, and other considerations.

Primary brain tumors are the tumors that originated in the brain and are named for the cell types from which they originated. They can be benign (non cancerous), meaning that they do not spread elsewhere or march into surrounding tissues. They can also be malignant and invasive (spreading to neighboring area). Secondary or metastasis brain tumors take their origin from tumor cells which spread to the brain from another location in the body. Most often cancers that spread to the brain to cause secondary brain tumors originate in the lumy, breast, and kidney or from melanomas in the skin.

In each primary brain tumor there are other connected parts such as edema and necrosis as in Figure 2.4. Edema is one of the main factors leading to mortality associated with brain tumors. By definition, brain edema is an increase in brain volume due to increased sodium and water content and results from local disruption of the blood brain barrier (BBB). Edema appears around the tumor mainly in white matter regions. Tumor associated edema is visible in MRI, as either hypointense (darker than brain tissue) or rarely isointense (same intensity as brain tissue) in T1-weighted scans, or hyperintense (brighter than brain tissue) in T2-weighted and FLAIR MRI (Figure 2.4). Necrosis is composed of dead cells in the middle of the brain tumor and is seen hypointense in T1-weighted images (Figure 2.4). A brain tumor may also infiltrate the surrounding tissues or deform the surrounding structures.
2.5 BRAIN TUMOR CLASSIFICATIONS

The classification of primary brain tumors is generally depends on the origin of the tissue and rarely on tumor location. Bailey and Cushing (Doolittle 2004) provided the initial brain tumor types in 1926. Their classification system proposed 14 brain tumor types, aimed at important concentration to the process of cell differentiation, and dominated views of gliomas until 1949 when a new system was introduced by Kernohan and Sayre (Doolittle 2004). Kernohan and Sayre given the important insight that different histopathologic appearances may not correspond to separate tumor types but rather different degrees of differentiation of one tumor type. They classified tumors into five subtypes: astrocytoma, oligodendroglioma, ependymoma, gangliocytoma, and medulloblastoma and very importantly added a four-level grading system for astrocytomas. The grading system was based on increasing malignancy and decreasing differentiation with increasing tumor grade. The addition of a grading system was a very important advance in classifying brain tumors, and provided information not only regarding tumors’ biologic behavior but also information that could be used to guide treatment decisions.
Daumas-Duport (2000) contributed significantly to the advances in brain tumor classification. They have developed the discrete variable classification system whereby tumors are graded based on the presence or absence of four cellular features: nuclear atypia, mitoses, endothelial cell proliferation, and necrosis. For example, grade I brain tumors have none of the four cellular features, grade II tumors have one of the features, grade III tumors have two features, and grade IV tumors have three or four features. The Daumas-Duport scheme has become known as the St-Anne classification system.

2.6 WHO CLASSIFICATIONS

The properties and characteristics of most general tumors of World Health Organization (WHO) classifications are reviewed in this section. In this review the discussion on the appearance of tumors in MRI images, the grade of tumors and some general information which will be helpful in the detection, segmentation and understanding of brain tumors in MRI are presented.

2.6.1 Gliomas

A brain tumor that develops from glial cells is called a glioma. About half of all primary brain tumors and one-fifth of all primary spinal cord tumors form from glial cells. Gliomas tend to grow in the cerebral hemispheres, but may also occur in the brain Stem optic nerves, spinal cord, and cerebellum. Gliomas are divided into subgroups depending on the origin of the glial cells. There are several types of gliomas, categorized by where they are found, and the type of cells that originated the tumor. The review of astrocytoma, gangliogioma, oligodendroglioma and ependymoma that are the most common types of gliomas are discussed here.
• **Astrocytoma**

Astrocytomas are primary brain tumors originated from connective tissue cells called astrocytes, which are star-shaped glial cell. They are the most common type of the brain tumors and account about 40% of all primary brain tumors. Astrocytomas are included in the category of malignant tumors, WHO and St-Anne grading system grade them based on the appearance of certain characteristics: atypia, mitoses, endothelial proliferation, and necrosis (Daumas-Duport 2000, Lopes 2002). These features reflect the malignant potential of the tumor in terms of invasion and growth rate. Tumors without any of these features are grade I, and those with one of these features (usually atypia) are grade II, tumors with 2 criteria and tumors with 3 or 4 criteria are WHO grades III and IV, respectively. Thus, the low grade groups of astrocytomas are grades I and II and high grade astrocytomas are grade III and IV.

• **Low grade astrocytoma (grades I and II)**

This type of tumors are distinguished well and develop comparatively slowly but can spread to nearest tissue. In common, low grade gliomas produce less mass effect than high grade astrocytomas, because they develop more slowly and stimulate small vasogenic edema. The position of these tumors is the cerebral hemisphere, the cerebellum or brainstem. Most common tumors of this type are pilocytic astrocytoma and diffuse astrocytoma which arise generally in children and young adults (Wen 2001, Henson 2005, Emedicine 2005). Both CT and MRI scan can help in the diagnosis of low grade astrocytoma. Generally, MRI is considered the study of choice. In MRI, low grade gliomas show decreased signal relative to surrounding brain on T1 sequences as shown in Figure 2.5. In T2 sequences and FLAIR, higher signal reflects both the tumor and surrounding edema.
(if exist) as shown in Figure 2.6. Pilocytic astrocytomas are often associated with a cyst, which may be particularly prominent on T2-weighted sequences. There is usually little or no contrast enhancement in MRI as shown in Figure 2.6 (Wen 2001, Henson 2005).

**Figure 2.5** Low grade astrocytoma. a) An axial slice of a T1-weighted image. b) An axial slice of a T2-weighted image. c) A sagittal slice of a contrast enhanced T1-weighted image (Emedicine 2005).

**Figure 2.6** Diffuse low grade astrocytoma (Grade II) (a) Coronal slice of contrast enhanced T1-weighted image. No enhancement is present with contrast enhancement. (b) Axial slice of T2-weighted image of the same tumor without surrounding edema (Emedicine 2005).
• High grade astrocytoma (grades III and IV)

Anaplastic astrocytoma and glioblastoma multiform (GBM) are most common tumors of this type and account approximately 30% of all primary brain tumors. These tumors grow more rapidly and infiltrate other nearby healthy cells. They are not well differentiated. Both types of high grade astrocytomas have similar presentation features. In general they tend to be less circumscribed than low grade astrocytomas and surrounded with more edema. The difference between anaplastic astrocytomas and GBMs is in appearance of necrosis in GBMs. High grade astrocytomas have a variable radiographic appearance. Anaplastic astrocytomas may appear as low density lesions or inhomogeneous lesions, with areas of both high and low density within the same lesion. Unlike low grade lesions, partial contrast enhancement is common. GBM is the most common and most malignant of the glial tumors. Composed of poorly differentiated neoplastic astrocytes, GBMs primarily affect adults, and they are located preferentially in the cerebral hemispheres. Much less commonly, GBMs can affect the brain stem in children and the spinal cord. These tumors may develop from lower-grade astrocytomas (grade II) or anaplastic astrocytomas (grade III) (Wen 2001, Mahesh 2004).

As shown in Figure 2.7, these tumors and surrounding edema have low signal intensity in T1-weighted and high signal intensity in T2-weighted MR images and enhancement is common. Hemorrhage may be present but calcification is unusual unless the tumor arise from a pre-existing lower grade lesion. These tumors are likely to penetrate along white matter tracts as in Figure 2.7 and often occupy and traverse the corpus callosum.
Figure 2.7  Glioblastoma multiform. a) Axial slice of T1-weighted image without Contrast enhancement. b) Same slice with contrast enhancement. c) Sagittal view of this tumor. d) T2-weighted image of the same tumor with surrounding edema. e) FLAIR image. f) Coronal slice of T1-weighted image (Emedicine 2005).

GBMs typically have an enhancing ring observed in T1-weighted images as in Figure 2.8 and a broad surrounding zone of edema apparent in T2-weighted images. The central hypodense core represents necrosis, the contrast-enhancing ring is composed of highly dense neoplastic cells with abnormal vessels permeable to contrast agents, and the peripheral zone of nonenhancing low attenuation is vasogenic edema containing varying numbers of invasive tumor cells. Several pathological studies have clearly shown that the area of enhancement does not represent the outer tumor border because infiltrating glioma cells can be identified easily within a 2cm margin (Emedicine 2005).
Figure 2.8  Glioblastoma multiform. a) Contrast enhanced axial T1-weighted of a ring enhanced tumor (necrotic). b) Axial T2-weighted image of the same tumor showing the surrounding edema (Wen 2001).

- Ganglioglioma

These tumors are gradually developing tumors present in children and young adults. Temporal lobes and cerebellar hemispheres are the most general positions for this type of tumors. In this type of tumors no surrounding edema is seen as shown in Figure 2.9, but usually they are contain with cyst.

The radiological look is nonspecific. The tumors look like oligodendrogiomas and show hypointense (darker than GM and brighter than CSF) in T1-weighted images and hyperintense in T2-weighted images with changeable enhancement (Figure 2.9) (Wen 2001). They do not enhance in CE- T1w images.
Figure 2.9 Ganglioglioma. (a) Contrast enhanced axial T1-weighted MRI showing non-enhancing hypointense frontal tumor. (b) The same lesion appears hyperintense on T2-weighted MRI (Wen 2001).

- **Oligodendroglioma**

These tumors are the other most general type of glioma, conventionally thought to include 2% to 5% of primary brain tumors and 4% to 15% of gliomas. It is understood that, in the past, many tumors that are actually oligodendrogliomas are diagnosed to be different types of astrocytomas. Also, with the best brain imaging provided by MRI, gliomas are being diagnosed more correctly than in the past. They are commonly slowly growing tumors and are often positioned within the frontal, temporal or parietal lobes. Cystic degeneration is common but hemorrhage and edema are uncommon. Oligodendrogliomas are unique, consisting of homogeneous, compact, rounded cells with distinctive borders and clear cytoplasm surrounding a dense central nucleus, giving them a “fried egg” appearance as shown in Figures 2.10 and 2.11.

With respect to St-Anne grading system, there are grade A and grade B of these tumors. In grade A contrast enhancement and necrosis
cannot be seen as shown in Figure 2.10 but in grade B contrast enhancement and necrosis are seen as shown in Figure 2.12. The tumor is usually positioned in the cortex and white matter, and penetration of the overlying leptomeninges may be seen (Engelhard 2003). MRI is the preferred modality. T1-weighted images generally display a hypointense mass as shown in Figures 2.10 and 2.11. T2-weighted images show a hyperintense mass with surrounding edema as shown in Figures 2.10 and 2.11.

Figure 2.10 Low grade oligodendroglioma. a) Non enhanced tumor in axial slice of contrast enhanced T1-weighted image. b) Same tumor on FLAIR. c) Sagittal view of the tumor (Emedicine 2005).

Figure 2.11 A cystic oligodendroglioma. a) Axial T1-weighted, showing varying degrees of hypointensity. b) T2-weighted image showing hyperintensity, especially of the central cyst. c) Contrast enhanced T1-weighted image showing ring formation at both the tumor-cyst, and tumor-brain interfaces (Engelhard 2003).
Figure 2.12 High grade oligodendrogloma. a) Contrast enhanced T1-weighted image. b) T2-weighted image from the same patient, showing isointense to hyperintense appearance of the mass (Engelhard 2003).

- Ependymoma

These tumors as shown in Figure 2.13 are glial tumors that begin from ependymal cells within the brain. This tumor is histologically benign but acts malignantly. Intracranial lesions generally start from the top of the fourth ventricle in children, while spinal ependymomas naturally arise in adults. Here the analysis of intracranial ependymoma is present.

Figure 2.13 Ependymoma. a) Axial view of contrast enhanced T1-weighted image. b) T2-weighted image
The existence of edema is unusual and polar cysts may be seen. With the management of contrast agent, the tumors generally enhance greatly and homogeneously. Ependymomas appear hypointense in T1-weighted and hyperintense in FLAIR images. Since this tumor is linked to ventricles, to differentiate the tumor from ventricles, FLAIR images are used. Ependymomas are usually hyperintense on T2-weighted sequences. In some cases, contrast enhancement of a cystic ependymoma may be minimal. In these cases, differentiating these tumors from intramedullary astrocytomias is intricate (Wen 2001, Henson 2005).

2.6.2 Medulloblastoma

Medulloblastoma most frequently arises in the posterior fossa of the brain. The tumor has the probable of spreading throughout the CNS. Cysts, areas of necrosis, and calcification are rare but edema is common. Adults, more frequently than children, can have the desmoplastic variant of medulloblastoma. This form of the tumor is positioned laterally in the hemisphere with unclear borders and small cystic or necrotic areas (Emedicine 2005).

MRI with the injection of gadolinium is the diagnosis test of option for medulloblastoma. Tumors appear hypointense on T1-weighted images, usually seen going up to the fourth ventricle. The brain stem is compressed and shifted vertically. By the administration of gadolinium in children, homogeneous enhancement normally occurs, whereas in adults, a more heterogeneous pattern is generally seen as shown Figure 2.14. T2-weighted and FLAIR images demonstrate a hyperintense mass with a surrounding area of edema as shown Figure 2.14. MRI can help distinguishing medulloblastoma from ependymoma: the latter extends further into the lateral
recess of the fourth ventricle. MRI can also assist to differentiate between medulloblastoma and exophytic brainstem glioma (Wen 2001).

![Image of MRI scans](image)

Figure 2.14 Medulloblastoma. a) Contrast enhanced axial T1-weighted image showing irregularly enhancing tumor in the cerebellar vermis. b) Axial T2-weighted MRI of the same patient showing increased signal in the tumor (Wen 2001).

### 2.6.3 Lymphoma

These tumors are normally occurring in the subcortical and subependymal white matter. Inside the brain substance, the uneven tumor edge extends by the side of perivascular spaces. The spinal cord is regularly affected in secondary lymphoma. Lymphoma tumors are frequently multiple with central necrosis in AIDS. Tumor lesions can traverse the midline and may appear as a butterfly tumor relating both cerebral hemispheres.

Association of the perivascular spaces with contrast enhancement or of the corpus callosum is robustly indicative of CNS lymphoma (Plotkin 2001).

The typical look of lymphoma is a hypointense nodule or mass on T1- weighted images and hyperintense on corresponding T2-weighted images. On contrast enhanced T1-weighted MRI, lymphoma tends to enhance strongly and diffusely. A ring like enhancing pattern is seen most frequently
in patients with AIDS (Acquired immune deficiency syndrome) as shown 
Figure 2.15. Frequently, little or no surrounding vasogenic edema is displayed 

![Figure 2.15 Lymphoma tumor. a) Axial contrast enhanced T1-weighted 
image shows ring enhanced tumor. b) Sagittal view of the 
same patient (Emedicine 2005).]

2.6.4 Meningioma

These tumors are the most common benign tumors. It takes 25-30% 
of all primary brain tumors. Para-sagittal region is the location of this tumor. 
They are more common in women and be present in middle-aged and elderly 
patients. Even though meningiomas are benign tumors, they are often 
accompanied by edema (Engelhard 2001).

On T1-weighted images, most meningiomas are well-circumscribed 
extra-axial masses, which are usually isointense with gray matter. Other 
meningiomas are slightly hypointense to gray matter. Because of this, they 
may be hard to appreciate on T1- weighted images. On T2-weighted images, 
meningiomas have a more variable appearance as shown Figure 2.16, which 
seems to relate to the consistency of the tumor. Rapid growth may cause areas 
of central necrosis, which are hypointense on T1-weighted and hyperintense 
on T2-weighted images. Cyst formation and hemorrhage may occur in 
meningiomas, but are relatively rare (Engelhard 2001, Wen 2001).
With gadolinium contrast agent, meningiomas usually show a marked, homogeneous enhancement pattern on T1-weighted images as shown Figure 2.16. When gadolinium is used, the improved resolution of the newer MR scanners allows better delineation of the extent of tumor spread into dura adjacent to the tumor and the degree of tumor invasion into the dural sinuses. Edema from a meningioma may produce a surrounding lower intensity (darker) signal on T1-weighted images, but is better seen as a higher intensity (whiter) signal on the T2-weighted and FLAIR images. It has been stated that 70% of patients with meningiomas have at least some degree of peritumoral edema. (Lobato 1996) reported that meningiomas located along the frontal convexity or middle third of the falx are most likely to be associated with edema formation. The existence and period of symptoms, tumor mass, and cortical damage amount are other parameters that have been found to associate with the creation of edema neighboring to meningiomas. FLAIR images can be used to better describe meningioma from neighboring cerebrospinal fluid.

Figure 2.16  Meningioma tumor. a) Axial slice of T1-weighted image. b) The same tumor on contrast enhanced T1-weighted image. c) Coronal view of T2-weighted image (Emedicine 2005).
2.6.5 Craniopharyngioma

Craniopharyngiomas grow in the region of the brain called the hypothalamus, which is nearer to the pituitary gland. It is generally found in children or young adults and takes around 1% of all brain tumors. The mixed solid and cystic nature of the tumor is obvious on MR images. By MRI test, the tumor is of variable T1 signal, frequently hyperintense. The T1 hyperintensity is generally secondary to high protein substance in the cyst fluid as shown Figure 2.17. On T2-weighted sequences, including FLAIR, the solid section is again generally heterogeneous, whereas the cysts are consistently hyperintense. Following contrast agent, there is almost invariable enhancement of the solid section and the side-line border of the cystic section on MR image. The enhancement of the solid section may be either uniform or heterogeneous (Curran 2005).

![Figure 2.17 Craniopharyngioma. a) Coronal contrast enhanced T1-weighted image showing an enhanced solid portion of the tumor together with a hypodense cystic component on the right side of the tumor. b) Sagittal view of the same tumor (Wen 2001).](image)

2.6.6 Pituitary adenoma

Pituitary adenomas include about 7% of primary brain tumors. They occur from the frontal lobe of the pituitary gland. MRI is the imaging choice of it. Microadenomas come into sight as low intensity lesions on
T1-weighted images. Gadolinium enhances the standard gland adjoining to the adenoma and highlights the lesion as shown in Figure 2.18. Macroadenomas are generally isointense on T1-weighted images and enhance homogeneously with gadolinium as shown in Figure 2.18. They show hyperintense in FLAIR and T2-weighted images. The multiplanar means of MRI provides the full extent of bigger lesions to be visualized (Bonneville 2005).

![Image of MRI scans](image)

**Figure 2.18** Pituitary adenoma. a) Coronal T1-weighted MRI showing a large pituitary macroadenoma. b) Coronal MRI showing the same tumor enhancing with contrast enhancement. c) T2-weighted image of the same patient (Emedicine 2005).

### 2.7 TUMORS CLASSIFICATION BASED ON THE LOCATION

Basically, all brain tumors are considered localized unless they cross the midline or the tentorium or unless they are described as having “drop” metastases in the spinal cord. The tumors can be classified by their location into 3 classes: local tumors, regional tumors and distant tumors. Local tumors confined to one hemisphere in one part of brain, meninges and ventricular system as illustrated in Figure 2.19. Regional tumors cross midline or tentorium invades bone, blood vessel, nerves and spinal cord. Distant tumors are extending to nasal cavity, nasopharynx, and posterior pharynx and outside the CNS. Local tumors are considered in the research work carried out in this thesis.
2.8 TUMORS CLASSIFICATION BASED ON THE RADIOLOGIC APPEARANCE

The brain tumors can be categorized into four types using radiologic appearance of tumors. They are, Non-enhanced, Full-enhanced without edema, Full-enhanced with edema and Ring-enhanced tumors. The discussion of all these types are presented in this section.

2.8.1 Non-enhanced tumors

This type of tumors does not take contrast agent and appear hypointense (darker than GM) in CW-T1w and T1-weighted images as shown in Figure 2.20. They are generally without edema or small edema. In FLAIR and T2-weighted images, they show as hyperintense as shown in Figure 2.20. Low grade astrocytomas, gangliogliomas and oligodendrogliomas are most general tumors of this type.
Figure 2.20  A non-enhanced tumor. a) Axial slice of T1-weighted. b) The same slice of contrast enhanced T1-weighted. c) FLAIR image.

2.8.2  Full-enhanced tumors without edema

These type tumors enhance with contrast injection in T1w images and roughly all pixels of the tumor are occur hyperintense in CE-T1w as shown in Figure 2.21. These tumors are without edema and show hypointense in T1-weighted images and hyperintense in T2-weighted and FLAIR images as shown in Figure 2.23. Meningimoas, ependymomas, lymphomas, craniopharyngiomas and pituitary adenomas are in this class.

Figure 2.21  A full-enhanced tumor without edema. a) Axial slice of T1-weighted image. b) The same slice of contrast enhanced T1-weighted image. c) T2-weighted image.
2.8.3 Full-enhanced tumors with edema

These tumors have two parts, the solid part and edema. The solid part takes contrast material and looks as hyperintense in CW T1-weighted images and hypointense in T1-weighted images, while the edema appears hypointense in T1-weighted images and contrast enhanced T1-weighted images as shown in Figure 2.22. In FLAIR (Also in T2-weighted images) both parts of the tumor appear hyperintense as shown in Figure 2.22. Anaplastic astrocytomas (high grade), high grade oligodendrogliomas, PNETs and some type of meningiomas can be considered in this group.

![Image of MRI scans]

Figure 2.22 A full-enhanced tumor with edema. a) Axial slice of T1-weighted image. b) The same slice of contrast enhanced T1-weighted image. c) FLAIR image.

2.8.4 Ring-enhanced tumors

These tumors have 3 sections. The central section is necrosis and appears hypointense in contrast enhanced T1-weighted and T1-weighted images. The solid section surrounds the necrosis and takes contrast agent, hence appears hyperintense in contrast enhanced T1-weighted images and hypointense in T1-weighted images as shown in Figure 2.23.
Figure 2.23  A ring-enhanced tumor a) Axial slice of T1-weighted image  
b) The same slice of contrast enhanced T1-weighted image. 
c) FLAIR image  

The third section is the edema which surrounds the solid section. The edema appears hypointense in both T1-weighted and contrast enhanced T1-weighted images. In T1-weighted images the solid section, edema and necrosis are hypointense, while the necrosis is darker than the other sections. FLAIR images show the edema and solid section as hyperintense signal, while the necrosis section appears hypointense as shown in Figure 2.23.GBM and high grade oligodendrogliomas have these characteristics.  

2.9 CONCLUSION  

The outcome of this chapter is that the T1-weighted image is not a proper one for perfect tumor segmentation, while T2-weighted or FLAIR images are more enough for segmentation of non-enhanced tumors. With reference to these outcomes and tumors characteristics review, this research work used the contrast enhanced T1-weighted and FLAIR images for brain tumor segmentation. This conclusion directs the proposed methods to put forward a model for segmentation of brain tumors.