CHAPTER 2

ANATOMY AND IMAGING MODALITY

2.1 ANATOMY OF THE BRAIN

The human nervous system consists of the central nervous system (CNS) and peripheral nervous system (PNS). The former consists of the brain and spinal cord, while the latter composes the nerves extending to and from the brain and spinal cord. The primary functions of the nervous system are to monitor, integrate (process) and respond to information inside and outside the body.

The brain is an important and complex organ that consists of soft, delicate, non-replaceable neural tissue. It is supported and protected by the surrounding skin, skull, meninges and cerebrospinal fluid. Skin protects the brain from physical damage, infection and helps to maintain constant temperature. The brain is protected by a shell called skull. It consists of 22 bones, that is divided into cranial bones (or cranium) and the facial bones. The later provides framework to the face and the former houses the brain. Cerebrospinal fluid is a clear liquid produced within spaces in the brain called ventricles. It is also found inside the subarachnoid space of the meninges which surrounds both the brain and the spinal chord. In addition, a space inside the spinal chord called the central canal also contains cerebrospinal fluid. It acts as a cushion for the neural tissues, also bringing nutrients to the brain and spinal cord and removing waste from the system. The meninges that surround the brain and spinal cord, are three membranous envelopes—the
pia mater, the arachnoid, and the dura mater. It covers the brain and spinal cord. The chief function of meninges and cerebrospinal fluid is to protect the central nervous system. Structural details of the brain are shown in the Figure 2.1.

Broadly, the brain can be divided into the cerebrum, brainstem, and cerebellum. The cerebrum is the largest and most highly developed part of the human brain. It encompasses about two-thirds of the brain mass and lies over and around most of the structures of the brain. The outer portion of the cerebrum is covered by a thin layer of gray tissue called the cerebral cortex. The cerebral cortex consists of folded bulges called gyri that create deep furrows or fissures called sulci. The folds in the brain add to its surface area and therefore increase the amount of gray matter and the quantity of information that can be processed. Most of the actual information processing in the brain takes place in the cerebral cortex. The cerebrum is divided into right and left hemispheres that are connected by the corpus callosum. Each hemisphere is in turn divided into four lobes.

1. The frontal lobe, which is in the front of the brain, controls “executive function” activities like thinking, organizing, planning and problem solving, as well as memory, attention, and movement.

2. The parietal lobe, which sits behind the frontal lobe, deals with the perception and integration of stimuli from the senses.

3. The occipital lobe, which is at the back of the brain, is concerned with vision.

4. The temporal lobe, which runs along the side of the brain under the frontal and parietal lobes, deals with the senses of smell, taste and sound apart from the formation and storage of memories.
The brain stem is located at the juncture of the cerebrum and the spinal column. It consists of the midbrain, medulla oblongata, and the pons. The brainstem coordinates motor control signals sent from the brain to the body. Even though it is the smallest of the three main players, its functions are crucial to survival. It also controls life supporting autonomic functions of the peripheral nervous system. Motor and sensory neurons travel through the brainstem allowing for the relay of signals between the brain and the spinal cord. The medulla oblongata takes an important role as an autonomic reflex centre involved in maintaining body homeostasis. In particular, nuclei in the medulla regulate respiratory rhythm, heart rate, blood pressure and several cranial nerves.

The cerebellum is located dorsal to the pons and medulla. It is comprised of white matter and a thin, outer layer of densely folded gray matter. The folded outer layer of the cerebellum (cerebellar cortex) has smaller and more compact folds than those of the cerebral cortex. Cerebellum contains millions of neurons to process the information and thus co-ordinates motor activities.

Figure 2.1 Structural details of the brain
2.1.1 Nerve Cells and its Functions

Neurons or nerve cells are the basic unit of nervous system. They are composed of a soma or cell body, a dendritic tree and an axon. The cell body (soma) is the factory of the neuron. It produces all the proteins for the dendrites, axons and synaptic terminals. Dendrites branch out in treelike fashion and serve as the main apparatus for receiving signals from other nerve cells. They function as an "antennae" of the neuron and are covered by thousands of synapses. The axon is the main conducting unit of the neuron, capable of conveying electrical signals along distances that range from as short as 0.1 mm to as long as 2 m. Many axon split into several branches, thereby conveying information to different targets. Many neurons do not have axons. In these so-called amacrine neurons, all the neuronal processes are dendrites. Basic structure of a neuron is shown in Figure 2.2.

Neurons carry messages in form of electrochemical process. There are three types of neurons: sensory neuron, motor neuron, and interneuron. A sensory neuron takes a message from the receptors in the sense organ to the CNS. A motor neuron sends a message away from the CNS to an effector, a muscle fiber or a gland. An interneuron is always found completely within the CNS and conveys messages between parts of the system. More neurons may be dedicated to certain regions of the body than others - for example, the fingers have many more nerve endings than the toes.

In addition to neurons, nervous tissue contains glial cells such as the Schwann cells covering the neurons with sheath. These cells maintain the tissue by supporting and protecting the neurons. They also provide nutrients to neurons and help to keep the tissue free of debris. The neurons require a great deal of energy for the maintenance of the ionic imbalance between themselves and their surrounding fluids, which is constantly in flux as a result of the opening and closing of channels through the neuronal membranes. Thus
while the brain is only 2% of the body weight, it consumes 20% of the energy and moreover 80% of this energy consumption is devoted to maintain the imbalance. Neurons are dynamically polarized, so that information flows from the fine dendrites into the main dendrites and then to the cell body, where it is converted into all-or-none signals, the action potentials, which are relayed to other neurons by the axon, a long wire like structure.

![Figure 2.2 Structural details of the Neuron](image)

### 2.2 WHITE MATTER AND GRAY MATTER

Neurons are interconnected with each other and to the other parts of the body by nerve fiber called axon that is protected by a fat layer, which is known as myelin. This is formed within the central nervous system by the oligodendrocyte and in the peripheral nervous system by the Schwann cell. This coating protects nerve fibers and helps in maintaining transmission of all nerve signals. The myelin gives the whitish appearance and hence it is called as the white matter. Lia Stannard says that white matter is located in the central and subcortical regions of the cerebral and cerebellar hemisphere of the brain. It makes up 60 percent of the total brain volume. On the other hand brownish-gray nerve tissue, especially of the brain and spinal cord composes of nerve cell bodies and their dendrites of neuron is called gray matter.
Research on the brain has shown that people have differing amounts of gray matter. More intelligent people has high amount of gray matter.

2.2.1 Age Correlates White Matter

The ageing brain exhibits an assortment of micro and macroscopic changes that ultimately result in some degree of cognitive and functional decline. Histological studies demonstrate a decrease in myelin density and in the number of myelinated fibers. Salat et al (2005) states that autopsy and volumetric neuroimaging studies suggest that BWM changes are more prominent than cortical changes with ageing, at least during certain segments of the age span and in certain regions of the brain. Zülkif et al (2008) states that, as children mature, they become more capable of executing tasks which may require complex cognitive functioning. Contributing to this cognitive development are capabilities such as working memory, inhibition and attention. These capabilities improve with age and have been attributed at least partially to prefrontal circuitry. Synaptic proliferation and pruning, as well as ongoing myelination, are assumed to be important mechanisms that shape cognitive development. Most of the neuro related pathological conditions gives the appearance of hyper intensity in white matter, when scanned through tensor sequence of MR imaging modality. This is also one of the frequent finding in elderly people, particularly during geriatric conditions. Ian et al (2003) says that cerebral white matter abnormalities relate to cognitive functioning in elders.

2.2.2 White Matter in Corpus Callosum

Zülkif et al (2008) states that the corpus callosum (CC) is a thick band of fibers located between the cerebral hemispheres. It is the major white matter tract and the major commissural pathway between the brain right and left hemispheres. It plays an integral role in relaying sensory, motor and
cognitive information between homologous regions in the two hemispheres. The CC is the largest connective fiber bundle in the brain; it accounts for approximately one-ninth of the supratentorial volume. The corpus and its precursors develop between the 8th and 20th gestational weeks. In general, the CC can be conceptualized as a set of overlapping channels responsible for the control of interhemispheric communication. It has been noted for being the most important structure for interhemispheric communication of sensory, motor and higher-order information between the hemispheres.

In addition to shuttling information between the hemispheres, the CC may allow information in one hemisphere to be shielded from the other. Transfer of information on the locus of touch from the fingertips of one hand to the other without looking also requires use of the CC. The information on which finger was touched must cross this neural bridge to get to the opposite hand.

2.3 MAGNETIC RESONANCE IMAGING

MRI is a painless and safe diagnostic procedure that uses a powerful magnet and radio waves to produce detailed images of the internal structures of the organs. Basically, the magnetic fields cause hydrogen nuclei, or protons, that are part of water molecules in tissue to align. Hydrogen has a significant magnetic moment and is abundant in the human body. For these reasons, hydrogen proton is used in routine clinical imaging. The nucleus of the hydrogen atom contains a single proton, which will behave as a tiny bar magnet. Because of the spin characteristics of the proton, if it is placed in a large external magnetic field, it will align in either a parallel (low energy state) or anti-parallel (high energy state) with the direction of the magnetic field. In addition to aligning with the applied field, the proton will precess at some frequency, which is given by the Larmor Equation (2.1)
\[ \omega = \gamma B \]  \hspace{1cm} (2.1)

where \( \omega \) = precessional frequency

\( \gamma \) = gyromagnetic ratio

\( B \) = Strength of the applied magnetic field

When magnetic field (B) is greater, the number of spins aligned in the low-energy state increases. The number of spins in the low energy state in excess of the number in the high-energy state is referred to as the spin excess. The magnetic moments of these excess spins add to form the net magnetization and thus the tissue placed in the magnetic field becomes magnetized.

Hydrogen exists in many molecules in the body. Water (consisting of two hydrogen atoms and one oxygen atom) comprises up to 70% of body weight. Hydrogen is also present in fat and most other tissues in the body. The varying molecular structures and the amount of hydrogen in various tissues effect how the protons behave in the external field. By placing the patient in a large external magnetic field, the tissue (hydrogen) is magnetized.

Duke Medicine News and Communications, (2004) have said that the pulses of radio frequency waves perturb this alignment, and the molecules give off telltale signals as they lose energy. The signature of such water molecules differs according to the tissue, providing the contrast that is a key to MRI's ability to sensitively detect the tissues and image them accordingly.

### 2.3.1 Diffusion Tensor Magnetic Resonance Imaging

Diffusion tensor MRI explores the micro movements of water molecules. It is based on the rendering of multiple raw MRI volumes using pulse sequences with several gradient directions and magnitudes (at least 6
noncolinear directions are necessary). Diffusion is the random motion of particles due to their thermal energy. This motion can be described as a random walk, in which the particles travel some distance before colliding with another particle and changing direction. Elias et al (2002) says Random motion of water molecules (diffusion) in the presence of a strong magnetic gradient results in MR signal loss as a result of the dephasing of spin coherence. The application of a pair of strong gradients to elicit differences in the diffusivity of water molecules among various biologic tissues is known as diffusion sensitization or diffusion weighting. The degree of diffusion weighting is described by the $b$ value, a parameter that is determined by the type of sensitizing gradient scheme implemented in the MR experiment. This imaging modality is unique in its ability to quantify changes in neural tissue microstructure non-invasively, and in this respect, it is an ideal tool for assessing brain development from birth to adolescence. O'Donnell, L.J. and Westin (2007) describes that the power of diffusion magnetic resonance images lies in the fact that the diffusion of water molecules probes the tissue structure at very small scales, much smaller than the voxel resolution.

Watts et al (2003) have said that the human brain undergoes extensive postnatal development: neurons differentiate and proliferate; neuronal connectivity is refined as new synapses form and others are pruned away; and the strength of this connectivity is modulated as neural tracts undergo an ongoing process of myelination that proceeds into adolescence. Peter and Derek (2002) states that DTMRI fiber tractography is a method for following fiber-tract trajectories within the brain and other fibrous tissues. Diffusion tensor imaging has been used to investigate white matter structural integrity in normal ageing.

DTMRI is the more sophisticated form of diffusion-weighted magnetic resonance imaging which allows for the determination of
directionality as well as the magnitude of water diffusion. This kind of magnetic resonance imaging can estimates damage to nerve fibers that connect the area of the brain affected by the stroke to brain regions that are distant from it, and can be used to determine the effectiveness of stroke prevention medications. It enables to visualize white matter fibers in the brain and can map (trace image) subtle changes in the white matter associated with diseases such as multiple sclerosis and epilepsy as well as assessing diseases where the brain’s wiring is abnormal, such as schizophrenia. A slice of DTMR image taken in axial direction of brain is shown in Figure 2.3.

![Brain slice as obtained from DTMRI procedure](image)

**Figure 2.3 Brain slice as obtained from DTMRI procedure**

### 2.3.2 Magnetic Resonance Venography

It is a MRI study of the blood vessels. Magnetic resonance venographs (MRV) are used to assess abnormalities in the blood vessels of patients with a history of stroke, aneurysm, heart disease, and atherosclerotic vascular disease. In this modality, by injecting coloring agents blood circulation is evaluated.
2.3.3 Functional Magnetic Resonance Imaging

It is a diagnostic method for learning how a normal, diseased or injured brain works and also to map brain activity. When neuronal activity increases there is an increased demand for oxygen, now haemoglobin becomes diamagnetic (when oxygenated) and remains paramagnetic when deoxygenated (no neural activity). This difference in magnetic properties leads to small differences in the MR signal. Hence this method is dependent on blood oxygenation level and highlights the region related to a particular activity.