Introduction

Hydrocephalus is a condition in which excess cerebrospinal fluid (CSF) builds up within the ventricles of the brain as a result of impaired balance between the production and absorption of CSF and may increase pressure within the head ***(Quencer, 1992).***

CSF has three crucial functions: 1) it acts as a "shock absorber" for the brain and spinal cord; 2) it acts as a vehicle for delivering nutrients to the brain and removing waste; and 3) it flows between the cranium and spine to regulate changes in pressure within the brain.

Hydrocephalus can occur at any age, but is most common in infants and adults age 60 and older. Adult hydrocephalus can be due to a variety of causes including **Normal Pressure Hydrocephalus (NPH)** and **Hydrocephalus Ex-Vacuo.** In an adult, the skull is rigid and cannot expand, so the pressure in the brain may increase profoundly.

Hydrocephalus Ex-vacuo occurs when a stroke or injury damages the brain and brain matter actually shrinks. CSF volume increases to fill the extra space. In these instances, the ventricles are enlarged, but the pressure usually is normal.

Normal Pressure Hydrocephalus results from the gradual blockage of the CSF draining pathways in the brain as the result of head injury, cranial surgery, hemorrhage, meningitis or tumor. Unfortunately, the cause of the majority of NPH cases is unknown. The ventricles enlarge to handle the increased volume of CSF, thus compressing the brain from within and eventually damaging or destroying the brain tissue.

Clinically, triad of Gait disturbance, urinary incontinence and dementia are the main symptoms of NPH patients. These symptoms are also common in patients with brain atrophy, so clinical differentiation between them is difficult. Conventional MRI also cannot differentiate between them as both have ventricular dilatation as a main finding in conventional MRI. So CSF Flowmetry is able to qualitatively assess and quantify CSF flow.. In NPH there is hyperdynamic CSF flow, while in brain atrophy patients, there is hypodynamic CSF flow***(Rizvi and Anjum, 2005).***

The protocol of CSF Flowmetry depends on analysis of the CSF flow properties at the level of the aqueduct of sylvius referring to pulsatile to-and-fro flow due to vascular pulsations rather than bulk transport of CSF.Phase contrast

MR imaging is a rapid, simple and non-invasive technique which is sensitive to even small CSF flows, and can be used to evaluate CSF flow both qualitatively and quantitatively. Cine phase contrast MR images show CSF flow in a dynamic, more easily appreciable, and in a more pleasing manner ***(Dincer and Ozek, 2011).***

Aim of the Work

Our goal in this study is to demonstrate the role of MRI CSF Flowmetry studies in diffretiating between various causes of adult onset hydrocephalus among adult population.

Anatomy of the Ventricular System

The CSF spaces comprise the ventricular system and subarachnoid spaces.

The ventricular system of the brain is composed of a set of adjoining cavities where CSF is produced and drained into the CSF spaces. CSF is produced within the ventricular system by specialized ependymal cells that line these ventricles known as the choroid plexus. This fluid serves to mechanically protect and regulate homeostasis within the cerebral interstitial fluid, as well as facilitate brain development ***(Stratchko et al., 2016).***

The lateral ventricles, third ventricle, aqueduct of Sylvius, and fourth ventricle form the ventricular system of the brain. It is embryologically derived from the neural canal, forming early in the development of the neural tube. The 3 brain vesicles (prosencephalon or forebrain, mesencephalon or midbrain, and rhombencephalon or hindbrain) are formed around the end of the first gestational month. The neural canal dilates within the prosencephalon, leading to the formation of the lateral ventricles and third ventricle. The cavity of the mesencephalon forms the cerebral aqueduct. The dilation of the neural canal within the rhombencephalon forms the fourth ventricle ***(FitzGerald and Folan-Curan, 2002nj)*.**

Lateral ventricle

The paired lateral ventricles are considered the largest of the ventricular cavities. They are composed of the body and atria centrally with the anterior/frontal, inferior/temporal, and posterior /occipital horns forming a C-shape, extending peripherally in their respective cerebral lobes **(Fig. 1)*(Stratchko et al., 2016).***

The lateral ventricles are separated from each other by the septum pellucidum, but communicate with the third ventricle and indirectly with each other through the interventricular foramen. They are lined by a thin ependyma, covered by ciliated epithelium, and contain cerebrospinal fluid secreted in considerable amount ***(Crossman, 2005).***

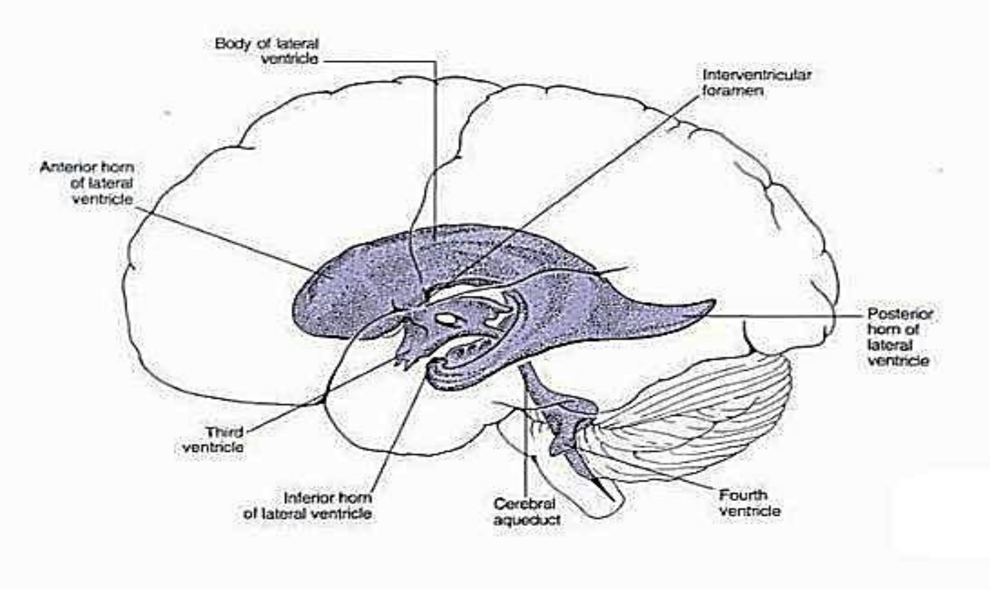


Fig.(1): Shows the anatomy of the ventricular system ***(Stratchko et al., 2016).***

The inferior or temporal horn is located within the temporal lobe. The roof is formed by the fibers of the temporal lobe; the medial border contains the stria terminalis and tail of the caudate. The medial wall and the floor are formed by the hippocampus and its associated structures **(Fig. 2)*****(Waxman, 2000).***

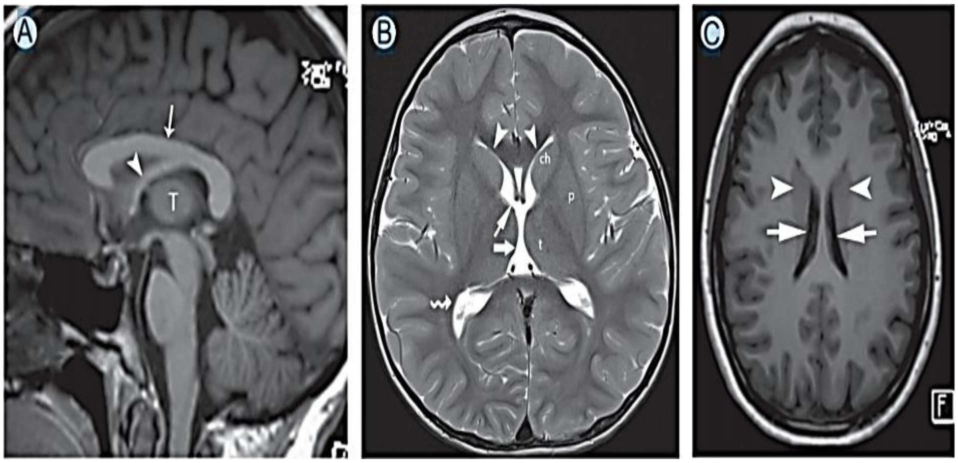


Fig.(2): Show the normal anatomy and relationships of lateral ventricle. Midline sagittal T1W I image, (A) corpus callosum (arrow) that forms the superior border of the lateral ventricles, fornix (arrowhead) that forms the superior margin of the third ventricle. T is thalamus. Axial T2WI, (B) frontal horns (arrowheads) of the lateral ventricle lined laterally by caudate head (CH). Lateral ventricles drain in the third ventricle (thick arrow) via foramen of Monro (thin arrow). p, putamen; t, thalamus. Axial T1WI slightly superior to (B), body of the lateral ventricles (arrows) surrounded by body of the caudate nucleus (arrowheads).WI, weighted image ***(Stratchko et al., 2016).***

Third Ventricle

The midline third ventricle is a narrow cavity situated between the thalami. The third ventricle communicates with the lateral ventricles via the foramen of Monro and with the fourth ventricle through the cerebral aqueduct of Sylvius. It has a roof, a floor and anterior and a posterior boundary and a pair of lateral walls ***(Stratchko et al., 2016).***

The roof is formed by a layer of epithelium which stretches between the upper edges of the lateral walls of the cavity. The floor slopes downward and forward and is formed mainly by the structures which constitute the hypothalamus ***(Stratchko et al., 2016).***

The third ventricle is bounded anteriorly by the lamina terminalis, the columns of the fornix, and the anterior commissure. It's bounded posteriorly by the pineal body, the posterior commissure, and the cerebral aqueduct. The interventricular foramen is situated at the junction of the roof and anterior wall of the ventricle, through which the third ventricle communicates with the lateral ventricles ***(Crossman, 2005).***

Each lateral wall of the third ventricle consists of an upper portion formed by the medial surface of the anterior two-thirds of the thalamus, and a lower portion consisting of an upward continuation of the gray substance of the ventricular floor ***(Crossman, 2005).***

The floor of the third ventricle can be subdivided into 3 different zones: the anterior premammillary portion, the intermediate or interpeduncular portion, and the posterior peduncular portion. The premammillary portion consists of the supraoptic and infundibular recesses, as well as the tuber cinerium of the hypothalamus. The interpeduncular portion extends from the mammillary bodies to the posterior aspect of the interpeduncular space. Finally, the peduncular space is made up of the midbrain tegmentum, situated just above the cerebral peduncles, which extends to the cerebral aqueduct **(Fig. 3)*(Stratchko et al., 2016).***

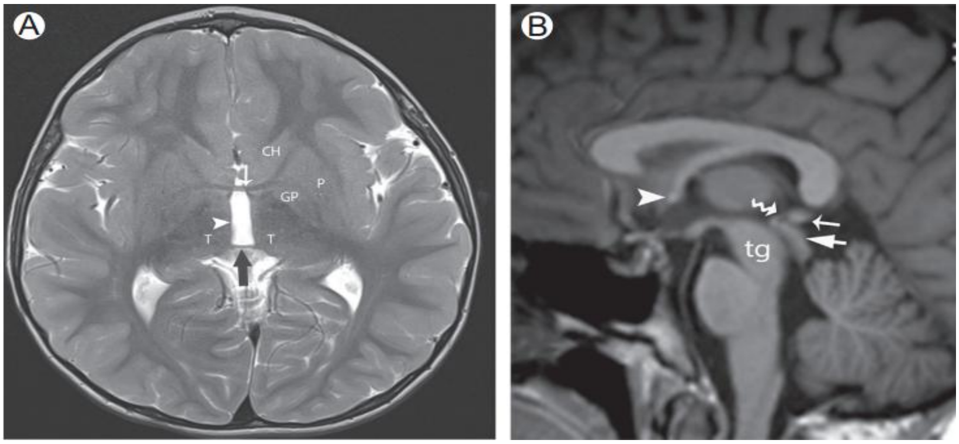


Fig.(3): Third ventricle and its relationships. Axial T2WI (A) images show the third ventricle in the midline lined bilaterally by thalami (T). Anteriorly it is lined by crux of the fornix and anterior commissure (thin white arrow) and posteriorly by posterior commissure (black arrow). CH, caudate head; P, putamen; GP, globus pallidus. Sagittal T1WI (B) shows anterior commissure (arrowhead), posterior commissure (spiral arrow), and pineal gland (thin arrow). Aqueduct lies between tegmentum (tg) and tectal plate (arrow). WI, weighted image ***(Stratchko et al., 2016).***

Aqueduct of Sylvius

The cerebral aqueduct of Sylvius serves as a communication for CSF flow from the third ventricle to the fourth ventricle. It traverses the dorsal aspect of the midbrain, surrounded by the periaqueductal gray matter, which is situated anterior to the tectum and posterior to the tegmentum. The aqueduct of Sylvius is susceptible to obstruction and resultant hydrocephalus because it is the narrowest portion of the ventricular system **(Figs. 4, 5)*****(Stratchko et al., 2016).***

Anatomically, the cerebral aqueduct is divided into three parts namely the pars anterior, ampulla and pars posterior which are separated by two natural constrictions of the aqueductal lumen one in the middle of the superior colliculus and the other at the level of the intercollicular sulcus. The pars posterior has the narrowest lumen of the cerebral aqueduct while the ampulla has the widest lumen ***(Lee et al., 2004).***

Fig.(4): Normal anatomy of the cerebral aqueduct as viewed in the sagittal plane The solid lines indicated by an A &B divide the aqueduct into the pars anterior, ampulla and pars posterior, craniocaudally ***(Lee et al., 2004).***

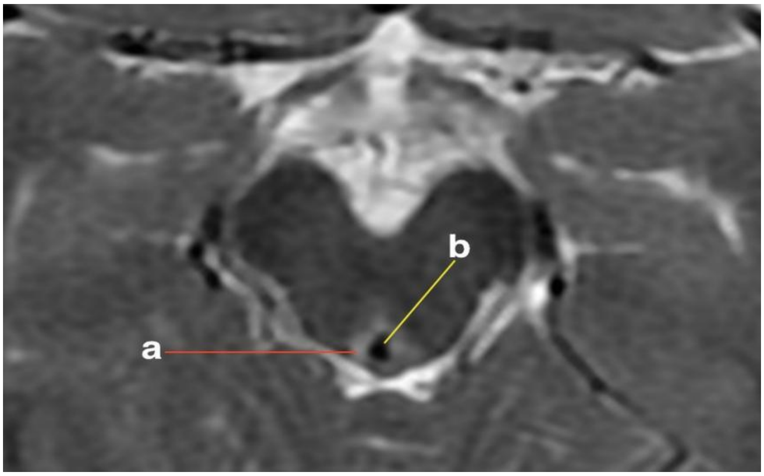
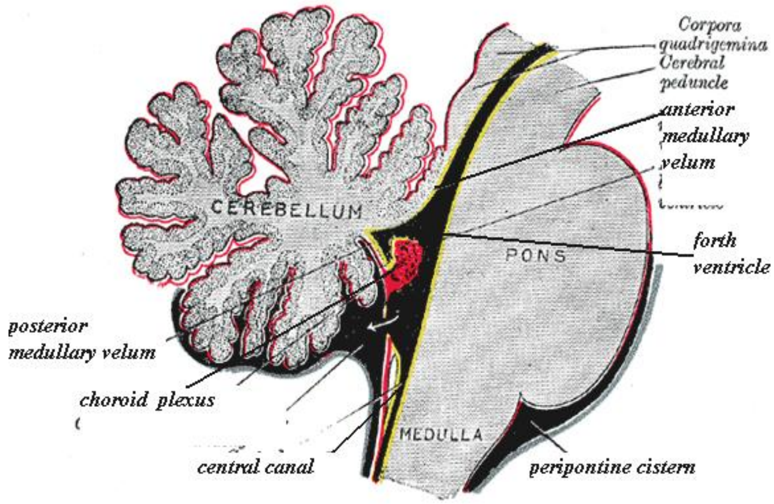


Fig.(5): Normal study in the axial plane through the level of midbrain demonstrating the cerebral aqueduct of Sylvius (b) and the periaqueductal grey matter (a) ***(Stratchko et al., 2016).***

Fourth Ventricle

The fourth ventricle is a diamond-shaped midline cavity between the brainstem anteriorly and the cerebellum posteriorly in the infratentorial region **(Fig. 6).** CSF enters the fourth ventricle via the cerebral aqueduct and exits via one of 3 routes: (1) through foramina of Lushka to the cerebellopontine angle cistern, (2) through the obex to the central spinal canal, and (3) through foramen of Magendie to the cerebellomedullary cistern. It’s formed of a roof, a floor, and lateral boundaries ***(Crossman, 2005).***

The roof is divided into superior and inferior segments by the fastigium. The superior medullary velum and the medial aspects of the superior cerebellar peduncles shape the superior roof of the fourth ventricle. The inferior medullary velum forms the inferior roof. The foramen of Magendie opens in the caudal aspect of the inferior medullary velum, and serves as a connection between the ventricular system and the cisterna magna ***(Crossman, 2005).***



<u>Fig.(6):</u> Sagittal section showing fourth ventricle ***(Crossman, 2005).***

The floor of the fourth ventricle is formed superiorly by the pons and inferiorly by the medulla. The floor can be further divided into 3 segments. The superior/pontine portion extends from the cerebral aqueduct to the level of the superior cerebellar peduncles. The intermediate/junctional section is a thin band between the inferior aspect of the superior cerebellar peduncle and the taenia of the fourth ventricle. The inferior/medullary segment extends from the taenia to the obex, which is in close proximity to the foramen of Magendie **(Fig. 7)*(Mortazavi et al., 2013).***

The junction of the roof and the floor of the fourth ventricles form the lateral recesses. The recesses communicate with the subarachnoid space at the level of the cerebellopontine angles via the foramina of Luschka ***(Mortazavi et al., 2013).***

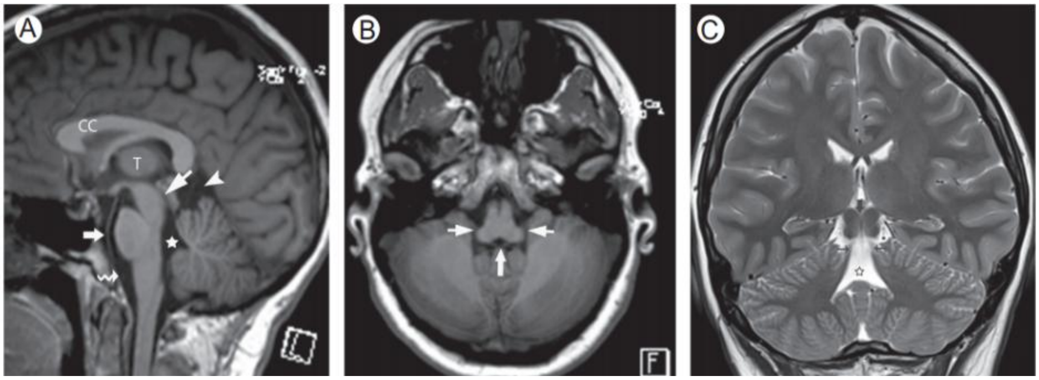


Fig.(7): Shows normal anatomy and relationships of the fourth ventricle. Sagittal T1 (A), axial T1 (B), and coronal T2 (C) WI, CC, corpus callosum; T, thalamus; and aqueduct of sylvius (arrow) that drain into the fourth ventricle (star). CSF space superior to the cerebellum is supracerebellar cistern (arrow head), anterior to the pons is prepontine cistern (fat arrow), and anterior to medulla is medullary cistern (spiral arrow) ***(Mortazavi et al., 2013).***

Subarachnoid space

The arachnoid membrane is a delicate membrane enveloping the brain and medulla spinalis, lying between the pia mater internally(which is adherent to the brain surface) and the dura mater externally (which is adherent to the skull). It is separated from the pia mater by the