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MORPHOMETRIC ANALYSIS OF THE HUMAN CEREBRAL LATERAL VENTRICLE USING MAGNETIC RESONANCE IMAGING

Thesis

Submitted in Partial Fulfillment for the Master Degree in Anatomy

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2009

جامعة العرب الطبية
كليـة الطـب
قسـم التشـــريح والأنسـجة

تحليل القياسات الشكلية للبطين الوحشي الدماغي البشري باستخدام التصوير بالرنين المغناطيسي

رسـالة مقـدمة من الطبيب

أشـــرف محمـــد المنصـــوري

قسم التشريح – كلية الطب – جامعة العرب الطبية

توطئة للحصول على درجة الماجستير في علم التشريح

المشـــرفون

الأستاذ الدكتور عـادل عباس بنـدق

أسـتاذ التشـريح
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أستاذ مسـاعد الأشعة التشخيصية والعلاجية
كلية الطب - جامعة العرب الطبية

2009

الذاريات، الايه 21.

CONTENTS

ACKNOWLEDGMENTS

It is a great pleasure to acknowledge and thank those whose assistance, cooperation and support have made the completion of this thesis possible.

I am very grateful and indebted to my principal supervisor who showed me the light in the dark road. He is **Prof. Dr. Adel Bondok**, Professor of Anatomy, Faculty of Medicine, Mansoura University, Egypt. He designed the protocol of this thesis and helped me in all the details of this thesis from planning, writing, reading to revising and editing the thesis. He has been generous with his time, his criticisms were exclusively constructive and his generous support was unlimited. Not only that, but also he performed and produced all the statistical charts in a professional method. He asked me for nothing but perfection. I really can't express my gratitude to him and all that I can say is that "Allah blesses him".

I am grateful to my co-supervisor **Dr. Faisal Shembesh,** Assistant Professor of Radiology, Benghazi Radiodiagnostic and Therapy Center, Arab Medical University, for his kind support.

I am also very grateful to **DR. Iman Idris Ali,** Head of Department of Anatomy and Histology, Alarab Medical University, for her unlimited support, cooperation and encouragement.

I am also grateful to **Dr. Salha Zoubi,** Assistant Professor of Histology and **Dr. Idris Albarasi,** Lecturer of Histology, for their support.

I would like to thank my colleagues in the department of Anatomy and my friends for their encouragement and support.

I like to thank those at Benghazi Radiodiagnostic and Radiotherapy Center for allowing me to use their facilities.

Special thanks & love to my parent, wife and my son for their support, enthusiasm and care.

INTRODUCTION

The human brain has been the focus of intense research over the centuries. It is well recognized that individuals vary considerably in brain volume, cytology, distribution of grey and white matter, gyral pattern, and in ventricular size **(Meyer, 1971)**.

The ventricular system of the brain is continuation of the central canal of the spinal cord. They comprise four ventricles; right and left lateral ventricles, third ventricle, and fourth ventricle. Each ventricle contains a choroid plexus that produces cerebrospinal fluid (CSF) used to bathe and cushion the brain and the spinal cord. The total volume of CSF depends on the age but the normal adult volume of about 150 ml is reached by the age of 5 years. Normal volume of the lateral ventricles has been measured by ultrasound (US) and does not exceed 12 to 15 ml. The third ventricle contains only 1 ml of CSF (**Enzmann and Pelc, 1991**).

The cerebral ventricular system in man occupies a mean volume of approximately 20 ml, varying from 10 to 50 ml. The lateral ventricles represent about 90% of the total ventricular system volume (**Nolte, 1993).** Several pathological conditions as the processes of expansible intracranial masses, the meningo-ventricular infections and the intraventricular hemorrhage can

cause alterations of the ventricular volume **(Berman & Banker, 1966; Boasquevisque et al., 2000)**.

The evaluation of the volume and measurements of the cerebral ventricles becomes important when one want to follow the evolution of the hydrocephaly or to define therapeutic conducts as the placement of ventricular valves which require reproducible results for evaluation and assessment or to assess other neurological diseases that interfere with normal and social activities like dementia and Alzheimer's disease where changes in the ventricles were observed **(Lombroso et al., 1968; Johnstone et al., 1976; Hobar et al., 1983; Hilpert et al., 1995; Liao et al., 1997; Garel & Alberti, 2006**). Evaluation of the cerebral ventricular system is a routine part of all fetal sonographic examinations. Ventriculomegaly and decreased choroid volume are indicators of poor fetal outcome, so it is important to know the normal variation of these parameters **(Hilpert et al., 1995).**

The CT (Computerized Tomography) and the MRI (Magnetic Resonance Imaging) are the methods more used in the evaluation of CNS diseases **(Degreef et al., 1992; Buchsbaum et al., 1997; Chudgar, 1999; Bernasconi et al., 2000; Dale et al., 2000; Brambilla et al., 2001; Levine et al., 2002; Duffner et al., 2003)**.

Several investigators have studied the cerebral ventricles quantitatively **(Gyldensted, 1977; DeCarli et al., 1992a & 1992b; Blatter et al., 1995; Hauser et al., 2000; Melhem et al., 2000; Jeong et al., 2005; Lewis et al., 2009)**. However, the methods and the suitable equipments used for the morphometric

measurements and analysis are still controversial in the literature (**Evans, 1942; Zatz 1979; Meese et al., 1980; McGahan & Phillips, 1983; Blumhagen & Mack, 1985; Shackelford, 1986; Jernigan et al., 1990; Riccabona et al., 1995).**

AIM OF THE WORK

The daily practice of magnetic resonance (MR) brain imaging technology requires a simple method to perform, which allows an accurate measurement of the ventricular system. The evaluation of the width of the lateral ventricles by means of the ventricular / hemispheric index, Evans' index and of the cross sectional areas are likely to meet all these requirements.

The present MR imaging-based morphometric study was carried out to define the normal quantitative values of the different parts of the human lateral ventricle to create a standard morphometric database of the cerebral ventricle in a normal Libyan population. It is also intended to compare the parameters of the right and left lateral ventricles in both males and females and to study the sex differences and age changes in the lateral ventricle from age of 20 years to age of 60 years. This database can be used as a guideline and as a reference for MRI diagnosis of different neurological diseases.

anatomical drawing of the ventricles. In the axial view, posterior horns of the lateral ventricles are not visible. It was probably due to the absence of air vents in the posterior horns and the use of unpreserved brain **(Clarke and Dewhirst, 1972)**.

Fig.3. Drawings of Leonardo da Vinci after his wax injection studies (1504–1507) **(Clarke and Dewhirst, 1972)**

About 20 years after Leonardo's wax studies, Berengario da Carpi (1460–1530) published his book "Isagoge Breves" in 1522. His anatomical illustrations were more like pictures and were much improved compared to Leonardo's illustrations. **Figure 4 (Clarke and Dewhirst, 1972)** shows the brain from above with one ventricle opened to show the vermis. In this figure, vermis shown as the sitting place of the choroid plexus where as in the dynamic cell doctrine it acted as a valve between cells one and two. Berengario located all the mental functions in the lateral ventricles and he argued that the other ventricles dealt with excretion, motion and sensation. His most famous book "Tractates' ed Fractua Calve Sive Cranei" is a surgical

text on cranial fractures. On the cover of his book, there is a head in profile showing the three cells **(Fig. 5)**.

Andreas Vesalius of Pauda (1514–1564) **(Figs. 6, 7)**, is known as the greatest of the Renaissance Anatomists. In his remarkable book "De Humani Corporis Fabrica" 1543 **(Poynter, 1964),** Vesalius argued against placing the functions of the soul in the ventricles. He argued that many animals have ventricles similar to those of humans and yet they were denied a reigning soul.

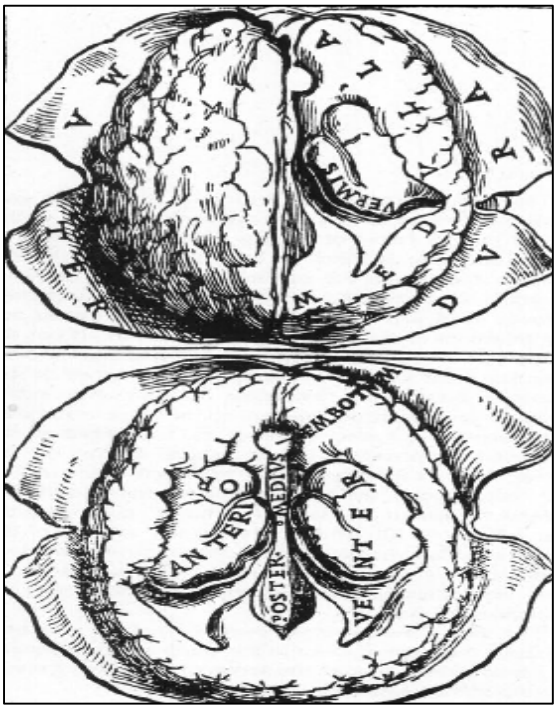

Figure 4. Anatomical illustration from Isagoge Breves **(Clarke and Dewhirst, 1972).**

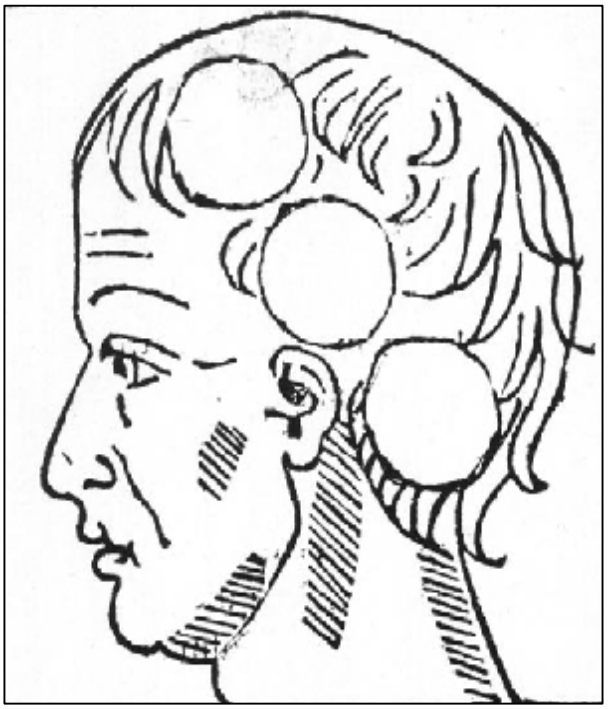

Figure 5. Cover of the famous book of Berengario da Carpi *"Tractatus ed Fractua Calve Sive Cranei"* **(Clarke and Dewhirst, 1972).**

With the work of Renaissance artists and Vesalius, the true anatomy of the ventricular system was established. It was shown that the ventricles contained a fluid, what is now called cerebrospinal fluid and it was highly unlikely that mental functions took place within it **(Dopson, 1927; Tascioglu and Tascioglu, 2005)**.

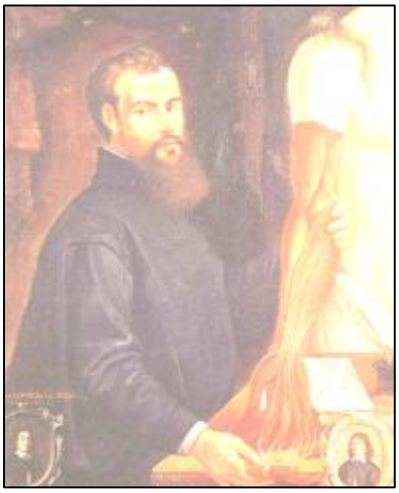

Fig. 6. Andreas Vesalius. (**Tascioglu & Tascioglu , 2005)**.

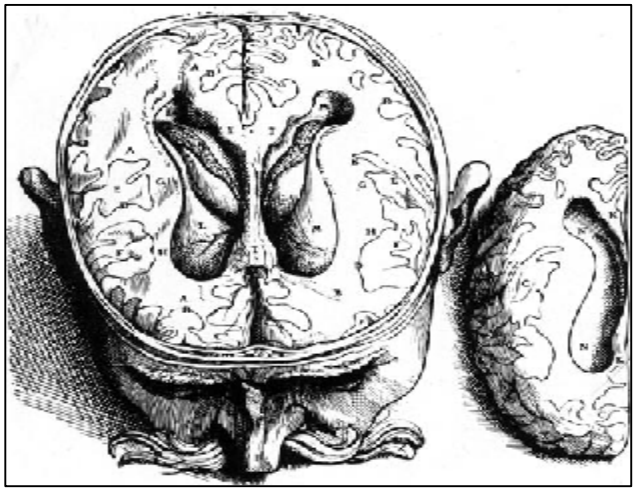

Fig. 7. Brain ventricles from his Book De Fabrica **(Tascioglu & Tascioglu, 2005)**.

DEVELOPMENT OF THE VENTRICULAR SYSTEM

The central nervous system appears at the beginning of the third week and takes origin from an elongated area of ectoderm, the neural plate, situated in the axial region of the embryo in front of Hensen's node and the primitive streak **(Hamilton et al., 1972; Sadler, 1998; Larsen, 2001; Dudek & Fix, 2005)**. The neural plate shows a median groove, the lateral margins of this groove grow and meet to form neural tube. At an early stage, on day 19, as the result of differential growth, this simple neural tube shows a demarcation into a cylindrical and elongated caudal portion, which becomes the spinal cord, and a shorter and broader cephalic portion, which becomes the brain. The central cavity of the developing brain soon shows three segmentally arranged dilatations known as the primary brain vesicles. Their cavities become the subsequent cerebral ventricles and aqueduct. The rostral dilatation is called the forebrain vesicle and its wall forms the prosencephalon. The intermediate dilatation is the midbrain vesicle; its wall forms the mesencephalon. The caudal dilatation is the hindbrain and its wall forms the rhombencephalon. The mesencephalon shows no fundamental changes in the subsequent development like the other two vesicles

that undergo marked modification. The rhombencephalon is subdivided during the fifth week into a more rostral, metencephalon that gives origin to the pons and cerebellum, and a more caudal myelencephalon that develops into the medulla oblongata. The prosencephalon divides into a postero-superior median portion, called the diencephalon and an antero-inferior pair of laterally directed invaginations in the developing cerebral vesicles and representing the future lateral ventricles.

The cavity of the diencephalon is called the third ventricle. Postero-inferiorly, it communicates freely with the mesencephalic cavity; antero-superiorly, it communicates on each side with the corresponding lateral ventricle by a large aperture, the future interventricular foramen (foramen of Monro). The fourth ventricle represents the cavity of the original rhombencephalon, and the mesencephalic cavity becomes the cerebral aqueduct of Sylvius (**Hamilton et al., 1972; Sadler, 1998; Larsen, 2001; Dudek & Fix, 2005).**

As the development proceeds, the lateral ventricle initially occupies most of the volume of the hemisphere but it progressively constricted by the thickening of the cortex. However, along the line between the floor and the medial wall of the hemisphere, the cerebral wall does not thicken but instead remains thin and form a groove called choroid fissure. A choroid plexus develops along the choroid fissure. The lateral ventricle extends the whole length of the hemisphere, reaching anteriorly into the frontal lobe and its posterior

end reaching the occipital lobe and curves around to occupy the temporal lobe (**Larsen, 2001; Dudek & Fix, 2005).**

The configuration of the third ventricle becomes more like that of the adult and each interventricular foramen becomes relatively smaller **(Boyd, 1955; Hamilton et al., 1972)**. During the third month of fetal development, the telencephalon undergoes rapid growth more than the rest of the brain. Ventrally, the growth associated with the basal ganglia and the cortical component of the ventral telencephalon has no ventricular cavity beneath it and becomes the cortex of the insula. Because of the differential growth pattern between the pallium, or cerebral cortex, and the basal ganglia, the pallium expands like the shell of the cavity being the lateral ventricle. At the same time, the rapidly growing basal ganglia push into the cavity an expanding fist that make the ventricle curve around the basal portion of the telencephalon in a C-shape manner. After the closure of the caudal neuropore, the developing brain ventricles and the central canal of the spinal cord become filled with the cerebrospinal fluid **(Burt, 1993; Dudek & Fix, 2005).**

SOME STUDIES ON DEVELOPMENT OF THE LATERAL VENTRICLE

Saliba et al. (1990) performed study on 87 preterm infants of 27 to 36 weeks' gestational age using serial ultrasound imaging of the brain and reported that lateral ventricle area measurements increased as age and head circumference increased. During the first six weeks of life, the rate of growth was 0.53 cm/week and the mean postnatal ventricular area growth velocity was 0.39 mm^2/ week. A reference range for lateral ventricle area developed from these serial measurements.

Alagappan et al. (1994) studied 500 fetuses to reassess the mean size of the lateral cerebral ventricular atrium by using axial ultrasound. Eleven fetuses had ventricular atrial measurements of 10 mm or more. The mean size of the ventricular atrium was 6.6 mm. They concluded that use of 10 mm as the upper limit of normal for the ventricular atrial measurement should be continued. Measurements of 10 mm or above should prompt a careful search for associated fetal abnormalities and consideration of amniocentesis.

Hilpert et al. (1995) described the normal size of the fetal lateral ventricular atrium in 608 healthy fetuses from 13 to 42 weeks' menstrual age. The atrium of the lateral ventricle was measured in the axial and coronal planes and was confirmed with previous observations.

Nadel and Benacerraf (1995) investigated the presence of a sex difference in the size of the fetal lateral ventricular atrium. The width of the lateral ventricular atrium was measured sonographically on 543 fetuses scanned at 17- 40 weeks. Lateral ventricular measurements of male and female fetuses were compared. They concluded that male fetuses have slightly larger cerebral lateral ventricles than female fetuses.

Achiron et al. (1997) used ultrasonography to study asymmetries of the fetal lateral ventricles in 7200 pregnant women. Lateral ventricular asymmetry was found in 21 subjects. In 15 fetuses, the body or the occipital horn of the left lateral ventricle was larger than the right, whereas in six fetuses, the right was larger than the left. They concluded that some degree of asymmetry of the lateral ventricles exists in the human fetal brain and is detectable in utero.

Liao et al. (1997) used ultrasound scans to measure the lateral ventricles of 540 neonates. In their study, coronal scans showed that the distance between the falx and the lateral wall of the body of the lateral ventricle and the greatest axis of the lateral ventricle correlated with increasing gestational age.

Fannon et al. (2000) investigated the developmental correlations of ventricular enlargement. Information on childhood development and magnetic resonance images were collected from 21 patients experiencing a first episode of psychosis. In their results,

21patients had significantly less whole brain volume and enlarged third and lateral ventricles compared to 25 controls. They concluded that enlargement of both third and lateral ventricles are present in first-episode psychosis.

ANATOMY OF THE VENTRICULAR SYSTEM

The cerebral ventricular system consists of series of interconnecting spaces and channels within the brain that are derived from the lumen of the embryonic neural tube and the cerebral vesicles. Within each cerebral hemisphere lies the large C-shaped lateral ventricle. Near its rostral end the lateral ventricle communicates through the interventricular foramen (foramen of Monro) with the third ventricle, which is midline, slit-like cavity lying between the two thalami and bounded inferiorly by hypothalamus. Caudally, the third ventricle is continuous with the cerebral aqueduct, a narrow tube that passes the length of the midbrain that is continuous with the fourth ventricle. The fourth ventricle is a tent shape cavity of the hindbrain and continues downward with central canal of the spinal cord. The ventricular system contains cerebrospinal fluid (CSF), which is mostly secreted by the choroid plexuses located within the lateral, third and fourth ventricles (Fig.8). CSF flows from the lateral to third ventricles via foramen of Monro then passes into the fourth ventricle. It leaves the fourth ventricle through three apertures to reach the subarachnoid space surrounding the brain **(Carpenter and Sutin, 1983; Burt, 1993; FitzGerald& Folan-Curran, 2002; Standing et al., 2005)**.

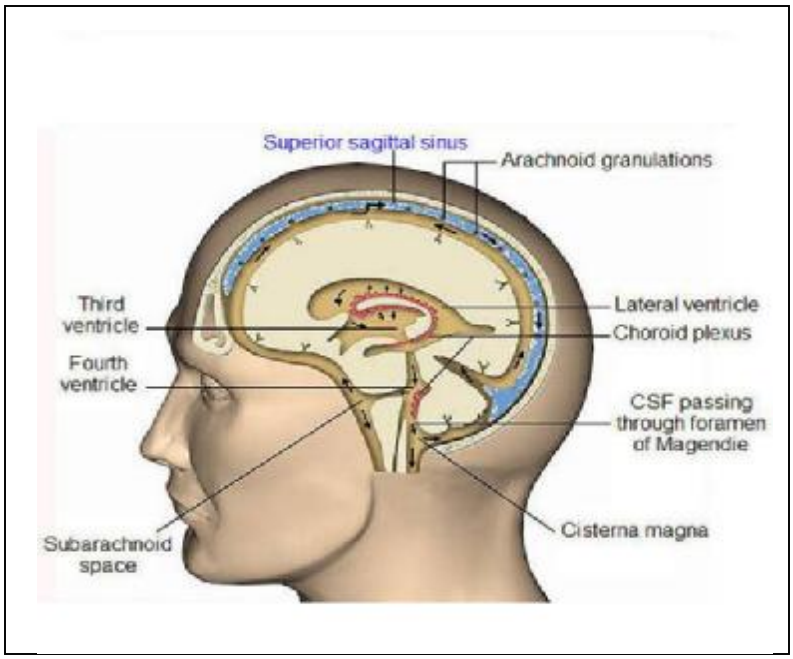

Fig.8. The ventricular system**. (Standing et al., 2005)**

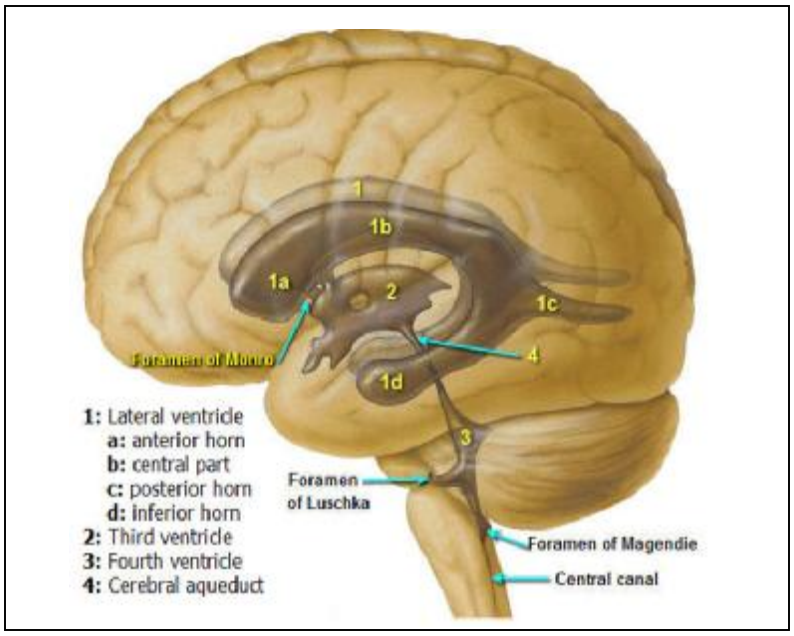

Fig.9. The parts of the lateral ventricle. **(Standing et al., 2005)**

THE LATERAL VENTRICLE

Viewed from its lateral aspect, the lateral ventricle has a roughly C-shaped profile with an occipital tail. The shape is a consequence of the developmental expansion of the frontal, parietal and occipital regions of the hemisphere that displace the temporal lobe inferiorly and anteriorly (Fig.9). Both the caudate nucleus and the fornix have adopted similar morphology, so that the caudate nucleus encircle the thalamus and the fornix traces the outline of the ventricle forward to the interventricular foramen. The lateral ventricle is customarily divided into a body and 3 horns: anterior, posterior and inferior **(Carpenter and Sutin, 1983; Standing et al., 2005).**

The anterior (frontal) horn lies within the frontal lobe anterior to the interventricular foramen. The posterior aspect of the genu of the corpus callosum bound it anteriorly. The roof is formed by the anterior part of the body of the corpus callosum. The anterior horns of the two lateral ventricles are separated by the septum pellucidum. The coronal profile of the anterior horn is roughly a flattened triangle in which the head of the caudate nucleus projects into the lateral wall **(Standing et al., 2005).**

The body lies within the parietal lobe and the posterior part of the frontal lobe. It extends from the interventricular foramen to the splenium of the corpus callosum. The bodies of the lateral ventricles

are separated by the septum pellucidum, which is attached to the body of the fornix. The coronal profile of the body of the ventricle is flattened triangle with inward bulging lateral wall formed by the thalamus inferiorly and the body of the caudate nucleus superiorly. The boundary between the thalamus and the caudate nucleus is marked by a groove that is occupied by the stria terminalis, and by the thalamostriate vein. The fornix is separated from the thalamus by choroidal fissure that is occluded by the choroid plexus. The body widens posteriorly to become continuous with the posterior and inferior horns at the collateral trigone or the atrium **(Burt, 1993)**.

The posterior (occipital) horn curves postromedially into the occipital lobe. It is usually diamond-shaped or square in outline. The two sides are often symmetrical. Fibers of the tapetum of the corpus callosum form the lateral wall and the roof of the posterior horn and separate the ventricle from the optic radiation. Fibers of the splenium of the corpus callosum (forceps major) pass medially as they sweep back into the occipital lobe and produce a rounded elevation in the upper medial wall of the posterior horn called bulb of the posterior horn. A second elevation below the bulb is called the calcar avis and is produced by the deeply infolded cortex of the calcarine sulcus **(FitzGerald& Folan-Curran, 2002; Standing et al., 2005)**.

The inferior (temporal) horn extends forwards into the temporal lobe. It curves round the posterior aspect of the thalamus (pulvinar). It curves anteriorly to end within 2.5 cm of the temporal pole, near the uncus. Its position relative to the surface of the hemisphere usually

corresponds to the superior temporal sulcus. The roof of the inferior horn is formed mainly by the tail of the caudate nucleus and the stria terminalis, which connects the amygdala at the anterior end of the ventricle with the septal area. The floor of the ventricle consist of the hippocampus medially and the collateral eminence, formed by the infolding of the collateral sulcus, laterally. The inferior part of the choroid fissure lies between the fimbria and the stria terminalis in the roof of the temporal horn. The temporal extension of the choroid plexus fills this fissure and covers the outer surface of the hippocampus.

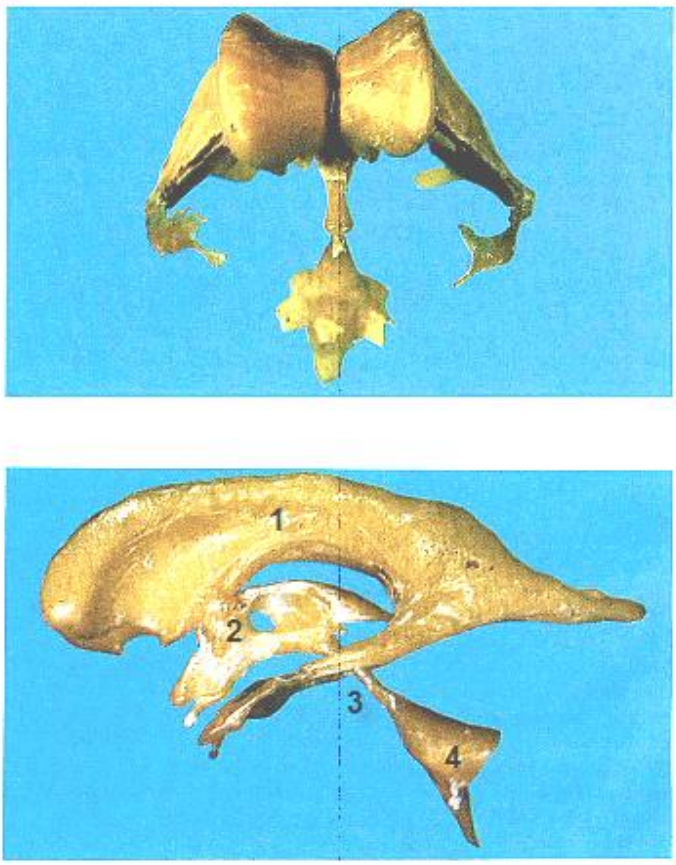

Fig 10: Resin cast of the ventricular system of the human brain showing lateral (1), the third ventricle (2) the cerebral aqueduct (3) and the fourth ventricle (4). Quoted from **Standing et al. (2005)**.

Both the lateral ventricles communicate via the foramina of Monro with the third ventricle, found centrally between the two thalami and the hypothalamus. The third ventricle communicates with the fourth ventricle via the cerebral aqueduct. Three foraminae (median and two lateral apertures) communicate the fourth ventricle with the subarachnoid space. The fourth ventricle continues with the central canal, allowing CSF to bathe the inside surface of the spinal cord as well (**Carpenter and Sutin, 1983; FitzGerald & Folan-Curran, 2002**).

Several studies support frequent reports of an asymmetry favoring an increased volume of the left compared to the right lateral cerebral ventricle **(Shenton et al., 1991)**.

In study of **Celik et al. (1995),** CT examination of 100 cases with no physical or neurological deficits revealed that the sizes of the cerebral ventricles increase with age in both sexes. Increase in the size of the third ventricle by age was statistically significant. Compared to women, the size of the third ventricle was larger in men.

Mu et al. (1999) performed a study to define the range of normal volume for the temporal horn of the lateral ventricle in different age groups ranging from 40 to 90 years in order to generate a guideline for the MR diagnosis and differential diagnosis of early Alzheimer disease. Their results concluded that differences in the mean value of standardized volumes of the hippocampal formation,

the amygdala, and the temporal horn correspond to differences in age among healthy subjects.

Sullivan et al. (**2002**) used MRI performed twice, 4 years apart, to compare rates of age-related size change of the corpus callosum, which inconsistently observed to thin with age, with change in the lateral ventricles, which are well established to enlarge. Percent change in size was significant for both the callosal and ventricular measures, but annual rate of ventricular expansion was significantly greater than annual rate of callosal thinning.

CIRCUMVENTRICULAR ORGANS

The circumventricular organs are midline sites in the ventricular walls where the blood brain barrier is absent **(McKinley et al., 2003)**. They include the vascular organ, subfornical organ, neurohypophysis, median eminence, subcommissural organ, pineal gland, and area postrema.

The circumventricular organs are six patches of brain tissues close to ventricular system contain neurons and specialized glial cells abutting fenestrated capillaries **(FitzGerald & Folan-Curran, 2002**). Specialized ependymal cells called tanycytes are also present and may be involved in secretions into CSF and transport of neurochemicals from subjacent neurons, glia or vessels to the CSF and transport of neurochemicals from CSF to the adjacent structures **(Carpenter and Sutin, 1983; Standing et al., 2005)**. In addition, these ependymal and subependymal glia cell layers are the source of undifferentiated stem cells in the adult **(Mercier et al., 2002)**, currently under intensive study for their potential neurorestorative properties.

CHOROID PLEXUS

In the roof of the third and fourth ventricles, and in the lateral ventricle along the line of the choroid fissure, the vascular pia mater lie in close apposition to the ependymal lining of the ventricles forming telachoroida which gives rise to highly vasculraized choroid plexus. CSF secreted by the choroid plexus into the ventricles at rate of about 500 ml per day **(Burt, 1993; Dudek & Fix, 2005; Standing et al., 2005)**.

In the lateral ventricle, the choroid plexus extends anteriorly as far as interventricular foramen. From which, the plexus passes posteriorly, in contact with the thalamus, curving round its posterior aspect (pulvinar) to enter the inferior horn of the ventricle and reaches the hippocampus. Throughout the body of the ventricle, the choroid plexus lies between the fornix superiorly and the thalamus inferiorly **(Carpenter and Sutin, 1983)**.

The blood supply of the choroid plexus in the lateral ventricle is usually via the anterior choroidal branch of the internal carotid artery and several choroidal branches of the posterior cerebral artery **(Burt, 1993; FitzGerald & Folan-Curran, 2002)**.

IMAGING OF THE VENTRICULAR SYSTEM

The history of neuroimaging began in the early 1900s with a technique called pneumoencephalography. This process involved draining the cerebrospinal fluid from around the brain and replacing it with air, altering the relative density of the brain and its surroundings, to show up better on an x-ray. It was considered to be incredibly unsafe for patients **(Griscom and O'Connor, 1995).** A form of magnetic resonance imaging (MRI) and computed tomography (CT) were developed in the 1970s and 1980s. The new MRI and CT technologies were considerably less harmful. Next come Positron Emission Tomography (PET) scans, which allowed scientists to map brain function. Learning from MRI, PET scanning, scientists were able to develop functional MRI (fMRI) with abilities that opened the door to direct observation of cognitive activities **(Chmielowski et al., 2004; Srijit and Shipra, 2007; Jain et al., 2008).**

Moniz (in1927) introduced cerebral angiography, whereby both normal and abnormal blood vessels in and around the brain could be visualized with great accuracy **(**Quoted from **Gawish et al., 2005)**.

Ultrasound being a safe, quick, noninvasive & repeatable modality has a definite role in diagnosis of hydrocephalus. However, the ultrasound waves cannot penetrate the bony skull. It is still used in neonatal brain imaging where the open anterior fontanelle is the

acoustic window. Hence, its use is limited between age group 6 months- 2 years. Often hydrocephalus can be diagnosed in utero by 15 weeks gestation. The ventricular height and the diagonal width are more appropriate for assessing ventricular dilatation in preterm neonates. In utero, an upper limit of 10 mm for the ventricular atrium is considered significant and hydrocephalus can be suspected **(Berg et al., 2000; Ichihashi et al., 2005; Correa et al., 2006).**

With the advent of computerized axial tomography (CAT), ever more detailed anatomic images of the brain became available for diagnostic and research purposes. The names of **Oldendorf in 1961 Hounsfield and Cormack in 1973 (** Quoted from **Gawish et al., 2005)** are associated with this revolutionary innovation, which enabled much easier, safer, non-invasive, painless and to a reasonable extent repeatable neuro-investigation.

Certain CNS abnormalities can be missed with routine US, especially if the ventricles are not dilated, as in the case of agenesis of the corpus callosum, this problem noted by **Bennett et al., (1996).** Because of these limitations, magnetic resonance (MR) imaging has been suggested as a useful adjunct in cases in which US findings are nonspecific **(Sonigo et al., 1998)**. MR imaging allows acquisition of multipalnar views and direct visualization of the brain parenchyma, thus providing a detailed evaluation of CNS anatomy in a manner not possible with US **(Levine et al., 1997; Erdem et al., 2007; Hakyemez et al., 2007).**

The possibilities of differentiation between a "normal" and an "enlarged" ventricular system by means of computerized tomography are limited. On the other hand, that differentiation is essential for the diagnosis of ventricular enlargement, hydrocephalus and brain atrophy. The daily practice requires a method, which allows an accurate measurement as well as a quick and simple performance. The evaluation of the width of the lateral ventricles by means of the ventricle index (VI) and of the ventricle-hemispheric index (V/H) using computed tomogram is likely to meet all these requirements **(Reisner et al., 1980).**

In the study of **Brinkman et al. (1981),** quantitative indexes of computed tomography included bifrontal, bicaudate ratios and ventricular ⁄ brain ratio (VBR) were compared in patients with Alzheimer dementia and in elderly persons with no history of neurologic diseases. Age-correlated ventricle-brain ratios were abnormal for half of the dementia patients; where as only a single subject in the control group had ventricles outside the limits of normal variation. Employment of quantitative indexes standardized for age may aid in differentiating cerebral atrophy associated with dementia from that associated with normal aging.

Study of the ventricular system with computed tomography has been of interest since the introduction of this modality. **Hughes and Gado (1981)** studied four linear measurements of the ventricular system. Three of these measurements were taken from the image at the level of the foramen of Monro. **A=** the width of the third ventricle;

B= the sum of the shortest distances between the caudate nucleus and the septum pellucidum; **C** = the width of the lateral ventricles just anterior to the foramen of Monro. **D** = the width of the narrowest part of the bodies of the lateral ventricle. The widest interparietal distance was measured from the image showing that part of the ventricle. A ventricular score (VS) was obtained with the following equation:

VS= A + B + C + D / Interparietal distance

Hirashima et al. (1983) studied the measurements of the area of the anterior horn of the right lateral ventricle and four ventricular indices from the CT scans of 198 normal cases: (1) maximum width of the anterior horns; (2) minimum width of the anterior horns; (3) sum of these maximum and minimum widths; and (4) the ventricular index. The size of the ventricular system increased steadily with age. The sum of the maximum and minimum widths of the anterior horns was most highly correlated with the area of the right anterior horn.

The premature infant brain has been thoroughly studied by sonography and normal standards for ventricular size have been established **(Hobar et al., 1983). Winchester et al. (1986)** examined the normal appearance of the lateral ventricles in 53 healthy full-term infants by sonography on the first to sixth days of life. Vaginal delivery had a statistically significant association with these “compressed’ lateral ventricles. Their study indicates that asymmetric ventricular size may be normal, and that shortly after birth most healthy infants have “compressed” lateral ventricles that should not be interpreted as cerebral edema.

Blatter et al. (1995) presented a normative volumetric database of total brain volume and total ventricular volume, based on a multispectral segmentation of brain MR. In this study standard axial T2-weighted MR images were performed. They concluded that these normative data tables could provide a comparison index for contrasting pathologic groups with a normative sample.

O'Hayon et al. (1998) compared volumetric area and linear measurement of ventricular size in pediatric patients with hydrocephalus. Sixty-four CT, MRI, and US scans from 25 children aged 0 -17 years with hydrocephalus were measured. Measurements included ventricular volume, a ventricular/brain ratio, and four standard linear measures (Evans' index, minimal lateral ventricular width, lateral ventricular span at the body and the frontal and occipital horn ratio). They concluded that the frontal／occipital horn ratio (FOR) is a simple method of evaluating ventricular size in pediatric hydrocephalus patients.

Kulkarni et al. (1999) characterized the measurement properties of the FOR in children with hydrocephalus. They concluded that the FOR is simple and linear reproducible method for assessments of hydrocephalus.

Levine et al. (2002) elucidated the imaging appearance of the fetal cerebral ventricles by comparing ultrasonographic and MR images. They reviewed MR and US images of 110 normal fetuses and 94 fetuses with central nervous system abnormalities to assess lateral ventricular morphology. They concluded that ventricular

contours differ with differing diagnosis of central nervous system abnormalities.

The development of a computer-assisted ultrasonic device offers new perspectives for the quantification of ventricular volume. **Csutak et al. (2003)** examined 250 healthy neonates with 3D cranial ultrasound. The volume of both lateral ventricles and the third ventricle were separately quantified and summated for the calculation of ventricular volume. The correlation between body weight, head circumference, gestational age and ventricular volume was statistically significant. 3D US appear to be an accurate imaging modality for the exact calculation of ventricular volume and therefore should be incorporated into the cranial sonographic assessment of ventricular size in infants.

Duffner et al. (2003) scanned thirty healthy volunteers and thirty patients suffering from hydrocephalus using high-resolution 3-D MR imaging. In healthy volunteers, the measurements confirmed the results previously obtained from ventriculography and from anatomic casts. In hydrocephalic patients, the ventricular system was found to be enlarged asymmetrically.

Grasby et al. (2003) studied 81 preterm neonates by ultrasound scans obtained nearest to 6 weeks of age. The ventricular index, the diagonal width and the ventricular height were measured and were used to grade the degree of dilatation. They concluded that the ventricular height and the diagonal width are more appropriate for assessing ventricular dilatation in preterm neonates.

Ichihashi et al. (2005) assessed ventricular volume with 3D ultrasonography and found that the lateral ventricular size became larger during the first two weeks after birth. The left ventricle was larger than the right one. There was no correlation between lateral ventricular volume and birth weight.

Garel and Alberti (2006) evaluated the similarities between fetal ultrasonography and MRI in the measurement of atrial diameter of the lateral ventricle on a coronal slice at the level of the choroid plexuses in 106 fetuses. Their results showed that the two techniques yielded results in close agreement. Ventricular atrial diameters below 10 mm tended to be slightly overestimated by ultrasonography, whereas those above 10 mm tended to be underestimated in comparison to measurements by MRI.

Kazan-Tannus et al. (2007) assessed which imaging plane is most reproducible for the performance of brain volumetry measurements in fetuses referred for ventriculomegaly. The results showed that the volumes increased with gestational age. They concluded that supratentorial parenchyma and lateral ventricular volumes can be reliably measured on fetal MRI, and imaging plane was not an important factor in measurement.

LATERAL VENTRICLE IN DIFFERENT DISEASES

The abnormality in the normal pressure hydrocephalus (NPH) occurs secondary to an abnormality in fluid removal, leading to an increase in ventricular size and encroachment of enlarged ventricles on adjacent brain tissue. The pressure exerted on the cerebral parenchyma by immense fluid-filled cavities deforms white matter tracts, causes gait abnormalities and incomplete control of the bladder, as well as difficulties in processing incoming stimulation and in producing responses. MRI or CT typically demonstrates ventricular dilation with preservation of the surrounding brain tissue. Compared with studies of normal patients, MRI of patients who have NPH demonstrates ventriculomegaly and maintained cerebral parenchyma. This finding is in contrast to the ventricular dilation associated with significant loss of brain tissue evident in images of patients who have Alzheimer's disease **(Verrees and Selman, 2004)**.

Dilatation of the temporal horns, increased frontal horn radius, and acuteness of the ventricular angle have been described as the classic structural changes suggestive of hydrocephalus (**El Gammal et al., 1987; Segev et al., 2001).**

Anderson et al. (2002) used a three-dimensional analysis to measure ventricular volume changes after shunting for idiopathic normal pressure hydrocephalus (INPH). They observed a decrease in ventricular volume after shunting in 10 of 11 patients.

Ernestus et al. (2002) examined thirty patients with occlusive hydrocephalus by the relevance of differentiated MR imaging. They found that MRI allows a very precise estimation of the pathophysiological and the anatomic prerequisites for endoscopic procedures.

Bazán-Camacho et al. (2004) described the evolution of ventricular dilatations during the early years of life as well as how to carry out a prospective estimate of the changes in the ventricular measurements for hydrocephalus by using ultrasonography. They concluded that ultrasonic encephalography plays a valuable role in the diagnosis and follow-up of ventriculomegalies.

Lee et al. (2005) evaluated the correlation between gait disturbance and midbrain diameter and the width of the lateral ventricles in patients with idiopathic normal pressure hydrocephalus (NPH) by using MRI. The results showed that the maximal midbrain diameter was significantly smaller in the NPH group than in the controls, there were inverse correlations between the midbrain diameter and the width of the lateral ventricles. They concluded that midbrain atrophy is significantly associated with gait disturbance in NPH.

Enlargement of the lateral cerebral ventricles is one of the earliest reported structural brain imaging abnormalities found in schizophrenia, as well as one of the most stable findings in morphometric investigations **(Buchsbaum et al., 1997; Mata et al., 2009). Raz et al. (1987)** studied the size of the cerebral ventricles of 14 young patients with schizophrenia and 12 controls. A volumetric analysis of the same 26 scans revealed enlargement of the lateral and third ventricles in the schizophrenics. On the other hand, **Wright et al.** (**2000)** have implicated preferential enlargement of the temporal horn or body of the ventricles. They found that the mean cerebral volume of the subjects with schizophrenia was smaller, but the mean total ventricular volume was greater.

Nopoulos et al. (1997) studied volumes of major brain regions of eighty schizophrenic patients (40 male and 40 female) and 80 healthy volunteers matched by sex and age. They concluded that male and female patients with schizophrenia have the same pattern of structural brain abnormalities, but male patients appear to manifest greater severity, especially with regard to ventricular enlargement.

Gaser et al. (2004) reported that thalamic shrinkage, especially of medial nuclei and the adjacent striatum and insular cortex, appear to be important contributors to ventricular enlargement in schizophrenia.

Nakamura et al. (2004) designed a study to investigate the extent to which schizophrenia patients can be differentiated from normal subjects by structural brain measures by using MRI. Significant enlargements of the left and right body of the lateral ventricle were observed in the male patients. Significant enlargements of the left inferior horn were observed in the female patients.

Styner et al. (2005) explored the effects of heritability and genetic risk for schizophrenia reflected in ventricular size and structure. They examined ventricular shape and size in the MRI studies of monozygotic (MZ) twin pairs discordant for schizophrenia, healthy MZ twin pairs, healthy dizygotic twin pairs, and healthy nonrelated subject pairs. Their results suggest that genetics have stronger influence on the shape of lateral ventricles than do the disease- related changes in the schizophrenia.

Beats et al. (1991) and **Wurthmann et al. (1995)** studied ventricular enlargement in geriatric depression and control persons with computed tomography. They found that patients with geriatric depression had a remarkable enlargement of the ventricles.

Abnormally large brain ventricles have been reported frequently in bipolar disorder. In addition, lateral ventriculomegaly might progress with repeated affective episodes and greater illness severity in bipolar disorder **(Davis et al., 1998; Hauser et al, 2000).**

Studies of patients with unipolar depression suggest associations between greater lateral ventricular volume and basal ganglia abnormalities **(Strakowski et al., 2000).**

Fiske et al. (2005) performed cerebral ultrasound examinations in 35 infants and early signs of ventricular dilation were reviewed. They noticed that displacement of the medial wall of the body of the lateral ventricle toward the midline is an earlier sign of ventricular dilation than the displacement of the lateral wall away from the midline.

Berg et al. (2000) examined 74 subjects with multiple sclerosis (MS) and ages- and sex-matched control subjects with MRI to assess the cross sectional area of the frontal horns of the lateral ventricles which were significantly larger in subjects with MS than in healthy ones. They concluded that measurement of the cross sectional area of the cerebral ventricle with MRI is quick and easy surrogate marker for serial follow-up examinations in patients with MS. Moreover, **Dalton et al. (2002)** investigated ventricular enlargement over one year in patients with MS and found significant ventricular enlargement in 27 of 55 patients who fulfilled the MRI criteria for MS.

Melhem et al. (2000) reviewed MR images of children with spastic cerebral palsy and found that lateral ventricular volumes of the moderate and marked motor deficit groups were significantly larger than those of the control and mild motor deficit groups.

Bradley et al. (2002) studied elderly subjects by serial volumetric brain MRI scans and concluded that rate of change analysis makes serial brain MRI a valuable surrogate marker for Alzheimer's disease.

Schmidt et al. (2004) studied the association of diabetes to MRI detected brain lesions to in 1,252 elderly individuals. The linear measurements of the ventricular diameter relative to the intracranial cavity defined the severity of subcortical atrophy. Diabetes was associated with cortical brain atrophy defined by ventricular dilatation but not with any focal brain lesions or subcortical atrophy.

Hemorrhage into the ventricles of the brain is one of the most serious complications of premature birth. Large intraventricular hemorrhage has a high risk of neurological disability and over 50 % of these children go on to develop progressive ventricular dilatation **(Sadleir and Tang , 2009).**