MORPHOMETRIC STUDY OF VENTRICULAR SIZES ON NORMAL COMPUTED TOMOGRAPHY SCANS OF ADULT BLACK ZIMBABWEANS AT A DIAGNOSTIC RADIOLOGY CENTRE IN HARARE-A PILOT STUDY

BY

ZILUNDU PRINCE L. M.

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FACULTY OF VETERINARY SCIENCE

UNIVERSITY OF ZIMBABWE

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ABSTRACT

The aim of the present study was to establish the range of the sizes for the different parts of the cerebral ventricular system. These simple measurements should be applicable to the brain Computed Tomography Scan reading without any need for advanced morphometric software package. Three hundred (150 females and 150 males) normal brain CT scans were obtained from a private Diagnostic Radiology centre in Harare for ventricular dimensions measurements (bifrontal, third ventricular and fourth ventricular dimensions). 18 hydrocephalus patients were also included in the study. A MILLENSYS DICOM Viewer Version 9® USA software program was used to measure ventricular dimensions in millimetres.

This study found an average (Mean±SE) frontal horn diameter, third ventricle width, fourth ventricle width, fourth ventricle height, Frontal Horn ratio (A/B), and the third ventricle ratio (C/D) for the sample being 31.8±0.2mm, 3.25±0.09mm, 10.6±0.1mm, 10.5±0.1, 0.313±0.002, and 0.030±0.002, respectively. Except for the fourth height which was not significantly affected by age ($p=0.515$), the present study showed that there was a significant difference between different age groups on all of the above measurements and ratios ($p<0.01$)

Criteria have been developed that are measurable, reproducible and applicable in routine diagnosis of dilated cerebral ventricles in adults. In general, the maximum frontal tips diameter greater than 48% or less than 25% corresponding plane are to be considered highly suspicious of abnormal ventricles. The overall frontal horn ratio of the eighteen hydrocephalus patients varied from 0.36 to 0.52 with an overall mean of 0.42.

DEDICATION

To all those involved in the teaching of anatomy - past, present and future

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CHAPTER ONE

1. INTRODUCTION

The human cerebral ventricular system contains a series of interconnecting spaces and channels which originates from the central lumen of embryonic neural tube. Cerebrospinal fluid filled ventricular system is an essential part of brain. The ventricular system in the cerebral hemispheres consists of two lateral ventricles; midline third and fourth ventricles connected by inter ventricular foramen and aqueduct of Sylvius respectively (Standring *et al.,* 1995). Understanding the normal and abnormal anatomy of the ventricular system of brain is helpful for clinicians, neurosurgeons, and radiologists in day-to-day clinical practice (Srijit and Shipra, 2007).

Pneumoencephalography and ventriculography are the older techniques of visualizing the ventricular system by injecting air through lumbar puncture under local anaesthesia (Evans, 1942; Hahn and Rim, 1976; Meese *et al.,* 1980). Ventricular system can also be studied by two dimensional ultrasonic studies especially in children (Davies *et al.*, 2000). In recent years, Computed Tomography (CT) scan and Magnetic Resonance Imaging (MRI) have replaced the older methods of studying ventricular system (Sabattini, 1982). Computerized Tomography is a revolutionary method of utilizing x-rays in the diagnosis. It is developed by Hounsfield GN, which provides images of transverse slices of brain without the use of contrast media in plain study (Gawler *et al.*, 1976; Sabattini, 1982; Gomori *et al.,* 1984).

1.1 BACKGROUND AND NEED

The advent of brain computerized tomography (CT) has afforded a generally safe, non-invasive means of examining the interior of the head, including evaluation of ventricular size (Gawler *et* *al., 1976;* Gallia *et al.,* 2006). Measurement of ventricular size dimensions has been made on polaroid pictures and of late, direct measurements are now possible on the soft copies of the CT scans, The digital CT scan machines currently in use also allow real time measurement of various dimensions of the ventricular system thus assisting in understanding its anatomy.

Morphometric analysis of cerebral ventricular system is important for evaluating changes due to growth, ageing, intrinsic and extrinsic pathologies (Le May, 1984; Aziz, 2004). It also helps neurosurgeons for localization and total removal of space occupying lesions around ventricular system like craniopharyngiomas and gliomas (Jacoby *et al.,* 1980). The study of shape and size of ventricular system recently has become a main focus of interest in studies of some neuropsychiatric diseases like schizophrenia and Alzheimer’s disease (McCarley *et al.,* 1989; Ashtari *et al.,* 1990; Gallia *et al.,* 2006) and chronic alcoholism (Rohlfing *et al.,* 2006). Knowledge of anatomy of cerebral ventricular system is important for endoscopic neurosurgery (Duffner *et al.,* 2003).

Morphometric analysis of ventricular system is also helpful in the diagnosis and classification of hydrocephalus and in assessment, follow-up of enlargement of ventricular system during therapy (ventricular shunts) (Losowska-Kaniewska and Oles, 2007; Ambarki *et al.,* 2010).

1.2 PROBLEM STATEMENT AND JUSTIFICATION

There is lacking evidence to date from available literature and in radiology practice of the ranges of the sizes of cerebral ventricles for the black adult Zimbabweans since currently used reference values were drawn from other populations and races that have different epidemiological, demographic and anatomical distribution. Radiologists are frequently faced with problems of deciding whether ventricles are within normal limits or enlarged for a patient's age. This has been a subjective decision based on experience (Haug, 1977; Gallia *et al.*, 2006) however, there is bound to be judgemental errors resulting in misdiagnosis. One such condition that results in a need for CT scan evaluation is hydrocephalus in adults.

1.3 RESEARCH QUESTION

Do the mean ventricular dimensions of adult black Zimbabweans differ from the standard reference values currently used in clinical practice which were drawn from studies done in other populations and/or of different races available in literature?

1.4 HYPOTHESIS

1.4.1 Null hypothesis:

The mean ventricular dimensions of the black Zimbabwean sample (Ẍ) are equal to normative reference values (μ) drawn from other populations whose averages have been published in available literature at 5% level of significance**: (H_0: $\ddot{X}=\mu$)**

1.4.2 Alternate hypothesis:

There is a difference between the mean ventricular dimensions of a sample drawn from the adult black Zimbabwean population as compared to normative reference values drawn from other populations whose averages have been published in available literature at 5% level of significance: **(H_1: $\ddot{X}\neq\mu$)**

1.4 AIM OF THE STUDY

This pilot study was set to establish baseline reference values for the lateral, third and fourth ventricular dimensions on normal brain Computed Tomography for adult black Zimbabweans patients, standardized for sex and age, from a sample pooled from patients who attended four radiology centres in Harare between January 2012 and May 2012.

1.5 OBJECTIVES

The objectives of the current study were to:

1. Determine the lateral, third and fourth cerebral ventricular linear dimensions on brain computed tomography scan in adult Zimbabweans who attended a private diagnostic radiology centre located in Harare between January 2012 and June 2012.
2. Determine the relationship of ventricular dimensions from CT scans across age groups.
3. Compare the mean values of dimensions in 1 above between males and females of comparative age groups.
4. Compute Linear Ventricular Brain ratios (Frontal horn ratio and third ventricular index) of adult Zimbabweans.

CHAPTER TWO

2.1 THE ANATOMY OF CEREBRAL VENTRICLES

In the adult human brain, there are four connected ventricles: two lateral ventricles within the cerebrum, a third ventricle within the diencephalon and a fourth ventricle lying between the cerebellum and the pons, shown in Fig. 2.1 below (Webber *et al.,* 1995; Lowery and Sive, 2009).

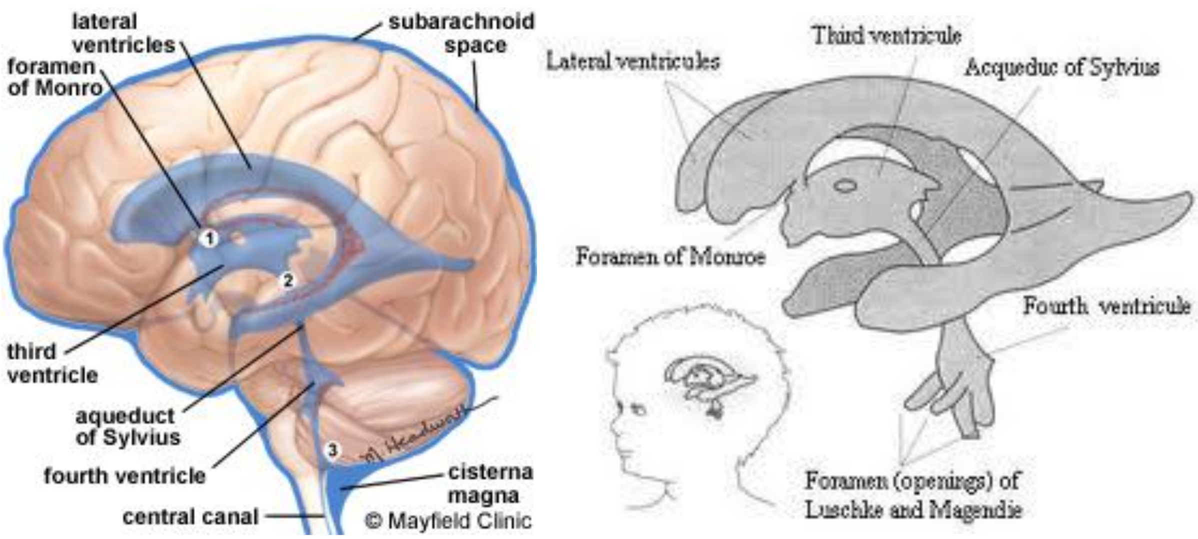

Fig. 2.1 Cerebral ventricles including relative position in the brain (source: Lowery and Sive, 2009).

The lateral ventricles, which lie within each cerebrum, are connected to the third ventricle (via interventricular foramina of Monro (labeled 1 in Figure 2.1) whilst the latter is linked to the fourth ventricle via the cerebral aqueduct of Sylvius (labeled 2 in Figure 2.1). In turn, the fourth ventricle joins to the spinal cord canal and the subarachnoid space that envelops the brain and spinal cord through foramina of central canal, Luschka and Magendie (Segev *et al.,* 2001; Pople, 2002; Lowery and Sive, 2009).

2.1.1 THE LATERAL VENTRICLE

The lateral ventricles, the first and second ventricles (Figure 2.1), are the largest cavities of the ventricular system and occupy large areas of the cerebral hemispheres. Each ventricle is a roughly C-shaped cavity lined with ependymal and filled with CSF. It may be divided into a body, which occupies the parietal lobe, and from which anterior, posterior and inferior horns extend into the frontal, occipital and temporal lobes respectively. Each lateral ventricle opens through an interventricular foramen into the third ventricle (Lowery and Sive, 2009). The tips of the frontal (anterior) horn are a region of interest in the measurement of bifrontal distance.

2.1.2 THE THIRD VENTRICLE

This is a slit-like cavity between the right and the left halves of the diencephalon (between two halves of the thalami). It communicates with the lateral and fourth ventricles as described above. The choroid plexus, which produces cerebrospinal fluid (CSF), lies in its roof (Webber *et al.*, 1995; Lowery and Sive, 2009). The maximum width of the ventricle has been widely used as a region of interest in various ventricular morphometric studies.

2.1.3 THE FOURTH VENTRICLE

The pyramid-shaped cavity filled with CSF is situated in the posterior part of the pons and the cranial part of the medulla and anterior to the cerebellum. Inferiorly, it tapers to a narrow channel that continues into the cervical region of the spinal cord as the central canal. It is lined with ependymal and is continuous superiorly with the cerebral aqueduct of the midbrain and inferiorly with the central canal of the medulla oblongata. CSF drains into the subarachnoid space from the fourth ventricle through a single median aperture of Magendie and paired lateral apertures of

Luschka. These apertures are the only means by which CSF enters the subarachnoid space (Lowery and Sive, 2009). If they are blocked, CSF accumulates and the ventricles distend, producing compression of the substance of the cerebral hemispheres in conditions such as hydrocephalus (Gallia *et al.,* 2006; Lowery and Sive, 2009). The greatest height and the width of the fourth ventricle are the parameters widely measured in various ventricular morphometric studies.

2.2 THE CEREBRAL VENTRICULAR SYSTEM AT WORK

The adult human brain contains about 140 ml of CSF, of which approximately 20 ml is within the ventricles and the remainder is surrounding the brain and spinal cord in the subarachnoid space (Lowery and Sive, 2009). Adult CSF is produced mainly by the choroid plexuses, highly vascular structures located within the ventricles (relative position shown by a red hue line in fig 2.1) and some CSF may be produced by the cells lining the ventricles (Segev *et al.,* 2001; Pople, 2002; Lowery and Sive, 2009).

It is now believed that CSF flows from the lateral ventricles to the third and fourth, and then out into the subarachnoid space where it is absorbed into the hematopoietic circulatory and lymphatic systems via the arachnoid granulations. Control of CSF flow is thought to originate in pressure gradient produced by secretion, arterial systolic pulsations, and changes in central nervous pressure during respiration and by beating cilia with uniform orientation located on the ependymal epithelium that lines the ventricles (Segev *et al.,* 2001; Pople, 2002; Greitz, 2004;Igbaseimokumo,2009; Lowery and Sive, 2009).

The notion of a circulatory system deep within the brain suggests functions analogous to the hematopoietic circulatory system, including the transport of nutrients and wastes, and the functions have been attributed to the adult CSF. In addition, CSF protects the adult brain from physical trauma, and recent data suggests that in both the embryo and adult brain, CSF may additionally carry signaling molecules that regulate neurogenesis and survival (Lowery and Sive, 2009).

In a healthy body, excess cerebrospinal fluid will drain away and be reabsorbed by the surrounding tissues, such as the arachnoid granulations. When the CSF builds up, the ventricles enlarge due to the extra fluid, and then press on the surrounding tissue of the brain, causing particular sets of symptoms, i.e. hydrocephalus (Pople, 2002; Greitz, 2004; Lowery and Sive, 2009).

Hydrocephalus may be congenital or it may be acquired, wherein some sort of obstruction occurs in the CSF dynamics in later years. There are many causes for hydrocephalus in adulthood. Briefly, they may include obstructive tumors, post-meningitic hydrocephalus, post-hemorrhagic hydrocephalus with a subarachnoid bleed, or post-traumatic hydrocephalus which may present with a bleed in the subarachnoid space.

Hydrocephalic conditions may also result from meningeal carcinomatosis (metastasis), or other primary tumors such as medulloblastomas, primitive neuroectodermal tumors, ependymomas and many other tumors that may spread along the subarachnoid space and obstruct the absorption of the CSF. In extreme cases especially in resource poor countries, a person may contract parasites that invade the subarachnoid space and produce pachymeningitis, such as cysticercosis and mycosis, among others (Aschoff *et al*., 1999; Pople, 2002; Abderrahmane *et al.*, 2006).

Ventricular dilatation is a common finding in hydrocephalus among other important clinical conditions affecting the healthcare system in Zimbabwe. Hydrocephalus is an important public health problem among adults whose diagnosis is partly confirmed on imaging (Auckland et al., 2008). Knowledge of ventricular size possible through CT scanning of the brain may assist in diagnosis and grading of enlarged cerebral ventricles

.2.3 EVALUATION AND MEASUREMENT OF CEREBRAL VENTRICLES

Before the advent of computed tomography (CT), radiological measurements measurements of cerebral ventricle sizes were made on pneumoencephalographic (PEG) pictures, mainly on anterior posterior views (Evans, 1942; Barrons *et al.,* 1976; Gonzalez *et al.,* 1978). The PEG methods have many sources of error as summarized by Sabattini (1982). These include deformation of anatomical structures due to x ray beams; and the brain swelling and dilatation of ventricles due to amount and location of introduced air. CT has been preferred because difficulties related to the contrast media (air) do not exist, direct visualization of structures is achieved even without moving the patient (Sabattini, 1982); Various approaches to quantification of cerebral ventricular/brain size have been used and they include: single section area estimates on CT scans (Synek and Reuben, 1976), linear measurements on CT scans (Meese *et al.*, 1980, Sabattini, 1982); and volumetric estimates on CT scans (Mathalon *et al.,* 1993).

Currently, with improved technology and development digitalized Computed Tomography, it has become possible to do direct linear measurements of cerebral dimensions on the CT scan machines and also to transfer soft copies of the CT scans to currently available functions to be read i.e. Windows or Mackintosh computer for measurements and more so, precise measurements of linear ventricular dimensions are possible due to modern consoles such a software programmes like Millensys Dicom Viewer® available on CT apparatus.

2.4 CHANGES IN THE BRAIN VENTRICLES: SEX AND AGEING

Changes in the brain with ageing have been the focus of many studies. Barron *et al.,* (1976) studied ventricular size during aging and found a gradual progressive increase in ventricular size from first to the sixth decade followed by a dramatic increase in the eighth and ninth decades. They found that the range of normal ventricular size was relatively wider in the eighth and ninth decades than in the first seven. According to a review by le May (1984) the brain grows rapidly early in life and reaches maximum weight by the third decade, thereafter regression soon begins. She also noted that regression of the brain in an individual is a normal process and could result in compensatory enlargement of the ventricles.

2.4.1 THE LATERAL VENTRICLES

Barron *et al.,* (1976) reported a normal slight progression in size of the lateral ventricles beginning at around the fourth decade and a more striking increase after the sixth decade. Hahn and Rim (1976) used linear ratios (of ventricular dimensions against the brain diameter on the same plane) to ensure that their results were independent from particular scale factors utilized in sizing up Computed Tomography scan images. Their results also do not bear the units of measurements employed; furthermore, the influence of variations in the size of ventricles due to anthropometric differences in normal individuals is minimized. In light of the above, they computed the frontal horn index as a range of 0.19 to 0.39 with a mean for all ages being 0.31 for the normal frontal ventricle These findings were consistent with the works of Hahn and Rim (1976) Gyldensted (1977), Haug, (1977), Wolpert (1977) and Meese *et al*., (1980).

Furthermore, Hahn *et al.,* (1977) studied the bifrontal index (Frontal horn ratio, FHR) of 388 normal brain scans and it was found to be 0.32 ± 0.04. Thus FHR, which can be interpreted as the maximum distance between the external margins of the frontal horns, is normally approximately one-third the width of the brain. Another study done by Park *et al,* (1990) in Korea with a larger sample size (n=1000) found a frontal horn index of 0.3±0.033.

2.4.2 THE THIRD VENTRICLE

In his study of the width of the third ventricle, Borgersen, (1966) noted that there is gradual widening of the third ventricle starting about the fourth decade, before then, he observed no or only a trace of the third ventricle. Similar results were obtained by Haug (1977). Both authors also found that mean values of the width of the third ventricle suggested a smaller ventricular system in the female than in the males in all ages beyond the second decade.

Gawler *et al*., (1976), Brinkman *et al*., (1982) and Soininen *et al*., (1982) found that the maximum width of the third ventricle had a mean of 0.46cm, 0.59cm and 0.92cm respectively with higher figures in males. D'Souza and Natekar (2007) found a width of 0.45cm in males compared to 0.39cm of females beyond the age of sixty years.

Third Ventricular ratio (the maximum width of the ventricle divided by the width of the brain at the same level has not been widely quoted in literature as an indirect measure of ventricular size. However, it was quoted as 0.02 in normal controls used in CT abnormalities study of schizophrenia by McCarley *et al*., (1989).

2.4.3 THE FOURTH VENTRICLE

A study done by Gawler *et al*., (1976) found the greatest height of the fourth ventricle to be less than 1.2cm with a mean of 1.08cm The width of the fourth ventricle as measured in later studies by Meese *et al*., (1980) and D'Souza and Natekar (2007) was found to be greater than the height in both sexes with males recording a significantly higher width (1.31cm), as compared to 1.21cm average of females. However, these studies found that there was a slight progression in the dimensions of the fourth ventricle with age.

2.5 VENTRICULAR SIZE IN HYDROCEPHALUS

In a group of 65 hydrocephalus patients, Hahn and Rim, (1976), the frontal horn ratio varied from 0.34 to 0.78, with a mean of 44.8±0.78. Le May and Hochberg, (1979), found a mean frontal horn index of 0.5 in patients with obstructive hydrocephalus.

CHAPTER THREE METHODOLOGY

3.1 STUDY SETTING

Three hundred normal brain Computerized Tomograms (CT) of adults black Zimbabweans aged between ten and eighty years were obtained from a privately owned diagnostic radiology centre, A, in Harare. The brain CT scans were taken from referred patients complaining of headaches but whose CT scan reading were found to be normal by a qualified radiologist between 01 January 2012 and 30 June 2012. Eighteen brain CT scans of diagnosed with hydrocephalus were included in the study for comparison purposes.

3.2 STUDY DESIGN

This was of a retrospective descriptive pilot study.

3.3 SAMPLING

Convenient sampling was used to obtain normal and hydrocephalus brain CT scans for measurements. All brain CT scans that met the inclusion criterion below were considered in this study.

3.3.1 INCLUSION CRITERION

The brain CT scans were included in this study if;

- They were from Black Zimbabweans (males and females).
- They were from participants aged between 10 and 80 years.

- The participants provided at least an oral consent or parent/guardian oral consent and an additional assent from participants less than 18 years but greater than 9 years old.
- The brain CT scans were described as normal by a radiologist with respect to:
  - Normal Cerebral ventricular size, form, shape and periventricular translucency.
  - Brain parenchyma normal with no evidence of space occupying lesions.

3.3.2 EXCLUSION CRITERION

CT scans were excluded in this study if;

- They were from patients who are non-Zimbabwe citizens by birth regardless of race.
- They were from patients of any other race besides black.
- They were obtained from patients of mixed race.
- They were obtained from patients whose reasons for CT scan evaluation was due to a stroke.
- They were described as normal by a Radiologist without comment on ventricular size.
- They were described as abnormal with;
  - Evidence of space occupying lesions or,
  - Cerebral hemorrhage

3.3.3. INCLUSION CRITERION FOR HYDROCEPHALUS CASES

The brain CT scans were included in this study if;

- They were from Black Zimbabweans (males and females).
- They were from participants aged between 10 and 80 years.

- The participants provided at least an oral consent or parent/guardian oral consent and an additional assent from participants less than 18 years but greater than 9 years old.
    - The brain CT scans were certified as abnormal (hydrocephalus) by a radiologist with respect to: Cerebral ventricular size, form, shape and periventricular translucency.

3.4 ETHICAL CONSIDERATIONS

Ethical clearance was sought from and granted by the Joint Research Ethics Committee (UZ) for use of patients' records. Permission was also sought and granted by the Consulting radiologists for use of their patients' records and equipment. Oral consent was sought from patients aged 18 and above for use of their results in this study whilst guardian oral consent was sort from parents/guardians of patients less than 18 years but greater than 9 years old with a supporting written child' assent. After obtaining consent and or supporting assent, all participants were asked to complete a designed questionnaire. Participants were contacted by phone from contact details obtained from the radiology centre.

3.5 CEREBRAL VENTRICULAR MEASUREMENTS

The current study used the linear measurement method utilizing a computer program Millensys Dicom Viewer 9 USA ®, graded in millimetres. This method is easy and straightforward in that it can be utilized by Radiologists and other healthcare professionals involved in radioimaging, especially in the resource poor setting like Zimbabwe.

Frontal Horn Index/ratio and Third ventricular Index/ratio were computed from the measurements taken from the CT scans. Evaluation of the Cerebrospinal fluid spaces was done without use of contrast media as it presents no great problem since there are considerable differences in density between CSF, brain tissue and bone (Meese *et al.*, 1980).

3.6 MEASUREMENT METHODS

The measurements described below were made using a computer program Millensys Dicom Viewer (Version 9®. USA); which is a software tool at the disposal of radiologists, radiographers and technicians that they can now use since the invention of digitalized CT scan machines. The measurement is calibrated to 0.1 millimetres. All other data is resented to three significant figures. The researcher made the following measurements:

A: The maximum bifrontal diameter: the transverse distance defined by a line connecting two anterior corners of the frontal horns (Hahn and Rim, 1976).

B: The first transverse diameter of the brain (brain width): the distance measured along the line of the bifrontal diameter (Hahn and Rim, 1976).

C: The greatest distances between each lateral margin of the third ventricle.

D: The second transverse diameter of the brain (brain width): the distance measured along the line of C extending from left to the right cortical surfaces.

E: The greatest height of the fourth ventricle.

F: The greatest width of the fourth ventricle.

The measurements A, B, C, and D listed above were used to compute the following ratios:

➢ Bi frontal ratio (Frontal Horn Ratio/index) - measured on the cut best showing the caudate nuclei describing the greatest distance between the tips of the frontal horns divided by the first transverse diameter of the brain along the same level (Hahn and Rim, 1976; Haug, 1977) (A/B).

➢ Third ventricle Ratio/index - the greatest distances between each lateral margin of the third ventricle divided by the distance measured along the line of the C extending from left to the right cortical surfaces (C/D).

The pictures in Figs 3.1 and 3.2 show regions of interest at which above measurements were made.

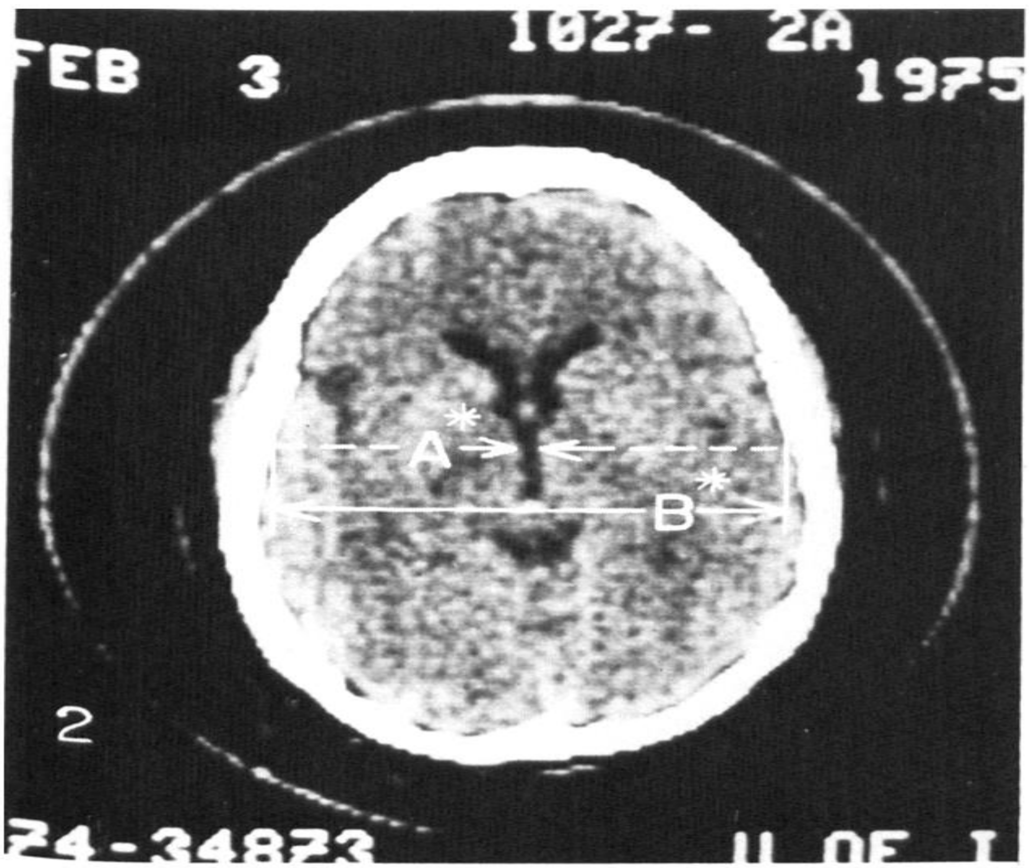

Fig. 3.1 measurements at the level of the third ventricle region of interest

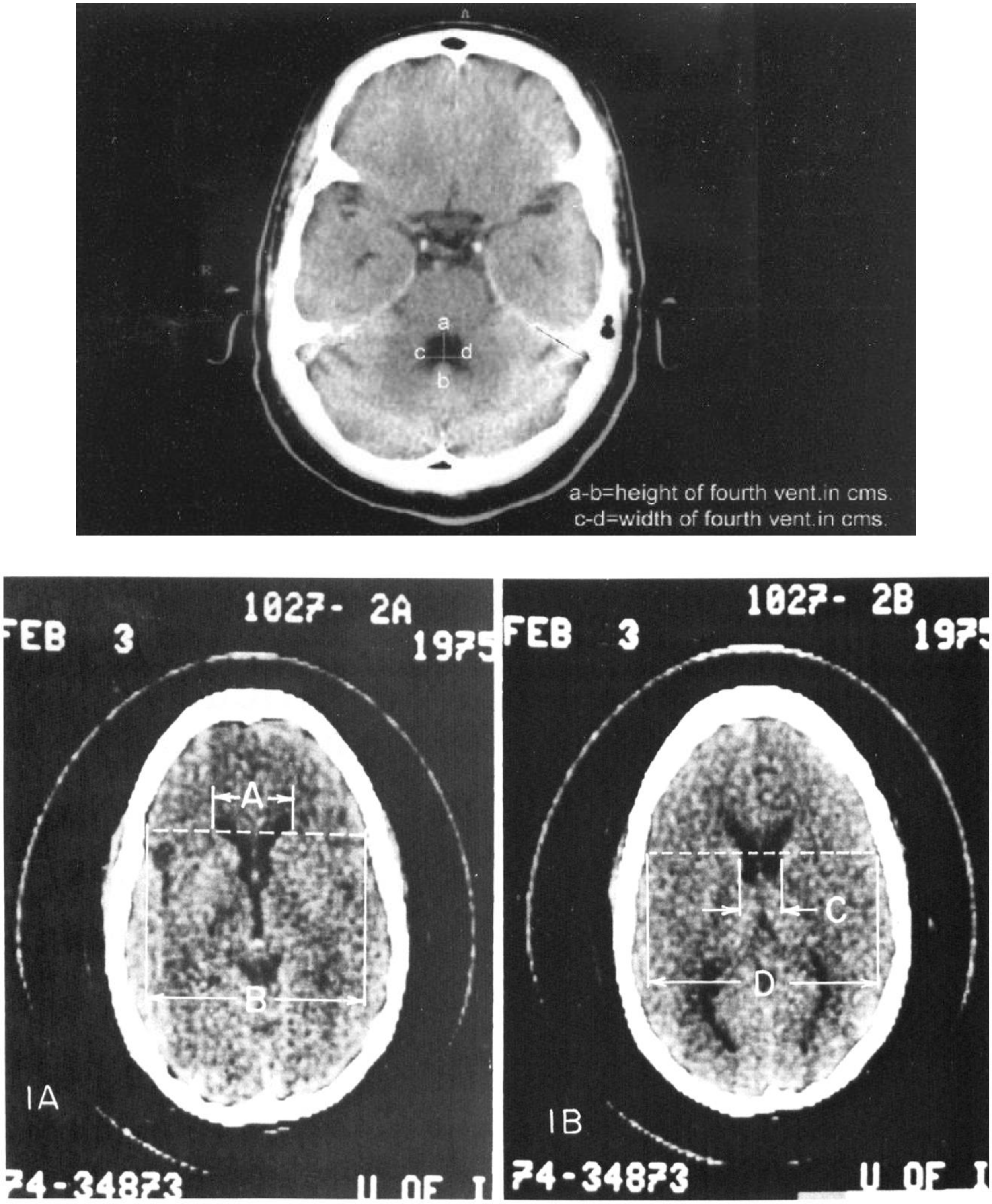

Fig. 3.2 measurements at the level of the fourth and lateral ventricles regions of interest

3.9 STATISTICAL ANALYSIS OF DATA

Statistical analysis of the data was performed by using Statistical Package for Social Sciences (SPSS) Version 16 USA ®. The mean, standard deviations and standard errors of all measurements were estimated and 95% confidence interval, both upper and lower, were calculated for all. The data was analysed by using ANOVA and student t-test for significance if differences of the measurements between males and females, the hydrocephalus (males and females), and the two groups (normal CT scan findings group (n=300) and hydrocephalus group (n=18).

CHAPTER FOUR RESULTS

4.1 INTRODUCTION

Three hundred and eighteen (318) brain Computed Tomography (CT) scan soft copies were obtained from a privately owned diagnostic radiology center in Harare. Three hundred of these brain CT scans were certified normal by the attending radiologist with respect to brain parenchyma and sizes of cerebral ventricles, while 18 were taken from hydrocephalus patients. The subjects whose CT scans of the brain were used were females (n=159; mean age 44±18) and males (n=159; mean age 40±19) aged between 10 and 80 years.

This study found an overall average (Mean ± SE) frontal horn width, third ventricle width, fourth ventricle width, fourth ventricle height, frontal horn ratio (FHR), and third ventricle ratio for the sample being 31.8±0.2mm, 3.25±0.09mm, 10.6±0.1mm, 10.5±0.1, 0.313±0.002, and 0.030±0.002, respectively (Table 4.1 below). Except for the width of the fourth ventricle height (p=0.52), there was a significant difference between different age groups on all of the above measurements and ratios.

The table below summarises the measurements made of the cerebral ventricles of all the 300 normal brain CT scans .

Table 4.1 Summary of measurements of ventricular dimensions

Measurements		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Frontal horn Tips diameter (mm)	10-19	40	31.7727	2.91990	.50829	30.7374	32.8081	26.80	37.40
	20-29	72	31.4819	2.51078	.29590	30.8919	32.0719	25.20	37.50
	30-39	33	30.5179	1.25906	.23794	30.0296	31.0061	26.70	32.10
	40-49	54	31.4574	2.47055	.33620	30.7831	32.1317	26.70	35.80
	50-59	41	31.6951	1.83180	.28608	31.1169	32.2733	27.50	35.10
	60-69	30	32.0000	1.47851	.32264	31.3270	32.6730	27.80	34.20
	70-79	30	35.1192	4.57375	.89699	33.2719	36.9666	28.50	47.90
	Total	300	31.8291	2.79128	.16832	31.4977	32.1605	25.20	47.90
Third ventricle Maximum Width (mm)	10-19	40	2.5636	.42339	.07370	2.4135	2.7138	2.00	3.30
	20-29	72	2.8319	.88855	.10472	2.6231	3.0407	1.20	7.60
	30-39	33	2.7750	.87586	.16552	2.4354	3.1146	1.60	4.60
	40-49	54	3.1796	1.18535	.16131	2.8561	3.5032	1.20	6.80
	50-59	41	2.7780	.64866	.10130	2.5733	2.9828	2.00	4.50
	60-69	30	3.5238	.73546	.16049	3.1890	3.8586	2.60	5.20
	70-79	30	6.4808	2.58720	.50739	5.4358	7.5258	2.70	14.20
	Total	300	3.2520	1.56229	.09421	3.0665	3.4375	1.20	14.20
	Total	300	1.1264E2	7.98272	.48138	111.6950	113.5903	11.27	131.90
Fourth width (Greatest)	10-19	40	11.0455	2.34135	.40758	10.2152	11.8757	7.80	16.70
	20-29	72	10.3250	2.30204	.27130	9.7840	10.8660	5.30	16.30
	30-39	33	10.5107	2.01960	.38167	9.7276	11.2938	7.90	15.00
	40-49	54	10.1852	1.74652	.23767	9.7085	10.6619	6.60	14.00
	50-59	41	9.6976	.85746	.13391	9.4269	9.9682	8.00	11.40
	60-69	30	12.3524	1.24283	.27121	11.7867	12.9181	9.80	15.10
	70-79	30	11.6346	1.97017	.38638	10.8388	12.4304	9.00	17.30
	Total	300	10.5880	2.02898	.12235	10.3471	10.8289	5.30	17.30
Fourth height	10-19	40	10.3636	2.40830	.41923	9.5097	11.2176	5.00	15.20
	20-29	72	10.4292	2.47906	.29216	9.8466	11.0117	4.80	15.40
	30-39	33	11.2929	2.04956	.38733	10.4981	12.0876	5.40	14.90
	40-49	54	10.2056	2.35752	.32082	9.5621	10.8490	4.90	14.30
	50-59	41	10.6000	1.92691	.30093	9.9918	11.2082	7.50	14.50
	60-69	30	10.9143	2.22784	.48616	9.9002	11.9284	4.80	16.10
	70-79	30	10.3154	2.51455	.49314	9.2997	11.3310	6.10	15.80
	Total	300	10.5171	2.31140	.13938	10.2427	10.7915	4.80	16.10

Table 4.2 analysis of variance of means of ventricular dimensions and ratios between males and females.

		Sum of Squares	df	Mean Square	F	Sig.
Frontal horn width	Between Groups	347.183	5	57.864	8.675	.000
	Within Groups	1787.624	294	6.670		
	Total	2134.807	299			
Third ventricle width	Between Groups	316.805	5	52.801	40.205	.000
	Within Groups	351.962	294	1.313		
	Total	668.766	299			
Fourth width	Between Groups	147.178	5	24.530	6.703	.000
	Within Groups	980.813	294	3.660		
	Total	1127.990	299			
Fourth height	Between Groups	28.078	5	4.680	.873	.515
	Within Groups	1435.792	294	5.357		
	Total	1463.870	299			
Frontal horn ratio	Between Groups	.047	5	.008	13.201	.000
	Within Groups	.160	294	.001		
	Total	.208	299			
Third ventricle ratio	Between Groups	.030	5	.005	8.380	.000
	Within Groups	.158	294	.001		
	Total	.188	299			

The frontal horn width is the largest of all dimensions with the third ventricular width being the least across all age groups (Table 4.1) and the fourth ventricular width and height are comparably equal and of intermediate size.

Table 4.3 Mean frontal horn diameter of males and females.

	Sex	N	Mean	Std. Deviation	Std. Error Mean	Levene's Test for Equality of Variances (p)
Frontal horn diameter	Female	150	31.2048	2.59881	.23338	0.622
	Male	150	32.3417	2.84732	.23171	
Frontal brain width	Female	150	1.0125E2	4.81163	.43210	0.821
	Male	150	1.0233E2	4.22142	.34353	
Third ventricle width	Female	150	3.0419	1.18508	.10642	0.064
	Male	150	3.4245	1.80011	.14649	
Third brain width	Female	150	1.1364E2	5.96271	.53547	0.274
	Male	150	1.1182E2	9.25958	.75353	
Fourth ventricle width	Female	150	9.7565	1.60524	.14415	0.000
	Male	150	11.2709	2.08948	.17004	
Fourth ventricle height	Female	150	10.2250	2.42506	.21778	0.601
	Male	150	10.7570	2.19279	.17845	

Table 4.3 shows the sex distribution of all the normal brain CT scan measurements. Except for the width of the fourth ventricle ($p<0.001$), there was no significant variation of all the measurements with sex ($p<0.3$). Generally, there was a non-significant tendency of the

dimensions of these parameters being higher in males as compared to females especially of the third ventricle (p=0.064).

4.2 FRONTAL HORN MEASUREMENTS ON NORMAL BRAIN CT SCAN

4.2.1 FRONTAL HORN DIAMETER AND AGE DIFFERENCES

There was a steady rise in the average size of the frontal horn diameter from the fourth decade of life (30.5±0.2mm) up to the sixth decade (31.7±0.3mm) with a marked high average frontal horn diameter distance in the seventh decade (32.0±0.3mm) although the average size of the frontal horns in the second (31.8±0.8mm), third (31.4±0.3), fifth (31.5±0.3mm) and sixth decade of life are comparable. There was a significant difference at between the second and the seventh decades of life (p=0.03). The fourth decade produced a lower mean value. The current study thus found a general tendency of decreased mean frontal diameter from adolescence to middle aged i.e. from 31.8±0.5mm (mean±SE) to 30.5±0.2mm respectively (p=0.562).

The average frontal horn diameter tends to increase with age from the middle age to the elderly (31.7±0.3mm) (p=0.103) with a significantly sharp increase in the old age (35.1±0.9mm) ($p<0.001$).

4.2.2 FRONTAL HORN DIAMETER AND SEX DIFFERENCES

The mean frontal horn diameter of males (green) was found to be generally larger than that of females (purple) during the second and third decades of life (Table 4.3 and Fig 4.1). Leveling off was noted in the middle ages after which there was a rise in feminine size in the seventh decade compared to that of men (Fig 4.1).

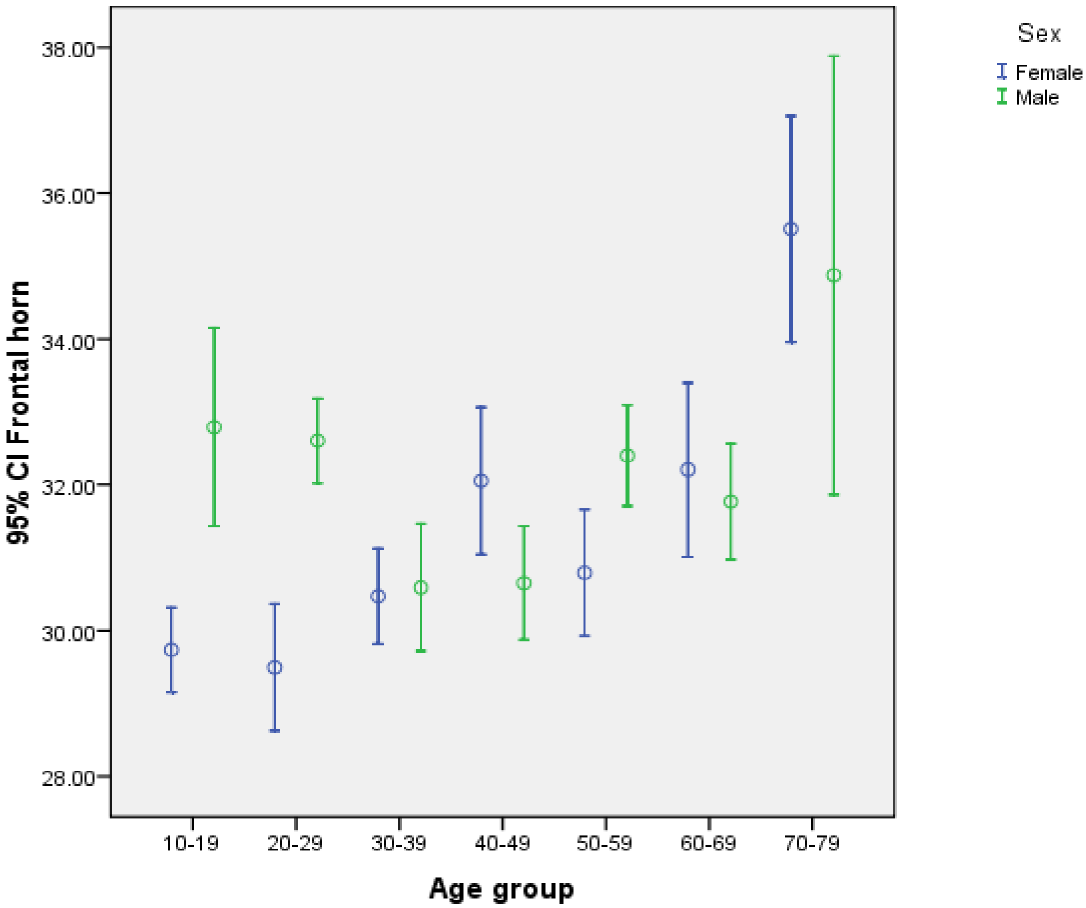

Fig. 4.1 average frontal horn diameters in males and females across age groups.

In this study, the mean frontal horn diameter of the lateral ventricle was found to be larger in males compared to females and also increased with age in all groups.

4.2.3 FRONTAL HORN INDEX/RATIO (FHR)

The frontal horn index or ratio was found to be averaging 0.313 in this study (table 4.3). The males, generally, were found to have a slightly larger mean frontal horn ratio than females (table 4.3).

The mean frontal horn ratio exhibited an uneven rise from third decade to the fifth decade, with a sharp decrease in the sixth decade followed by a rapid rise in the next decade (Fig 4.2). There were significant mean differences between the frontal horn ratios of the second (10 to 19 years) and the fifth and sixth decades ($p<0.05$).

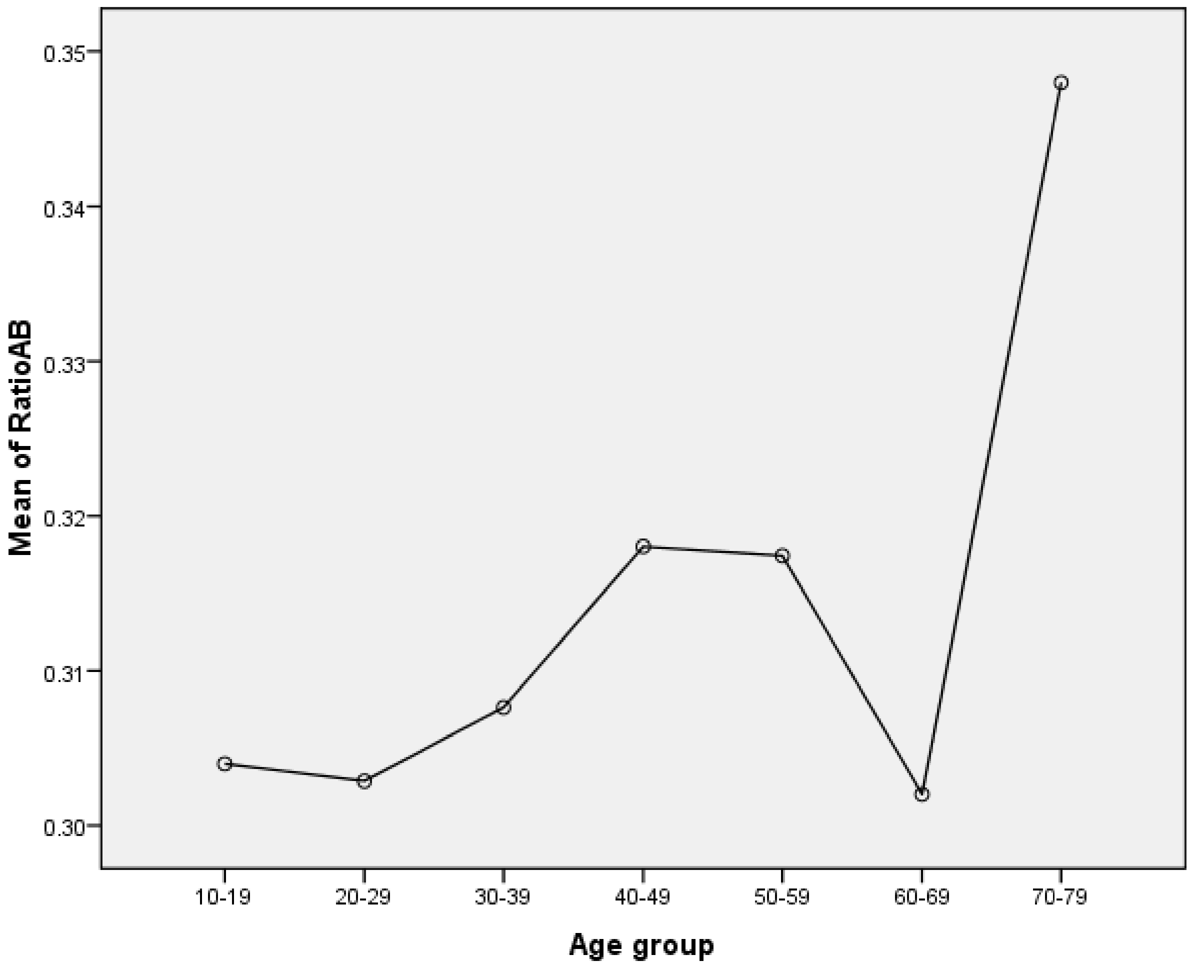

Fig. 4.2 variation of frontal horn ratios with age groups (in years).

The Fig. 4.3 shows mean frontal horn ratio (FHR) for each age group and how they vary. It was observed that in the first two decades under study, males had a greater mean as compared to females. The highest was recorded in the 50 to 59 year age range of males while the eldest range had women with the greater mean ratio.

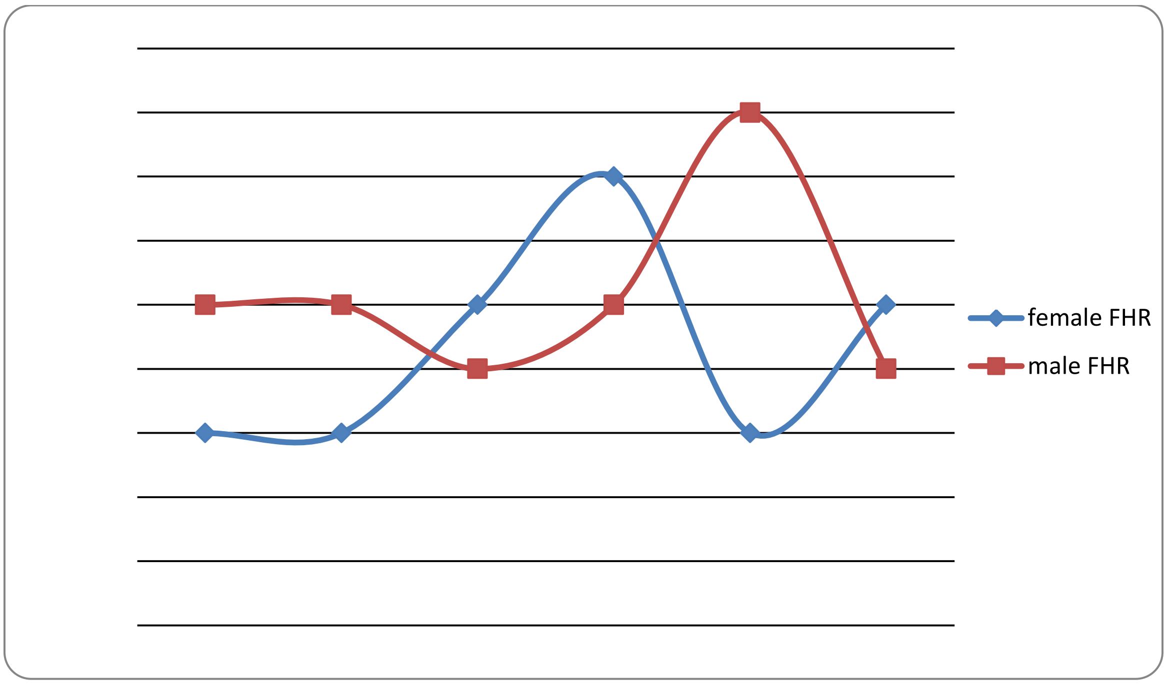

Fig. 4.3 shows mean frontal horn ratio for each age group.

.4.3 THIRD VENTRICLE MEASUREMENTS

Table 4.1 and 4.2 show the means of the maximum width of the third ventricle. There was an exponential rise in the size of the third ventricular ratio from the second to the 40 to 49 decade followed by a slight dip after which the graph rises steeply. The overall average width of the third ventricle was 3.04mm and 3.42mm in females and males, respectively.

The third ventricular index was computed as shown in the table 4.4.

Table 4.4 Variation of mean third ventricular indices with sex.

	10-19	20-29	30-39	40-49	50-59	60-69	70-79
Males	0.02	0.03	0.03	0.03	0.02	0.03	0.06
females	0.02	0.02	0.02	0.03	0.03	0.03	0.05

Males generally had a non-significant tendency of a larger mean third ventricular ratio (0.0329± 0,03380) compared to that of women (0.0268±0.01070) (p=0.064). There was however, a significant increase of the third ventricular ratio (p=0.039) with a sharp increase evident during the old aged individuals (Table 4.4).

4.4 THE FOURTH VENTRICLE MEASUREMENTS

These are shown in the Table 4.1 and Table 4.3 the width of the fourth ventricle was found to be larger than the height in males. A significant difference between males and females across age groups on the width of the fourth ventricle (p<0.001) was recorded (Table 4.2). However, an insignificant tendency of sex differences of the size of the fourth ventricle with that of males being greater than females was noted (p>0.1) (Table 4.2 and 4.3). The mean of the fourth ventricle height and width were all found to be comparable across all age groups.

4.5 CEREBRAL VENTRICLES IN HYDROCEPHALUS PATIENTS

The table 4.5 shows the mean ventricular dimensions of the hydrocephalus patients drawn from a private diagnostic centre from which the normal brain scans of the main study were obtained from. The current study found an overall average (mean±SE) frontal horn with, third ventricular width, fourth ventricle heidht, fourth ventricle width, frontal horn ratio and third ventricle ratio of 41.4±1.56, 7.7±1.04, 13.5±0.62, 14.6±0.70, 0.42±0.004 and 0.069±0.001, respectively

Table 4.5 cerebral ventricle parameters of 18 patients with hydrocephalus.

	N	Minimum	Maximum	Mean	
	Statistic	Statistic	Statistic	Statistic	Std. Error
Third ventricle width	18	3.70	16.70	7.7389	1.04344
frontal horn width	18	34.00	55.50	41.5056	1.55531
4th ventricle height	18	8.00	17.00	13.4833	.61577
4th ventricle width	18	8.00	20.00	14.5833	.69547
Frontal horn ratio (FHR)	18			0.4163	.004
3rd ventricle ratio	18			0.0685	0.001

4.5.1 FRONTAL HORN MEASUREMENTS IN HYDROCEPHALUS PATIENTS

These results are only presented for comparisons with main data from the normal brain CT scans. The table 4.6 shows that the hydrocephalic male patients, overally, had an insignificantly higher mean frontal horn ventricular diameter compared to female hydrocephalus patients (p=0.406). The overall frontal horn rations of the eighteen hydrocephalus patients varied from 0.36 to 0.52 with an overall mean of 0.42.

Table 4. 6 Mean frontal horn diameters of males and females.

SEX	Mean	N	Std. Deviation	Std. Error of Mean
Females	40.1667	9	7.98013	2.66004
Males	42.8444	9	4.98099	1.66033
Total	41.5056	18	6.59862	1.55531

4.5.2 THE THIRD VENTRICLE IN HYDROCEPHALUS PATIENTS

The average mean third ventricular ratio for all hydrocephalus patients was found to vary from 0.036 to 0.13 with an overall mean of 0.07±0.008. In the current study, male hydrocephalus patients had a higher mean third ventricular diameter than their female counterparts and the difference between groups was statistically significant (p=0.01) (Table 4.7).

Table 4.7 Average third ventricular width in males and females with hydrocephalus.

SEX	Mean	N	Std. Deviation	Std. Error of Mean
Females	4.7556	9	1.12928	.37643
Males	10.7222	9	4.51048	1.50349
Total	7.7389	18	4.42694	1.04344

4.5.3 THE FOURTH VENTRICLE IN PATIENTS WITH HYDROCEPHALUS

The mean height and width of the fourth ventricle were 13.5±0.62 and 14.6±0.70, respectively. This study found an average (Mean ± SE) fourth ventricular height to be significantly greater in males (Mean=15.2±SE0.83) than in female hydrocephalus patients (Mean= 11.8±SE 0.44) ($p=0.002$). However, the current study also found no significant statistical difference ($p= 0.106$) between the mean width of the fourth ventricle between males (higher, 15.7±1.12) and females (13.4±0.68) with hydrocephalus.

CHAPTER FIVE DISCUSSION

5.1 INTRODUCTION

In 1942, William Evans felt the need for a quantitative expression to describe more accurately the degree of enlargement of the cerebral ventricles and to define normal limits of the cerebral ventricles, and linear measurements were adopted (Evans, 1942). He defined and computed a ratio of transverse diameter of the anterior horns to the greatest internal diameter of the skull in the sagittal direction. This index was for children and the normal range was 0.20 to 0.25, and that a ratio of 0.25 to 0.30 represents early ventricular enlargement while values above 0.30 define ventricular enlargement. Due to a calculation error of the coefficient of variation he set at 12.9 instead of a correction by Zatz (1979) set at 0.129 later meant that the index was more variable and therefore a less significant quantity than the measurement of transverse diameter of the anterior horns of the lateral ventricles in adults (Toma *et al.*, 2010). In light of the above arguments, Meese *et al* (1980) evaluated CT scans of 170 healthy individuals evaluating and measuring CSF spaces in different age groups and computed the Frontal Horn ratio in the same manner as in the current study. Evans, (1942) calculated a ratio using dimensions taken at different levels of the skull making it liable to measurement errors and variability. The current study is unique in the sense that the frontal horn index is describing ventricular size as a fraction of the brain width of the same level.

5.2 FRONTAL HORN MEASUREMENTS

The width of the frontal horns was found to increase with age from the fourth (30.5±0.02) to the sixth decade of life (31.7±0.03) with a noted steep rise in old age (seventh decade). The current findings are similar to observations in previous studies by Hahn and Rim (1976) Gyldensted (1977), Haug, (1977), and Wolpert (1977). However, the second and third decades, in the present study had mean frontal diameters greater than the averages for the above mentioned previous authors. The differences may be attributed to epidemiological distribution of the probable causes of ventromegaly such as the high prevalence of HIV/AIDS in Zimbabwe, predisposing the adolescents and young adults to neurological conditions that would then explain the observed trend of slightly enlarged ventricular sizes. The current sample was drawn from patients whose CT scans of the brain were certified normal by a radiologist but their HIV status unknown and the cause of their headaches could not be explained by parenchymal or ventricular changes. In light of the above, it is recommended that future studies must focus on correlating presenting conditions of patients and the ultimate diagnosis with sizes of cerebral ventricles. Comparisons could also be made between HIV positive and negative patients in future studies

Also when compared with previous studies mostly conducted in developed countries, the local sample was drawn from a narrow population of Harare patients attending a privately owned diagnostic centre. In addition to this both current and the said previous studies (Hahn and Rim, 1976; Haug, 1977; D'Souza and Natekar, 2007) normal CT scan findings were sampled from people who had health complaints warranting CT scan evaluation of the brain, i.e headaches. Henceforth, it will be difficult to draw conclusions about the general Zimbabwean population, although these results of the current study can still be useful as baseline results for future prospective studies that may be conducted to develop local evidence-based normative reference values upon which cerebral ventricular size can be compared with for instance in the diagnosis of hydrocephalus in adults; at least for the general Zimbabwean and possibly black Africans. Thus, the findings from this study require care when being extrapolated to the generality of the Zimbabwean population. It is therefore recommended that future studies need to target healthy people carefully selected from the normal population of Zimbabweans and compared with that of patients with neurological disorders.

The present study found that the frontal horn ratio at the level of the tips varied from a minimum value of 0.24 to a maximum 0.47, averaging 0.31±0.027 (Mean±SD) confirming results of a previous study by Hahn and Rim (1976) whose normal range varied from 0.19 to 0.39 with an average of 0.31±0.04. These previous studies used normal brain scans of patients but, however, a computerized method of measurement of dimensions was used in both studies.

Also noted in the current study was the interesting tendency of the frontal diameter to increase with age, a feature observed by Hahn and Rim (1976). In terms of normality, the present study produced results that are comparable to previous normative studies but were less than those reported by le May and Hochberg (1979) in which they computed frontal horn index in 100 patients with obstructive hydrocephalus. In the Le May and Hochberg study (1979), the frontal horn index was found to be 0.5 or greater in 56% of hydrocephalus patients. The current study analysed eighteen CT scans of hydrocephalus patients and found an overall mean frontal horn ratio of 0.42 (RANGE: 0.36 TO 0.52). In order to bridge the gap in the continuum of normal to abnormal (large) ventricular sizes, a follow up study is recommended which will include measurements of ventricular sizes from a large sample in those reported as having hydrocephalus and/or with various degrees of ventromegaly.

A follow up study done by Hahn *et al.,* (1977), found the mean frontal horn ratio/index of 0.32±0.038 with a range of 0.19 to 0.39 (n=388). Another study done by Park *et al*, (1990) in Korea with a larger sample size (n=1000) found a comparable frontal horn index of 0.3±0.033 and they also described a correlation with increasing age from the age of one year to 80 years. Celik *et al.,* (1995) found a similar mean ventricular ratio of 0.3 in a Turkish sample of 100 healthy individuals. In the measurements of the lateral ventricles, it was observed that the frontal horn ratio in men increase significantly with age but showing no significant difference between the two sexes (Celik *et al.,* 1995). The similarities and differences noted here reflect comparability in methodologies be used when measuring transverse ventricular dimensions, for instance, brain width is more appropriate as the denominator in the indices hence the alternative name cerebro-ventricular index for the frontal horn ratio was adopted since it is the edge of the brain not the frontal bones that are visualized on the non-contrast CT scans used in these studies.

The current study confirm the results from previous study by Meese *et al.,* (1980), which found that the values of the frontal horn index in the first two decades of life are significantly different from those for all other ages. It is therefore suggested that future studies should focus on separate set of normal values for the adolescence and young adults. We confirm that the normal values in adults up to the age of 60 are relatively consistent with findings from previous studies, and a single set of values for this age span is adequate for all races. However, as observed in this study and in Meese *et al.,* (1980) normal values after the age of 60 would appear to fall into a third natural group because of the sharp rise in both the dimensions and the frontal horn index. The significant increase in size could be interpreted as an expression of a physiological process of aging and deserves special attention in future studies. It is known that at this age, global cerebral atrophy occurs naturally as part of normal ageing and as such there could be compensatory enlargement of ventricles resulting in observed higher values (Gomori *et al.*, 1984). Further studies are also indicated in the 60 years and above age groups in order to distinguish between normal aging and conditions such as normal pressure hydrocephalus and dementia among others in which ventricular dilatation has been suspected.

5.3 THIRD VENTRICLE SIZE

The range in the current study of the third ventricle width was between 2 to 8.2 millimetres (mean= 3.23mm) and there was a steady rise across age groups until the seventh decade, after which there was a sharp rise. The mean ventricular diameter of the current study is slightly less than that previously reported by Haug (1977) in which he found an average third ventricle size of 3.38. He used a smaller sample size compared to the current study; however, the general trend that third ventricle sizes in males were larger than those in females was confirmed. The current findings were also in agreement with studies by Celik *et al*., (1995) in which compared to women, the size of the third ventricle was larger in men. Eleven normal subjects studied earlier by Gawler *et al.*, (1976) produced a mean third ventricle size of 4.6mm which was larger than the maximum size of 4.4mm observed in the current study; this may be due to a small sample in their study and the age range difference as they used patients aged between 18 to 30 years.

Studies by Gawler *et al*., (1976), Brinkmann *et al.*, (1982), Soininen *et al*., (1982) also reported that the maximum width of the third ventricle had a mean of 46mm, 59mm and 92mm respectively with higher figure in males. All these researchers used elderly people above the ages of sixty years and as such their findings can only be compared with the sixth (3.5±0.16) and seventh (6.5±0.51) age groups of the current study. The first two are comparable with current study while the high result (92mm) in the study by Soininen *et al.*, (1982) probably reflect the relatively higher age ranges used (mean age 77 + 6 years) which is beyond the subjects sample in the current study. Such high value findings for the sizes of the third ventricle width could be a result of the fact that value of CT in evaluating brain morphology in elderly people is diminished: this is because in normal aging ventricles undergo compensatory dilatation with increasing age due to factors such as cortical atrophy, a common feature at this age range (Le May, 1984).

D'Souza and Natekar, (2007) found a 42mm average, still with a higher male average 45mm±0.29. In general males have big heads and big brain sizes as compared to females of the same age (Mathalon *et al.*, 1993) and as such is expected that the cerebral ventricles of males are larger. Third ventricles were also found to increase in size with age in this study, a result which was in line with Haug (1977) and Celik *et al*., (1995). However, the discrepancies in the average size of the third ventricle may result from the subjective nature of the point at which the "maximum diameter of the third ventricle" could be measured from. Therefore, there is need in future studies to define a specific region of interest with respect to the third ventricle, a point that will act as a reference point in bringing about comparability with previously quoted ventricular dimensions.

The third ventricle was visualized in all normal brain CT scans, although a few were trace dimensions, this finding is not in agreement with a study by Borgesen (1966) in which he showed that the third ventricle was mostly invisible or minute on normal scans before the fourth decade in a study of 140 USA patients with normal CT scans. His study was on postmortem cadavers subject to ventricular distortions naturally and during dissection.

Third Ventricular ratio (the maximum width of the ventricle divided by the width of the brain at the same level) was found to be 0.03 in the current study. It has not been widely quoted in literature as an indirect measure of ventricular size. However, it was quoted as 0.02 in normal controls used in CT abnormalities study of schizophrenia by McCarley *et al*., (1989). The sample size was very small (n=9) and they were recruited on the basis of not taking any medication as a basis for being normal which served a purpose better as a control for schizophrenia than being free from neurological disease.

5.4 THE FOURTH VENTRICLE

Fourth ventricle width was generally found to be larger in males than in females, a finding which was statistically significant in a study by Gawler *et al.*, (1976) and D'souza and Natekar, (2007). The latter reported a ventricular width of 10.8 mm comparable with 10.5 mm in the current study; however he used a very small sample size of 11 patients. The ventricle was poorly visualized in some scans and has largely been neglected in linear measurements literature.

5.5 THE VENTRICULAR MEASUREMENTS IN HYDROCEPHALUS PATIENTS.

The hydrocephalus group was only included for comparisons with the main data from normal CT scans of the brain. Mean frontal horn diameters, third ventricular width, fourth ventricle width, fourth ventricle height, frontal horn ration and third ventricle ratio of the current study were all significantly lower than those measured and computed from the hydrocephalus group ($p<0.05$). The current data (from hydrocephalus group, n=18) was comparable with the findings reported by Hahn and Rim (1976) whose averages were 0.42 and 0.45. The slight difference could be due to the smaller sample size used in the current study. It is hereby recommended that future studies use larger sample sizes of patients with hydrocephalus.

The frontal horn index of the current study (0.42) was far lower than an average of 0.5 reported by Le May and Hochberg (1979) in which they only evaluated patients with obstructive type of hydrocephalus known to result in marked ventromegaly. Future studies should focus on correlating type of hydrocephalus with the ranges in the cerebral ventricular morphometry.

CHAPTER SIX: RESEARCH LIMITATIONS AND RECOMMENDATIONS

6.1 LIMITATIONS

The study limitations were;

- The study was retrospective lacking prospective evidence and a normal (apparently healthy) group of individual for comparisons, contact all patients who were meeting the inclusion criterion and also to do an aggressive follow up of participants to obtain that information about the associated clinical presenting complaints (diagnosis and treatment) from their doctors or hospitals.
- Use of convenient sampling method from a privately owned radiology centre leaving other diagnostic centres within and outside Harare (for example Karanda Hospital and Bulawayo) and this restricts ability to generalize data to the Zimbabwean black population.
- The data that was available for study was from January to June 2012. Before then, these centres used analogue machines and were not keeping reports and soft copies, so this limited the possible sample size. They also delete their records on average, after two months making data unavailable for research purposes.
- The centres do not keep hard copies of the scans in archive for research purposes and also do not have all other diagnostic information about the patients serve for a chief complaint (e.g. headache), sex and age. Such data was even missing for some patients who were excluded.
- It was difficult to get enough data for other races such as local Caucasians and Indians for comparisons as only three Caucasians and one Indian descendant was obtained and as a result not included in the study.

- ❖ Only data from patients with normal findings on the CT scans who sought CT scans were mostly presenting with headaches implying a suspected neurological disorder thereby making them not representative of the normal, healthy Zimbabwean population.
- ❖ This study did not include abnormal CT scans with respect ventricular size for comparisons with such conditions as hydrocephalus. Eighteen hydrocephalus patients were obtained but their findings were not included in the main data analysis owing to small size and the fact that they were at various levels of treatment, meaning that their ventricular sizes could be confounded by the treatment regimens they were undergoing.
- ❖ The study was limited to a major private radiology center because at the time of data collection there was no functional CT scan machines at all public health institutions in Harare, hence the sample is biased towards the minority that are able to pay for the expenses. Therefore, excluding the general public limit us to make conclusive statements from this pilot study for the general Zimbabwean population.

6.2 RECOMMENDATIONS

The following recommendations are hereby made:

- ❖ Priority should be given to support such elementary studies by providing funding for future studies so that they are done prospectively, in order to get a set of values for ventricular sizes suitable for our population at different ages and sex.
- ❖ To obtain samples of CT scans from all centres in the country so as to obtain a larger, representative sample whose results would be generalised to Zimbabwean population

- A study including a larger sample of Hydrocephalus patients so as to find out the continuum from normal ventricular size to the abnormal levels and thus complete the need for normative reference ranges.

- Future studies need also to be more focused on including healthy participants without complains of any kind to undergo full neurological and medical examinations for a sample of the natural normal populations in the assessment of ventricular sizes, with enough funding to obtain the CT scans on these persons.
- In case of retrospective studies or even cross sectional, there is need for radiology centres to archive their data in a more orderly and accessible format and even keep it for longer periods if possible since they all now use digital CT scan machines with expandable memory.
- Future studies may also focus on obtaining data for different races and compare the ventricular sizes, social status among other factors affecting ventricular sizes.
- The government and stakeholders should also prioritize maintaining CT machines at government hospitals so that such facilities are made available to the general public with subsidized costs.

CHAPTER SEVEN: CONCLUSION

The range of ventricular dimensions are presented for use as baseline results upon which future studies may build on to adjust standards dimensions to be used in routine clinical examination for at least black Zimbabweans to be able to judge accurately ventricular dilatation. The frontal Horn Index (frontal Horn Ratio), also called the cerebroventricular index, was found to be 0.31 in females and 0.32 in males. Therefore, it is suggested that:

- ❖ In males the maximum frontal tips diameter greater than 48% or less than 27% of the width of the brain on the corresponding plane are to be considered highly suspicious of abnormal ventricles. Henceforth, in individuals with a bifrontal tips diameter of more than 48% of brain width are described as dilated and further investigations should be carried out to account for the ventriculomegaly.
- ❖ In females, the maximum frontal tips diameter greater than 39% or less than 25%, of the width of the brain on the corresponding plane are to be considered highly suspicious of abnormal ventricles. That is to say in those with a bifrontal tips diameter of more than 39% of brain width at that level is dilated and further investigations should be carried out to account for the ventriculomegaly.
- ❖ In general, the maximum frontal tips diameter greater than 48% or less than 25% corresponding plane are to be considered highly suspicious of abnormal ventricles. That is to say in those with a bifrontal tips diameter of more than 48% of brain width at that level is dilated and further investigations should be carried out to account for the ventriculomegaly.

- The maximum third ventricle diameter greater than 8.2% or less than 1.2%, of the width of the brain on the corresponding plane are to be considered highly suspicious of abnormal ventricles.
- The present study reported that there was a significant difference between mean ventricular dimensions of different age groups on all of the above measurements and ratios ($p<0.01$) except for the fourth height which was not significantly affected by age ($p=0.515$)
- The overall frontal horn ratio of the eighteen hydrocephalus patients varied from 0.36 to 0.52 with an overall mean of 0.42; and the ventricular dimensions in this group were generally greater than that observed in the main study group of those with normal brain CT scans.
- In light of the above research limitations and recommendations, the current study rejects the null hypothesis and accepts that there is a difference between the mean ventricular dimensions of a sample drawn from the adult black Zimbabwean population as compared to normative reference values drawn from other populations whose averages have been published in available literature at 5% level of significance:

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APPENDICES

APPENDIX A DESCRIPTIVE STATISTICS

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Frontal horn A	10-19	40	31.7727	2.91990	.50829	30.7374	32.8081	26.80	37.40
	20-29	72	31.4819	2.51078	.29590	30.8919	32.0719	25.20	37.50
	30-39	33	30.5179	1.25906	.23794	30.0296	31.0061	26.70	32.10
	40-49	54	31.4574	2.47055	.33620	30.7831	32.1317	26.70	35.80
	50-59	41	31.6951	1.83180	.28608	31.1169	32.2733	27.50	35.10
	60-69	30	32.0000	1.47851	.32264	31.3270	32.6730	27.80	34.20
	70-79	30	35.1192	4.57375	.89699	33.2719	36.9666	28.50	47.90
	Total	300	31.8291	2.79128	.16832	31.4977	32.1605	25.20	47.90
Frontal horn level brain Width B	10-19	40	1.0440E2	3.55576	.61898	103.1362	105.6578	96.20	111.10
	20-29	72	1.0396E2	2.71459	.31992	103.3177	104.5935	98.70	111.40
	30-39	33	99.2679	2.70679	.51154	98.2183	100.3174	95.00	104.70
	40-49	54	98.9278	4.97380	.67685	97.5702	100.2854	87.10	104.10
	50-59	41	1.0021E2	5.82168	.90919	98.3722	102.0473	94.70	111.10
	60-69	30	1.0592E2	1.90647	.41603	105.0512	106.7869	101.60	108.80
	70-79	30	1.0089E2	1.70175	.33374	100.2050	101.5797	97.20	105.60
	Total	300	1.0185E2	4.52102	.27263	101.3091	102.3825	87.10	111.40
Third ventricle max width C	10-19	40	2.5636	.42339	.07370	2.4135	2.7138	2.00	3.30
	20-29	72	2.8319	.88855	.10472	2.6231	3.0407	1.20	7.60
	30-39	33	2.7750	.87586	.16552	2.4354	3.1146	1.60	4.60
	40-49	54	3.1796	1.18535	.16131	2.8561	3.5032	1.20	6.80

	50-59	41	2.7780	.64866	.10130	2.5733	2.9828	2.00	4.50
	60-69	30	3.5238	.73546	.16049	3.1890	3.8586	2.60	5.20
	70-79	30	6.4808	2.58720	.50739	5.4358	7.5258	2.70	14.20
	Total	300	3.2520	1.56229	.09421	3.0665	3.4375	1.20	14.20
Third Ventricle level brain width D	10-19	40	1.1383E2	3.29978	.57442	112.6633	115.0034	107.10	118.60
	20-29	72	1.1340E2	4.25639	.50162	112.4026	114.4030	104.30	127.20
	30-39	33	1.0836E2	2.81941	.53282	107.2710	109.4575	102.60	113.60
	40-49	54	1.1156E2	14.84731	2.02046	107.5110	115.6161	11.27	122.40
	50-59	41	1.1526E2	6.61706	1.03341	113.1724	117.3496	107.40	131.90
	60-69	30	1.1609E2	3.50983	.76591	114.4928	117.6881	110.40	121.90
	70-79	30	1.0896E2	3.91347	.76749	107.3809	110.5422	104.50	119.00
	Total	300	1.1264E2	7.98272	.48138	111.6950	113.5903	11.27	131.90
Fourth width E	10-19	40	11.0455	2.34135	.40758	10.2152	11.8757	7.80	16.70
	20-29	72	10.3250	2.30204	.27130	9.7840	10.8660	5.30	16.30
	30-39	33	10.5107	2.01960	.38167	9.7276	11.2938	7.90	15.00
	40-49	54	10.1852	1.74652	.23767	9.7085	10.6619	6.60	14.00
	50-59	41	9.6976	.85746	.13391	9.4269	9.9682	8.00	11.40
	60-69	30	12.3524	1.24283	.27121	11.7867	12.9181	9.80	15.10
	70-79	30	11.6346	1.97017	.38638	10.8388	12.4304	9.00	17.30
	Total	300	10.5880	2.02898	.12235	10.3471	10.8289	5.30	17.30
Fourth height F	10-19	40	10.3636	2.40830	.41923	9.5097	11.2176	5.00	15.20
	20-29	72	10.4292	2.47906	.29216	9.8466	11.0117	4.80	15.40
	30-39	33	11.2929	2.04956	.38733	10.4981	12.0876	5.40	14.90
	40-49	54	10.2056	2.35752	.32082	9.5621	10.8490	4.90	14.30
	50-59	41	10.6000	1.92691	.30093	9.9918	11.2082	7.50	14.50
	60-69	30	10.9143	2.22784	.48616	9.9002	11.9284	4.80	16.10

	70-79	30	10.3154	2.51455	.49314	9.2997	11.3310	6.10	15.80
	Total	300	10.5171	2.31140	.13938	10.2427	10.7915	4.80	16.10
RatioAB	10-19	40	.3040	.02105	.00366	.2965	.3115	.26	.35
	20-29	72	.3029	.02348	.00277	.2974	.3084	.24	.36
	30-39	33	.3076	.01490	.00282	.3019	.3134	.27	.33
	40-49	54	.3180	.01973	.00268	.3126	.3234	.28	.36
	50-59	41	.3174	.02718	.00424	.3089	.3260	.25	.36
	60-69	30	.3020	.01068	.00233	.2972	.3069	.27	.32
	70-79	30	.3480	.04405	.00864	.3302	.3658	.29	.47
	Total	300	.3128	.02753	.00166	.3096	.3161	.24	.47
Ratio C/D	10-19	40	.0226	.00419	.00073	.0211	.0241	.02	.03
	20-29	72	.0250	.00802	.00094	.0231	.0268	.01	.07
	30-39	33	.0257	.00859	.00162	.0224	.0291	.01	.04
	40-49	54	.0345	.05038	.00686	.0207	.0482	.01	.39
	50-59	41	.0239	.00447	.00070	.0225	.0254	.02	.04
	60-69	30	.0303	.00567	.00124	.0277	.0328	.02	.04
	70-79	30	.0597	.02463	.00483	.0498	.0697	.02	.13
	Total	300	.0302	.02619	.00158	.0271	.0333	.01	.39
Ratio E/F	10-19	40	1.1080	.28627	.04983	1.0065	1.2095	.73	1.98
	20-29	72	1.0341	.32129	.03786	.9586	1.1096	.53	2.33
	30-39	33	.9768	.32941	.06225	.8491	1.1045	.63	1.98
	40-49	54	1.0437	.28271	.03847	.9665	1.1208	.68	2.18
	50-59	41	.9420	.17715	.02767	.8860	.9979	.66	1.28
	60-69	30	1.1840	.32860	.07171	1.0344	1.3335	.76	2.48
	70-79	30	1.1960	.36940	.07245	1.0468	1.3452	.61	2.13
	Total	300	1.0520	.30586	.01844	1.0157	1.0883	.53	2.48

INFORMED CONSENT FORM

My name is Zilundu Prince LM. I am a Master of Science student at the University of Zimbabwe, Department of Preclinical Studies. I am conducting a study to assess the range in size of cerebral ventricles found in the brain by making measurements on the CT scans of the brain.

The results of the current study will enable radiologist better diagnose conditions in which there will be changes in the said cerebral ventricle system and also assist the neurosurgeons who perform surgeries of the brain in understanding the anatomy of the area for safety of patients among other benefits.

Your identity will remain anonymous and there is no harm to you, or financial benefit for your consent.

I hereby seek permission to use a copy of your brain CT scan stored at Private Diagnostic Radiology centre, A.

Permission granted: □YES □ NO □ Not reachable

Signed:……………………………………..