



## **INTRACRANIAL COMPARTMENT VOLUMES AND THEIR DISTRIBUTION AMONG CLINICALLY DIAGNOSED PATIENTS WITH NORMAL PRESSURE HYDROCEPHALUS AND BRAIN ATROPHY IN A NIGERIAN POPULATION**

**\*Mohammed, A. <sup>1</sup> and Anthony, C. U. <sup>2</sup>**

<sup>1</sup>Department of Medical Radiography, College of Health Sciences, Bayero University, Kano, Kano State Nigeria.

<sup>2</sup>Department of Radiography and Radiological Sciences, Nnamdi Azikiwe University, Nnewi Campus, Nnewi, Anambra state, Nigeria

\*Corresponding Author: e-mail: [mabba.radg@buk.edu.ng](mailto:mabba.radg@buk.edu.ng) [+2348038706272]

### **ABSTRACT**

*Normal pressure hydrocephalus is a form of non-obstructive hydrocephalus characterized by the triad of symptoms. These symptoms are typical or atypical. Because of its potential reversibility, researchers have paid attention to its diagnosis and in differentiating it with other forms of dementia such as brain atrophy. To determine the intracranial compartment volumes and their differences among patients with NPH and Brain Atrophy (BA). This was a cross-sectional study involving consenting patients diagnosed with NPH and BA who were referred for routine brain CT. Medical conditions known to influence intracranial volume were excluded. Age -matched normal control were clinically and radiologically confirmed normal and were also recruited. Intracranial volumes and CSF distribution determination was based on Cavalieri test point computation principle. Test point summation was on a locally developed software for this purpose. Overall, the values of BA recorded higher mean values for most of the intracranial compartment volumes. Intraventricular volume was consistently higher in NPH groups. Statistical difference exists among intraventricular and total intracranial CSF volume across patients with BA, NPH and control. A post hoc test revealed control-NPH comparison across these variables. Control-BA comparison was evident in total intracranial CSF volume only. Higher mean values of intracranial compartment volumes were observed in patients with BA than among patients with NPH and their control. Anthropometric indices did not show any difference between patients with BA, NPH and their control. These indices can be used as basis in objectively differentiating NPH from BA*

**KEY WORDS:** Brain atrophy, Diagnosis, Intracranial volume, Normal pressure hydrocephalus

### **INTRODUCTION**

The term Normal Pressure Hydrocephalus (NPH) was first presented by Adams Hakim in 1965 as a form of non-obstructive hydrocephalus with enlargement of ventricles, normal CSF pressure and a triad of symptoms that is potentially reversible (Damasceno 2015, Nassar & Lippa 2016). These symptoms include gait disturbance, mental retardation and urinary incontinence (Damasceno 2015, Nassar & Lippa 2016). A pathologic history to the central nervous system such as subarachnoid injury, hemorrhage and meningitis usually explains the onset of NPH. However, idiopathic NPH (iNPH), is a more common clinical syndrome affecting older people (De-Vis *et al.*, 2016). Presently, there is no clear

pathological diagnosis for idiopathic NPH and diagnosis is based on patient's response to shunt surgery (Qin 2011, Jack *et al.*, 2010).

Similarly, the similarities between NPH and Brain Atrophy (BA) are justified by the range of diagnostic tests for differentiating them (Damasceno 2015). However, most of these tests are invasive and presents with varying degree of potential complications. Advanced neuroimaging modalities are another complementary diagnostic test used in improving the diagnosis and management of NPH and BA. Unfortunately, the number of neuroimaging features that aids diagnosis of NPH are usually subjective and in most cases have overlapping features similar to

BA or NPH (Fox & Schott 2004, Miskin *et al.*, 2017).

Pathologically, patients with BA have generalized loss in volume and density of the cerebral tissue. This leads to increased spaces which will obviously be filled with CSF. The ventricles are disproportionately dilated than the cortical sulci which are narrower or obliterated at the high convexity and midline in patients with NPH (Damasceno 2015, Lee *et al.*, 2010), while CSF is significantly elaborated in the peripheral intracranial region and sub-arachnoid spaces in patients diagnosed with BA, thus making the cortical sulci prominent (Szczeppek *et al.*, 2015).

The cavalieri method is one outstanding method which provides quantitative volumetric estimates regarding 3D structures using 2D sectional images (Roberts *et al.*, 2000, Akdogan *et al.*, 2010, Sahin&Elaki, 2012). Volumetric estimates from this method on Computed Tomography (CT) images is reported to be reliable, objective and easily reproducible (Akdogan *et al.*, 2010, Sahin & Elaki, 2012, Akosman 2013). Therefore, the present study aims to report a non-invasive, objective and easily reproducible ante-mortem method of diagnosing NPH and BA using volumetric intracranial differences from a resource limited population where the availability of MRI scanners and sophisticated medical image processing/ analysis software is near nonexistent.

## **MATERIALS AND METHODS**

This was a descriptive, cross-sectional and age-matched study which was carried out in the CT suite of the Department of Radiology, Aminu Kano Teaching Hospital, Kano, Nigeria from March 2018

to November 2020. It involves consenting patients that reported to the neurosurgery and neurology specialty clinics who were clinically diagnosed with NPH and BA and were routinely sent for brain CT. The CT images were acquired with a 160-slice Toshiba Aquilion (Prime) CT-scanner (model CG CT-0321, manufactured in Dec. 2013 and installed in 2015) under standard protocol. Using purposive sampling, true samples that met inclusion criteria were all recruited. Patients with any medical history known to influence intracranial and cerebral structures were excluded (Szczeppek *et al.*, 2015). Approval to carry out the study was sort from the National human research and ethics committee (NHREC/21/08/2008/AKTH/EC/2666). Similarly, normal CT brain examinations that were radiologically and clinically confirmed normal were recruited into the study as healthy age-matched control.

Volume estimation was based on the Cavalieri's principle (Akdogan *et al.*, 2010, Mazonakis *et al.*, 2004). This was facilitated by the use of a locally developed software which was developed specifically for this study. The software, named *voXas\_2018* has abilities to read DICOM images and are applied for visual analysis of 3D tissue density matrix, a characteristic similar to CT images (VisNow 2011). Selected CT slices were staked and displayed and a determined graduated grid is randomly superimposed on loaded images. Each area of interest is delineated using stereological planimetry –cursor aided method and total test points were recorded (Fig. 1). Total test points of Cerebral tissue (CRBL), Intra-ventricular CSF (InVen) and extra-ventricular CSF (ExVen) were recorded for each patient.

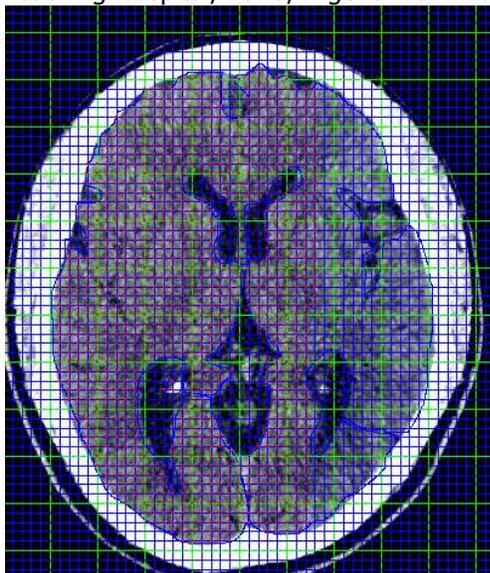


Figure 1: Test point computing by *voXas\_2018*

**BAJOPAS Volume 14 Number 1, June, 2021**

Recorded data from the software were then automatically transferred to Microsoft excel sheet version 2009 for windows 8 for volumetric estimation using the Cavalieri formula (Akdogan *et al.*, 2010, Mazonakis *et al.*, 2004).

The formula is given as

$$V = (Q) \times (a) \times (t)$$

Where:

V = Volume (cm<sup>3</sup>)

Q = Sum of test points hitting object (target structure) = (q1 +q2+q3+ . . .+qn)

a = The Unit area represented by each grid point (cm<sup>2</sup>)

t = Slice thickness (cm)

The accuracy of volumetric outcome from this method was compared with other stereological techniques of volume estimation (Akdogan *et al.*, 2010, Mazonakis *et al.*, 2004). Similarly, strength of measurement (r) was computed between the two methods. Intra-class correlation coefficient

(ICC) was used for this purpose and showed perfect reliability with a Cronbach's alpha of 0.89. Data was analyzed using SPSS v20 (IBM corp. 2015). A *p*value of ≤0.05 was regarded as statistically different.

**RESULTS**

A total of twenty-nine (29) CT series that met all inclusion criteria were recruited into the study. This comprised 7(24.1%), 8 (27.6%) and 14 (48.3%) clinically established cases of Brain Atrophy (BA), Normal Pressure Hydrocephalus (NPH) and Control groups, respectively. Majority of the CT series were males 59% individuals. The age range of participants from 0.33years – 40 years with an overall mean age of 13.62±14.29 years. Participants were grouped into age categories. Majority of the CT series were from 1-5years age group (27.6%). Age group <1years accounted for the CT series with the least frequency (10.3%) (Table 1).

Table 1: Distribution of participants according to age categories

Age Group (years)	Group			Statistics			
	BA	NPH	Control	Frequency (%)	Mean Age ± SD	Min	Max
<1	1	1	1	3(10.3)	0.42±0.09	0.33	0.5
1-5	2	2	4	8(27.6)	2.50±1.31	1	4
6-10	1	3	3	7(24.1)	7.43±1.5	6	9
16-20	2	1	2	5 (17.2)	18.20±1.1	17	20
36-40	1	1	4	6(20.7)	38.67±0.82	38	40
<b>TOTAL</b>	<b>7(24.1%)</b>	<b>8(27.6%)</b>	<b>14(48.3%)</b>	<b>29(100)</b>	<b>13.62±14.29</b>	<b>0.33</b>	<b>40</b>

**Key:**BA: Brain Atrophy, NPH: Normal Pressure Hydrocephalus, Freq: Frequency, Min: Minimum, Max: Maximum

The descriptive statistics of the overall intracranial compartment volumes according to the groups (BA, NPH and control) and independent of age-grouping is presented in table 2. Overall, the values of BA recorded higher mean values for most of the intracranial compartment volumes.

Table 2: Descriptive Statistics of Intracranial volumes according to Group

Variables	BA (n=7)			NPH (n=8)			CONTROL (n=14)		
	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.
Age	11.90±14.49	0.33	40.00	10.80±12.64	0.42	38.00	16.18±15.52	0.50	39.00
Br_vol(cm <sup>3</sup> )	1031.95±399.12	664.85	1881.70	817.92±432.41	134.85	1350.70	948.04±260.01	345.85	1269.50
InV_vol(cm <sup>3</sup> )	31.99±17.90	14.10	63.40	72.48±51.52	25.75	189.00	18.75±9.73	6.50	35.70
Ex_ven_vol(cm <sup>3</sup> )	89.22±68.91	22.90	230.00	45.80±30.88	6.45	97.00	35.94±17.30	4.00	70.50
Tcsf_vol(cm <sup>3</sup> )	121.21±76.19	37.00	275.70	118.28±50.45	46.90	214.45	54.69±23.20	10.50	101.80
TIcrV_vol(cm <sup>3</sup> )	1153.16±409.32	701.85	1990.70	936.20±417.95	283.70	1485.60	1002.73±277.91	356.35	1332.30

Key: Br\_vol: Brain/cerebral Volume, InV\_vol: Intraventricular volume, Ex\_ven\_vol: Extra-ventricular volume, Tcsf\_vol: Total cerebrospinal fluid volume, TIcrV\_vol: Total intracranial volume.

Based on age grouping, the intracranial compartment volumes and some anthropometric variables were presented for each age group. Table 3-5 presents the values for the 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> age categories. Similarly, BA series recorded higher mean values for most of the intracranial compartment volumes while anthropometric variables were within similar range.

Table 3:

Variables	BA (n=1)			NPH (n=3)			CONTROL (n=3)			Overall (n=7)		
	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.
Age	6	6	6	8±1.73	6	9	7.33±1.53	6	9	7.43±1.5	6	9
Weight(kg)	24	24	24	30±6	24	36	27.67±3.22	24	30	28.14±4.49	24	36
Br_vol(cm <sup>3</sup> )	779	779	779	872.67±254.45	694	1164	764.67±362.59	346	977	813±261.81	346	1164
InV_vol(cm <sup>3</sup> )	21	21	21	85±90.34	26	189	11.33±6.11	6	18	44.29±64.77	6	189
Ex_ven_vol(cm <sup>3</sup> )	42	42	42	29.33±25.78	6	57	30.67±23.29	4	47	31.71±20.57	4	57
Tcsf_vol(cm <sup>3</sup> )	63	63	63	114.67±87.89	47	214	42±27.79	10	60	76.14±64.7	10	214
TIcrV_vol(cm <sup>3</sup> )	842	842	842	987.33±217.31	777	1211	807±390.58	356	1034	889.29±274.15	356	1211

Key: Br\_vol: Brain/cerebral Volume, InV\_vol: Intraventricular volume, Ex\_ven\_vol: Extraventricular volume, Tcsf\_vol: Total cerebrospinal fluid volume, TIcrV\_vol: Total intracranial volume.

Table 4:

Variables	BA (n=2)			NPH (n=1)			CONTROL (n=2)			Overall (n=5)		
	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.
<b>Age</b>	17.5±0.71	17	18	20	20	20	18	18	18	18.2±1.1	17	20
<b>Weight(kg)</b>	46	46	46	48	48	48	43±4.24	40	46	45.2±3.03	40	48
<b>Br_vol(cm<sup>3</sup>)</b>	1447.5±614.48	1013	1882	1351	1351	1351	926±268.7	736	1116	1219.6±431.08	736	1882
<b>InV_vol(cm<sup>3</sup>)</b>	49.5±19.09	36	63	38	38	38	16.5±7.78	11	22	34±19.58	11	63
<b>Ex_ven_vol(cm<sup>3</sup>)</b>	71.5±36.06	46	97	97	97	97	29±8.49	23	35	59.6±35.1	23	97
<b>Tcsf_vol(cm<sup>3</sup>)</b>	121±16.97	109	133	135	135	135	45.5±16.26	34	57	93.6±45.81	34	135
<b>TIcrV_vol(cm<sup>3</sup>)</b>	1568.5±597.51	1146	1991	1486	1486	1486	971.5±284.96	770	1173	1313.2±456.06	770	1991

**Key:** Br\_vol: Brain/cerebral Volume, InV\_vol: Intraventricular volume, Ex\_ven\_vol: Extraventricular volume, Tcsf\_vol: Total cerebrospinal fluid volume, TIcrV\_vol: Total intracranial volume.

Table 5: Descriptive Statistics of Intracranial volumetric indices for age group 5

Variables	BA (n=1)			NPH (n=1)			CONTROL (n=4)			Overall (n=6)		
	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.	Mean± SD	Min.	Max.
<b>Age</b>	40	40	40	38	38	38	34.5±0.58	38	39	38.67±0.82	38	40
<b>Weight(kg)</b>	84	84	84	72	72	72	74.5±2.38	72	77	75.67±4.59	72	80.48
<b>Br_vol(cm<sup>3</sup>)</b>	854	854	854	1322	1322	1322	1157.5±79.87	1094	1270	1134.33±164.37	854	1322
<b>InV_vol(cm<sup>3</sup>)</b>	46	46	46	56	56	56	27.5±7.33	20	36	35.33±13.77	20	56
<b>Ex_ven_vol(cm<sup>3</sup>)</b>	230	2300	230	31	31	31	49.25±14.43	37	70	76.33±76.46	31	230
<b>Tcsf_vol(cm<sup>3</sup>)</b>	276	276	276	87	87	87	77±17.19	63	102	111.83±81.62	63	276
<b>TIcrV_vol(cm<sup>3</sup>)</b>	1130	1130	1130	1408	1408	1408	1234.25±70.61	1165	1346.6	1245.83±105.08	1130	1408

**Key:** Br\_vol: Brain/cerebral Volume, InV\_vol: Intraventricular volume, Ex\_ven\_vol: Extraventricular volume, Tcsf\_vol: Total cerebrospinal fluid volume, TIcrV\_vol: Total intracranial volume

Explanatory variables were tested for normality using Shapiro-Wilk's test and most variables were not normally distributed ( $p < 0.05$ ). Kruskal-Wallis (non-parametric) statistics that assessed the differences in intracranial compartment volumes across age groups (BA, NPH, Control) indicated significant difference in intraventricular and total

intracranial CSF volumes only ( $p \leq 0.05$ ). A one-way non-parametric (pairwise comparison) post hoc analysis was conducted on InV\_vol and Tcsf\_vol. Significant difference was consistent in Control-NPH comparison across the two variables while Control-BA comparison was evident in Tcsf\_vol only (Table 6).

**Table 6:** Post-hoc Kruskal-Wallis (pairwise comparison) analysis

Statistic	Median (IQR)	Group Comparison	Chi Square	Std. Error	Std. Test Statistic	p value
<b>InV_vol</b>	26(29)	Control-BA	6.11	3.94	1.55	0.364
		Control -NPH	14.46	3.77	3.83	<b>0.001</b>
		BA-NPH	-8.36	4.41	-1.90	0.17
<b>Tcsf_vol</b>	70(62)	Control-BA	9.89	3.94	2.51	<b>0.036</b>
		Control -NPH	11.41	3.77	3.02	<b>0.007</b>
		BA-NPH	-1.52	4.41	-0.35	1.00

**Key:***InV\_vol*: Intraventricular volume, *Tcsf\_vol*: Total cerebrospinal fluid volume,

## DISCUSSION

Overall brain volume (BV) of age-matched control subjects in this study was  $948.04 \pm 260.01 \text{cm}^3$ . Luders *et al.*, (2009) in Los Angeles reported BV of normal sample as  $1406.57 \pm 101.69 \text{cm}^3$  and  $1406.62 \pm 101.41 \text{cm}^3$  in men and women respectively. Akdogan *et al.*, (2010) in Turkey reported BV of  $1343.01 \pm 179.62 \text{cm}^3$  and  $1177.55 \pm 184.95 \text{cm}^3$  for male and female respectively. Similarly, Resnick *et al.*, (2000), reported BV of  $1017.6 \pm 80.3 \text{cm}^3$  and  $915.9 \pm 81.7 \text{cm}^3$  in men and women, respectively. The mean ages of participants from Akdogan *et al.*, (2010), Ludas *et al.*, (2009) and Resnick *et al.*, (2000) studies were higher than that of the present study which was just 16.18 years as against 41.2 years (Akdogan *et al.*, 2010), 42.96 years (Luders *et al.*, 2009) and 70.4 years (Resnick *et al.*, 2000) from the 3 cited studies. It is established, brain development continues to increase even beyond the age of 16 years (Matsuzawa *et al.*, 2001. Karacan *et al.*, 2013) while at 40 years it is believed that neuronal loss begins to set in (Karacan *et al.*, 2013, De-Vis *et al.*, 2016). Thus, this explains the variation in of BV in the present study. Furthermore, about 71% of the distribution from the control group were children below the ages of 20 years. Since 75% of the brain is developed at the age of 2 years, synaptic pruning and cell death are most active during these early years and changes in brain structure continue throughout life (Karacan *et al.*, 2013, Giedd *et al.*, 1996). Omer *et al.*, (2014) further supported this by stating that cranial, cortical and sub cortical volume continue to increase by age up to 21-30 years then become steady till subsequent decades of life. The brain volume for patients with BA and NPH in the present study was  $1031 \pm 399.12 \text{cm}^3$  and  $817 \pm 432 \text{cm}^3$ , respectively. Szczepek *et al.*, (2015) reported brain volume of  $1130 \pm 14 \text{cm}^3$  and  $1258 \pm 39 \text{cm}^3$  among patients with BA and NPH,

respectively (Szczepek *et al.*, 2015). This highlights similarities between the two studies. However, differences were observed in NPH between the two studies. An obvious reason may be attributed to differences in research designs and age distribution between the two studies. The distribution of NPH had far lower mean age of 10.8 years against 56.7 years reported by Szczepek *et al.*, (2015). Similarly, Blatter *et al.*, (1995) reported a 5-decade normative study on volumetric analysis of brain using MRI<sup>21</sup>. However, Blatter *et al.*, (1995) faulted his results and cautioned the reliability of generalizing their findings in a number of ways ranging from non-calibration of the equipment to not controlling for effect of age. However, these factors were addressed by the present study and may suggest the reliability of our findings. However, there was no significant difference in brain volume between BA, NPH and control across the 3-decades reported.

Result of this study revealed total intraventricular (InV\_vol) CSF volume for the control, BA and NPH as  $18.75 \pm 9.73 \text{cm}^3$ ,  $31.99 \pm 17.9 \text{cm}^3$  and  $72.48 \pm 51.52 \text{cm}^3$ , respectively. Slightly higher values were reported by Akdogan *et al.*, (2010) in keeping with age differences due to participants distribution. However, Szczepek *et al.*, (2015) who conducted a relevant study, highlighted that a higher value of CSF in the intraventricular cranial compartment was obtained in patients with NPH than in BA group. This is supporting the present study in which higher value of intraventricular CSF volume was observed among patients with NPH. Furthermore, the present study established significant difference in InV\_vol between NPH and Control groups. This could possibly be due to the estimated intraventricular CSF volume in patients with NPH was about 3-fold when compared to that of age-matched control in the present study. However, no significant difference was observed between control-BA and BA-NPH comparisons.

This study revealed total extra-ventricular (Ex\_ven) CSF volume of  $35.94 \pm 17.3 \text{cm}^3$ ,  $89.22 \pm 68.91 \text{cm}^3$  and  $45.80 \pm 30.88 \text{cm}^3$  among Control, BA and NPH groups, respectively. Extra-ventricular (Ex\_ven) CSF compartment may be a good marker is differentiating NPH and BA. Under normal conditions, BA has been attributed with normal aging which replaces normal cerebral tissue with CSF (Gur *et al.*, 1999, Akdogan *et al.*, 2010). The obvious intracranial compartment that is emphasized is the cerebral cortex which is anatomically related with the sub-arachnoid spaces is the Ex\_ven. This claim is supported by Szczepek *et al.*, (2015) whereby they stated higher values of CSF volume was noticed in the sub-arachnoid spaces and basal cisterns among their patients with BA than in those with NPH. However, despite the obvious numerical differences in extra-ventricular CSF volume across the groups (BA, NPH and Control), the difference was not statistically significant. An attributable factor in this respect may be the smaller sample size for patients with BA in the current study.

This study found a total CSF volume (Tcsf) of  $121.21 \pm 76.19 \text{cm}^3$ ,  $118.28 \pm 50.45 \text{cm}^3$  and  $54.69 \pm 23.20 \text{cm}^3$  among patients with BA, NPH and age-matched controls, respectively. Similar pattern was reported by Szczepek *et al.*, (2015) whereby total CSF volume among their patients with BA and NPH were found to  $251 \pm 24 \text{cm}^3$  and  $227 \pm 17 \text{cm}^3$ , respectively. However, they did not include control group into their study. A general finding indicates Tcsf volume of patients with BA and NPH from the works of Szczepek *et al.*, (2015) and this study were far above the normal range of age-matched controls reported in the present study and also the work of Blatter *et al.*, (2015) that reported a mean total intracranial CSF volume of  $119.92 \pm 33.63 \text{cm}^3$  and  $124.03 \pm 38.1 \text{m}^3$  for females and males, respectively. The distribution of CSF between BA, NPH and age-matched control groups were obviously different. Statistically significant differences exist in total CSF volume among patients with BA and their age-matched control. This is because the continuous loss of neural tissues with the gradual replacement with CSF overtime among patients with BA (Akdogan *et al.*, 2010, Szczepek *et al.*, 2015). However

## REFERENCE

Akdogan, I., Kiroglu, Y., Onur, S., and Karabulut, N. (2010). The volume fraction of brain ventricles to total brain volume: a computed tomography stereological

statistical difference between patients with BA and NPH could not be established in the present study. Mean value of total intracranial volume (TICrV) in patients with NPH and control in the present study was found to be  $936.20 \pm 417.95 \text{cm}^3$  and  $1002.73 \pm 277.91 \text{cm}^3$ , respectively. A relevant study conducted by Bradley in (2004) in the United States (US) assessed the intracranial volume of 51 patients with clinically suspected NPH (mean age 75 years for men & 77 years for women) and compared with control subjects ( $n=55$ ; mean age men 71 yrs, women 74 years). Findings from the present study appeared to be in disagreement with the work of Bradley (2004). Thus, the reason for the variation in this study could be due to the smaller sample size in NPH ( $n=8$ ), lower mean age of 10.8 years and the large standard deviation ( $SD = \pm 417.95 \text{cm}^3$ ) could have accounted for this variation when compared with the sample size ( $n=14$ ), mean age 16.18 years and  $SD (\pm 277.91 \text{cm}^3)$  from our control. Furthermore, there was no differences between BA, NPH and Control across all the age categories studied.

There are some potential limitations to this study that needs to be considered when interpreting the data. The low number of participants witnessed across all the three conditions was limited our study. This is largely due to the study design to control effect of age. This action grossly excluded a significant number of available potential participants from the groups of BA and normal healthy control.

## CONCLUSION

Higher mean values of intracranial compartment volumes were observed in patients with BA than among patients with NPH and their age matched control. Hence, intracranial compartment volumes can be a reliable non-invasive index in differentiating these common but difficult to diagnose medical conditions. Anthropometric indices did not show any difference between patients with BA, NPH and their control.

## Conflict of Interest.

We (authors) exclusively declare that there is no conflict of interest in this work.

study. *Folia morphologica*; 69(4): 193-200.

Akosman, M. S. (2013). Recent developments and the importance of the volume estimation in biomedical sciences. *Open Access Anatomy*, 1(3):27.

- Blatter, D. D., Bigler, E. D., Gale, S. D., Johnson, S. C., Anderson, C. V., Burnett, B. M., et al.,(1995). Quantitative volumetric analysis of brain MR: normative database spanning 5 decades of life. *American journal of Neuroradiology*; **16**(2): 241-251.
- Bradley, W. G., Safar, F. G., Hurtado, C., Ord, J., &Alksne, J. F. (2004). Increased intracranial volume: a clue to the etiology of idiopathic normal-pressure hydrocephalus? *American Journal of Neuroradiology*; **25**(9): 1479-1484.
- Damasceno, B. P. (2015). Neuroimaging in normal pressure hydrocephalus. *Dementia & neuropsychologia*; **9**(4): 350-355.
- De-Vis, J. B., Zwanenburg, J. J., Van der Kleij, L. A., Spijkerman, J. M., Biessels, G. J., Hendrikse, J., and Petersen, E. T. (2016). Cerebrospinal fluid volumetric MRI mapping as a simple measurement for evaluating brain atrophy. *European radiology*; **26**(5): 1254-1262.
- Fox, N. C., and Schott, J. M. (2004). Imaging cerebral atrophy: normal ageing to Alzheimer's disease. *The Lancet*; **363**(9406): 392-394.
- Giedd, J. N., Snell, J. W., Lange, N., Rajapakse, J. C., Casey, B. J., Kozuch, P. L., et al.,(1996). Quantitative magnetic resonance imaging of human brain development: ages 4–18. *Cerebral cortex*; **6**(4): 551-559.
- Gur, R. C., Turetsky, B. I., Matsui, M., Yan, M., Bilker, W., Hughett, P., & Gur, R. E. (1999). Sex differences in brain gray and white matter in healthy young adults: correlations with cognitive performance. *Journal of Neuroscience*; **19**(10): 4065-4072.
- Jack, C. R., Wiste, H. J., Vemuri, P., Weigand, S. D., Senjem, M. L., Zeng, G.(2010). Brain beta-amyloid measures and magnetic resonance imaging atrophy both predict time-to-progression from mild cognitive impairment to Alzheimer's disease. *Brain*; **133**(11): 3336-3348.
- Karacan, K., Kosar, M. I., Çimen, M., Solak, O., Sahin, B., Karacan, K., et al.,(2013). Determination of Lateral Ventricle and Brain Volume in Children with Stereological Method Using MRI. *International Journal of Morphology*, **31**(1).
- Lee, W. J., Wang, S. J., Hsu, L. C., Lirng, J. F., Wu, C. H., Fuh, J. L. (2010). Brain MRI as a predictor of CSF tap test response in patients with idiopathic normal pressure hydrocephalus. *Journal of neurology*; **257**(10): 1675-1681.
- Luders, E., Gaser, C., Narr, K. L., Toga, A. W. (2009). Why sex matters: brain size independent differences in gray matter distributions between men and women. *Journal of Neuroscience*; **29**(45): 14265-14270.
- Matsuzawa, J., Matsui, M., Konishi, T., Noguchi, K., Gur, R. C., Bilker, W., Miyawaki, T. (2001). Age-related volumetric changes of brain gray and white matter in healthy infants and children. *Cerebral cortex*; **11**(4): 335-342.
- Mazonakis, M., Karampekios, S., Damilakis, J., Voloudaki, A., &Gourtsoyiannis, N. (2004). Stereological estimation of total intracranial volume on CT images. *European radiology*; **14**(7): 1285-1290.
- Miskin, N., Patel, H., Franceschi, A. M., Ades-Aron, B., Le, A., Damadian, B. E.(2017). Diagnosis of normal-pressure hydrocephalus: use of traditional measures in the era of volumetric MR imaging. *Radiology*; **285**(1): 197-205.
- Nassar, B. R., &Lippa, C. F. (2016). Idiopathic normal pressure hydrocephalus: a review for general practitioners. *Gerontology and geriatric medicine*; **2**: 2333721416643702.
- Omer, M. A. A., Alasar, E. M. M., Mohamed, E. M., Gar-elhab, G. A., & Sakin, Y. M. B. (2014). Measurement of Cranial and Brain Ventricle Volumes Relative to Pathologies. *International Journal of Science and Research*; 987-991.
- Qin, Q. (2011). A simple approach for three-dimensional mapping of baseline cerebrospinal fluid volume fraction. *Magnetic resonance in medicine*; **65**(2): 385-391.
- Resnick, S. M., Goldszal, A. F., Davatzikos, C., Golski, S., Kraut, M. A., Metter, E. J., et al, (2000). One-year age changes in MRI brain volumes in older adults. *Cerebral cortex*; **10**(5): 464-472.
- Szcepek, E., Czerwosz, L. T., Nowiński, K., Czernicki, Z., &Jurkiewicz, J. (2015). Analysis of intracranial volume ratios by means of cerebrospinal fluid deployment indicators. *Folia neuropathologica*; **53**(2): 121-127.
- VisNow (2011). visualization software developed at Laboratory of Visual Analysis at Interdisciplinary Center of Mathematical and Computational Modeling. <http://visnow.icm.edu.pl>. Accessed 18 Apr 2015.