Optimisation of Clinical measuring procedure for the fourth Ventricle size of Human Brain using Computed Tomography technique for Clinical application

I. Shirazu[2*], B. K. Owusu[1], T A Sackey[2], and E. K. Tiburu[1]

[1]Department of Biomedical Engineering, University of Ghana, Legon-Accra

[2]Radiological and Medical Sciences Research Institute, Ghana Atomic Energy Commission, Accra-Ghana.

***Corresponding Author:** sissahaku@ug.edu.gh

ABSTRACT

Computed Tomography (CT) scans and Magnetic Resonance Imaging techniques have contributed immensely in resolving the challenges of volumetric measurement of body organs, which are essential in diagnosis of pathological conditions. Visualization of the size and shape of the ventricles have therefore become a reality with CT scan, thereby aiding clinicians to diagnose complex neurological diseases. The aim of this study was to optimised clinical measuring procedure of the fourth ventricle of the human brain to determine the normal size and shape using voxel-count method as a baseline reference data for clinical application. The materials used include the CT scanner and retrospective image data. MeVisLab measuring tool was used to measure the linear dimensions (width, length and thickness), whilst the voxel count method was used to estimate the volume of the fourth ventricle. The results showed that the values for the age groups 61-70, 51-60, 41-50, 31-40 and 21-30 were 99.63 mm, 99.00 mm, 98.29 mm, 97.86 mm and 96.40 mm respectively. It was observed that age group 61-70 had the largest predictor and 21-30 being the smallest. The study established values of ventricular volume for gender and specific age groups which served as baseline reference data for standard reference ventricular dimensions for use in clinical practice in Ghana for neurological disorders.

Keywords: optimisation, neurological diseases, voxel, ventricular, fourth ventricles.

1.0 INTRODUCTION

Medical imaging is a field of science defined as a way of non-invasively acquiring both anatomic and physiologic information about the human body(Hendee, 1999; Olarinoye-Akorede et al., 2015) (Hendee, 2009). Furthermore, imaging of the human brain has become facile with the evolution of Computed Tomography (CT) scan and Magnetic Resonance Imaging (MRI). These modalities have contributed immensely in resolving the challenges of volumetric measurement of body organs in normal subjects, which are crucial in diagnosis and tracking of pathologies (Hendee, 2009; Jaumah, 2009). Aside the usage of these modalities in the diagnosis of tumors, blood products, calcifications, cysts, and the presence of oedema and mass effects (Duffner et al., 2003; Gallia et al., 2006; Rohlfing et al., 2006), they have also contributed immensely in studying details of the ventricular system of the brain for diagnosing brain abnormalities such as enlargement (Olarinoye-Akorede et al., 2015; Srijit & Shipra, 2007). Visualization of the size and shape of the ventricles has therefore become a reality with CT scan, thereby aiding neuroradiologists and clinicians to diagnose severity of ventricular enlargement (Rohlfing et al., 2006; Srijit & Shipra, 2007).

Although, both modalities are generally non-invasive and safe; CT is preferred to MRI because it is cheaper with short acquisition time and clearer boundary demarcation (Ambarki et al., 2010; Goo, 2021; Riello et al., 2005). On the other hand, MRI has a higher resolution compared to CT. Nonetheless, due to its ability to significantly detect changes in brain morphology with better and clearer visualization CT scans are preferred to MRI (Zhang et al., 2008). CT scan is also considered as the most affordable and faster imaging modality used for the investigation of structures in the brain including the ventricles (Gawler et al., 1976). This explains why CT scan represents over 50% of all CT examinations carried out in radiology centers. CT has therefore become the commonest tool for evaluating brain atrophy. CT brain scans are mostly ordered by physicians to evaluate brain structures for the presence of abnormalities such as hemorrhage, skull fractures, tumors, and headaches. However, certain neuropsychiatric diseases like schizophrenia and Alzheimer's disease and chronic alcoholism have been linked with the ventricular system (Ashtari et al., 1989; Duffner et al., 2003; Gallia et al., 2006; McCarley et al., 1993; Rohlfing et al., 2006b). Cerebral ventricles are known to have a relatively fixed shape and size for age specifics in the absence of any pathology (Deewaker et al., 2015).

Furthermore, diseases such as schizophrenia, dementia and depression, the lateral and/or third ventricles appear enlarged (Goo, 2021; Zilundu et al., 2009). For cases of schizophrenia, imaging has reported a structural enlargement of the lateral cerebral ventricle just at the early stages of the disease (Goo, 2021; Acer, 2019). Furthermore, experimental studies have reported changes in the size of cerebral ventricles of people suffering from bacterial meningitis (Zilundu et al., 2009). Also, neuropathological researches has shown widened ventricles in cases of Alzheimer's disease characterized with macroscopically detectable cortical atrophy resulting into loss of brain volume (Zhang et al., 2008). The aforementioned diseases associated with the ventricular system has made it the most utilized technique for the identification of abnormalities during brain studies (Goo, 2021; Zilundu et al., 2009).

2.0 OBJECTIVES

The objective of this study was to optimize a clinical measuring procedure of the fourth ventricle size of human brain. This will lead to the determination of a standard ventricular size and volume model on normal CT of the brain and to propose standardisa-

-tion of fourth ventricle dimensions and its characteristics in neurocysticercosis. Additionally, to determine baseline reference volume and linear dimensions of fourth ventricle using voxel-based method.

2.0 EQUIPMENT

CT scanners with specific scanning protocol to acquire the images and MeVisLab workstation as a measurement tool for the linear and volume measurement were used.

3.0 METHODS

Images were retrieved from the database of 16 slice Hitachi Supria CT scanner manufactured by Hitachi Medical Corporation, Japan.
With the following specifications and feastures of the scanner.

a. Whole-body high-speed scanning protocol with less than 1 sec/rot

b. 75 cm wide gantry bore with compact foot-print

- Effective field of view: 500mm
- X-ray tube: 5 MHU
- Maximum output: 48kW
- Slice Thickness: 0.675 mm
- Slices per Rotation: 16
- Intuitive GUI design with 24-inch-wide monitor

Figure 1: Hitachi Supria 16 slice CT scanner

3.1 Image Acquisition Protocol

A dedicated head scanning protocol on Hitachi Supria CT scanner was used to acquire the images. Below are detailed imaging parameters contained in the head protocol for image acquisition.

Table 1: Table of Basic Head Scan Protocol of Hitachi Supria scanner.

Technical Parameters			
Scan Type	Normal	**Table Direction**	OUT
Tube Current	350mA	**Scan Interval**	2s
Tube Voltage	120KV	**Bow Tie**	Normal
Collimation	1.24* 16	**Scan Mode**	8i
Filter	12(0)	**FOV**	220mm
Scan Time	0.75s		
Thickness	2.5mm		
Dose Validation	Head Phantom		

3.2 MeVisLab (MVL) Application Software

MeVisLab is a cross-platform application for medical image processing and scientific visualization. Some of the features of the software include advanced algorithms for image registration, segmentation and quantitative morphological and functional image analysis.

4.0 METHODOLOGY

CT scans which were declared normal by reporting radiologists of the facility between the period 2018 and 2021 were retrieved from the local database (PACS) of the facility and copied unto an external drive. The images were fed into the measurement software (MVL and Horos). The sample size was drawn from the population upon review. All CT scans stored in the local database (PACS) of have unique numbers and this was used to trace client's nationality in HAMS (Hospital Administration and Management System) software used to register the client before the scan. However, clients' names were hidden on measuring software.

4.1 Data Processing and Measurements

First, a voxel-count method was used to experimentally deduce fourth ventricle volume. Secondly, using measured linear fourth ventricle dimensions of width, length and thickness; a mathematical model was used to compute fourth ventricle volume.

4.2 Experimental Method

This experimental approach was done manually using voxel count method described in chapter two. This process involved the use of the region of interest (ROI) tool incorporated in MeVisLab application software. ROI tool was used to draw an outline around the boundary of the fourth ventricle from surrounding tissues. The ROI captured the total number of voxels within the boundary drawn around the fourth ventricle. The total number of voxels was automatically generated on each slice that contained the 4^{th} ventricle. The measurement was repeated three times for each image and the average total number of voxels was recorded. With known pixel size and slice thickness generated by the scanner together with recorded average total number of voxels, the equation below was then used to compute volume of the 4^{th} ventricle (Shirazu et al., 2017; Zilundu et al., 2009) 4^{th} VV = Total number of voxels x slice thickness x pixel size

The advantage of applying voxel count method in volume estimation is that, the anatomy of the organ been measured is irrelevant during measurements (Prince LM, 2012). However, this method of volume measurement may be associated with partial voluming, whereby true voxels of the 4^{th} ventricle may contain voxels of surrounding tissue leading to an overestimation of the volume. To avoid this, the ROI was carefully drawn to ensure the 4^{th} ventricle's boundary was well demarcated from surrounding tissues. This was achieved accurately because of the sharp contrast between the 4^{th} ventricle and the surrounding tissues. For uniformity across images on MVL platform, slice thickness of 2.5 mm image size of 512*512 matrix were maintained. However, the pixel size varied between 0.382/0.382-0.464/0.464. Image matrix of higher resolution helps to avoid measuring innacuracies (Jacoby et al., 1980; Prince LM, 2012).

4.3 Linear Fourth Ventricle Measurement

This process involved the measurement of linear fourth ventricle dimensions 4^{th} V_D, namely VW, VT and VL. VW is the lateral diameter/width, VT the anterior-posterior diameter/thickness and VL is the longitudinal diameter/length of the fourth ventricle. Both the VW and VT were measured on axial planes whereas VL was taken on a sagittal plane. These measurements were taken by scrolling to the slice of the image that visualizes the widest or greatest of the fourth ventricle. Also, both width and thickness of fourth ventricle were taken at the same time on the same slice as shown on Figure below Secondly, Minitab statistical software was used to model the relationship between 4^{th} V_D and 4^{th} VV. The shape of the fourth ventricle was considered irreverent in Minitab modeling process, however three linear measurements of VW, VT and VL obtained earlier were used to compute the volume. The relationship between 4^{th} VV and 4^{th} V_D were presented in results. The derived modeled equations were defined according to age groups and gender. In all, ten linear equations were obtained.

Finally, the obtained modeled equations from Minitab modeling process were applied in python programming tool to write a script. The modeled equations were defined in the script using conditional clauses based on gender and age groups. The script was subsequently translated into a user-friendly graphic user interface in the format of an installable desktop application. This application provides an easy way of calculating volume of fourth ventricle by entering particulars such as 4^{th} V_D (VW, VT and VL), age and gender.

5.0 RESULTS

All linear ventricular measurements (width, length and thickness) were in the unit of millimeters and cubic millimeters for volume measurement. Presentation of the summarized values of the entire experimental processes, including data analysis is presented in Table 7 to Table 12. From Figure 7, out of 200 respondents, 100 respondents representing 50% were female while 100 representing 50% of the respondents were male. This indicates an equal representation of both males and females.

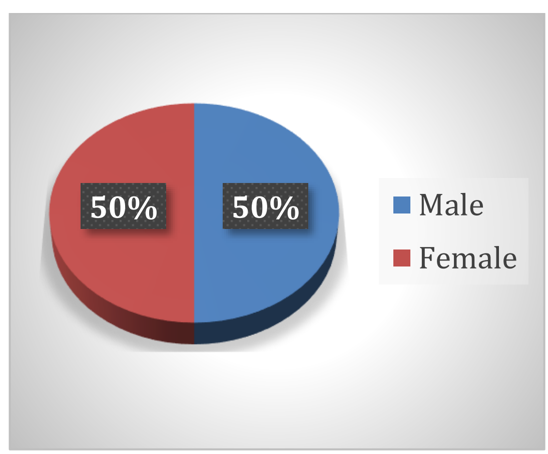

Figure 7: Gender of Respondents

5.1 Image Data Acquisition

Figure 2 and 3 shows axial CT brain image of the fourth ventricles using brain CT protocol scan image with the lateral and fourth ventricles in profile on the MVL platform. Whilst figure 4 shows voxel count measurement of the 4th ventricle in MVL platform. Figure 5 shows the width and thickness of fourth ventricle on an axial plane and figure 6 shows 4th ventricle on a sagittal plane.

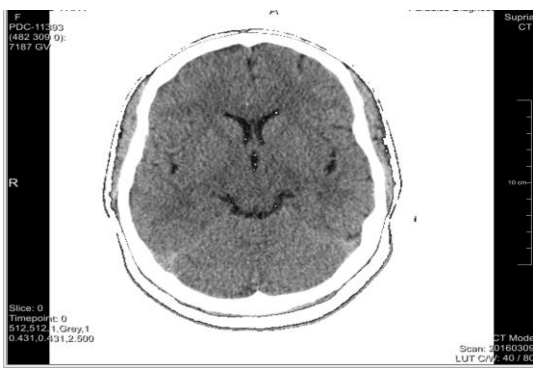

Figure 2: An axial CT brain scan of the fourth ventricles.

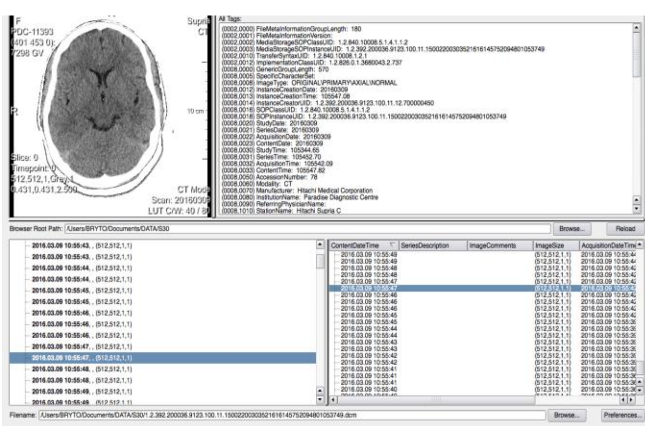

Figure 3: MeVisLab Interface

Figure 4: Voxel count measurement of the 4th ventricle in MVL platform.

Figure 5: Width and thickness of fourth ventricle on an axial plane

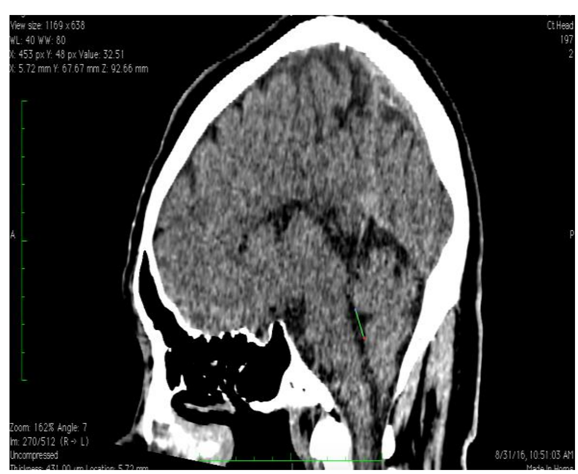

Figure 6: 4th ventricle on a sagittal plane

5.2 Fourth Ventricle Volume

Voxel-Based Method was used to experimentally acquire volume of fourth ventricle and the results are presented in the table 2 and 3 below.

Table 2: Male Fourth Ventricle Volume

Sample	21-30	31-40	41-50	51-60	61-70
1	1389.4923	1389.4923	1497.0892	1265.3559	1556.3887
2	1173.1150	1173.1150	1340.5752	1700.3002	1524.6827
3	950.3301	950.3301	1488.6728	1457.4922	1947.5528
4	926.7949	926.7949	1574.3520	1743.9428	1865.7377
5	1197.6940	1197.6940	1568.9696	1522.3384	1408.6876
6	963.8883	963.8883	1586.3727	1636.6324	2027.0044
7	1198.2583	1198.2583	1584.9374	1810.2895	1967.3169
8	1099.5318	1099.5318	1488.1575	1360.3897	1641.5422
9	1026.8539	1026.8539	1143.1176	1801.3031	1610.6248
10	1080.7619	1080.7619	1229.1124	1598.3934	1397.0775
11	931.1515	931.1515	1159.8149	1611.1317	2355.8787
12	1112.0450	1112.0450	1496.9175	1755.6061	1423.0841
13	1059.3643	1059.3643	1569.5078	1447.4711	2053.4883
14	1228.4994	1228.4994	1564.3049	1869.3705	2000.9158
15	1360.8809	1360.8809	1274.4753	1876.0068	1927.7887
16	862.6540	862.6540	1566.0163	1802.8327	1967.9098
17	1105.5954	1105.5954	1502.2421	1732.0883	1636.7328
18	1037.4752	1037.4752	1190.7425	1257.8946	1928.1840
19	1120.2255	1120.2255	1298.9338	1576.2437	1536.3466
20	1102.9620	1102.9620	1250.7258	1818.3574	1413.9878

Table 3: Female Fourth Ventricle Volume

Sample	21-30	31-40	41-50	51-60	61-70
1	953.0641	1057.4787	1501.8986	1201.7746	1751.7918
2	928.5114	1616.6240	1355.1457	1653.4733	1431.9077
3	960.3243	1013.1990	1500.8680	1809.5247	1943.3653
4	989.7690	1445.8693	1497.1906	1225.3961	1752.1506
5	1113.9345	1334.0736	1552.4460	1539.6678	1714.8326
6	1314.3827	1159.0164	1356.6242	1619.9743	2231.3137
7	857.0603	1344.5479	1235.6203	1560.3737	1709.6297
8	1233.9174	995.5525	1430.1015	1501.0398	1463.7773
9	937.9265	974.2859	1594.8051	1231.9346	1235.0914
10	1180.8208	1200.2372	1504.1233	1177.5628	1707.8355
11	995.3456	1170.1033	1357.9385	1521.8231	1208.3175
12	1005.2745	1379.0798	1348.2460	1447.4711	1711.3150
13	1153.7284	955.3158	989.3746	1640.4290	1728.2430
14	1199.5205	977.8124	1520.1697	1271.6468	1816.0218
15	942.7906	1169.6948	1149.3393	1562.8423	1760.9419
16	1078.8744	1381.5913	1585.6550	1171.9586	1676.0794
17	1190.0110	971.8538	1154.6062	1536.2513	1630.9070
18	924.4285	1057.2000	1429.2427	1887.4700	2097.6643
19	1323.0947	1036.6684	1463.0801	1616.6240	2033.0385
20	847.6968	974.0427	1020.1218	1853.0805	1846.1367

6.0 DISCUSSIONS

The averaged measured predictor values for the age groups 61-70, 51-60, 41-50, 31-40 and 21-30 were 99.63 mm, 99.00 mm, 98.29 mm, 97.86 mm and 96.40 mm respectively. It was observed that age group 61-70 had the largest predictor and 21-30 been the smallest. As established earlier that ventricle volume increases with ageing, and it was more easy measuring volumes of larger ventricles because they look dilated and well visualized. The maximum percentage variation among samples was less than 5%, which means that the model has 95% accurate predictability.

Ten model equations were developed; five each for males and females for the age group (21-30, 31-40, 41-50, 51-60 and 61-70). A comprehensive decision support application software tool has been developed for easy, accurate and user-friendly GUI as part of diagnostic procedure for the calculation of volume of fourth ventricle to aid neurological diagnosis in clinical practice. These would help neurosurgeons in their diagnosis, localization and surgical removal of tumors and lesions (craniopharyngiomas and gliomas) surrounding the ventricular system.

7.0 CONCLUSIONS

The study established values of ventricular volume for age and gender specific groups that would serve as baseline reference values on which future studies can build on to establish standard reference ventricular dimensions for use in clinical practice in Ghana to monitor ventricular and neurological disorders relating to the fourth of the ventricular system. In conclusion, mathematical modeling and measuring tools with MeVisLab holds a high prospect in medical imaging for measuring, predicting organ volumes. The developed comprehensive decision support application software tool has been tried and has been successful in the diagnostic procedure for the calculation of volume of fourth ventricle to aid neurological diagnosis in clinical practice.

ACKNOWLEDGEMENT

I would like to acknowledge Ghana Atomic Energy Commission and the ICTP through the Associate program (2020–2025) for the support I received from the two institutions. Additionally, I acknowledge the participating facilities for allowing me to carry out the research in their facilities.

REFERENCES

A.M., F., Acer, N., Turgut, A. T., Özsunar, Y., Turgut, M., Agapejev, S., Exhibit, S., Lamers, M. J., Klein, W. M., Hendricks, S., Ph, D., Jh, D., Higj, C. H. D. G., Hij, G., Id, D. C., Hd, G. H., Hij, C. I., Id, C. I. H., Kurth, F., … Chen, D. (2009). Ventricular Enlargement in Schizophrenia Related to Volume Reduction of the Thalamus, Striatum, and Superior Temporal Cortex. NeuroImage, 17(1), 1–6.

Ambarki, K., Israelsson, H., Wåhlin, A., Birgander, R., Eklund, A., & Malm, J. (2010). Brain ventricular size in healthy elderly: Comparison between evans index and volume measurement. Neurosurgery, 67(1). https://doi.org/10.1227/01.NEU.000037093-9.30003.D1

Ashtari, M., Zito, J. L., Gold, B. I., Lieberman, J. A., Borenstein, M. T., & Herman, P. G. (1989). Computerized Volume Measurement of Brain Structure. Investigative Radiology, 25(7), 798–805.

Deewaker, P., Hari, P. L., Sharma, P., & Ram, B. C. (2015). Evaluation of Size of Ventricles of Human Brain using Magnetic Resonance Imaging Technique. Journal of Institute of Science and Technology, 20(1), 6–14.

Duffner, F., Schiffbauer, H., Glemser, D., Skalej, M., & Freudenstein, D. (2003). Anatomy of the cerebral ventricular system for endoscopic neurosurgery: a magnetic resonance study. Acta Neurochirurgica, 145(5), 359–368.

Gallia, G. L., Rigamonti, D., & Williams, M. A. (2006). The diagnosis and treatment of idiopathic normal pressure hydrocephalus. Nature Clinical Practice Neurology, 2(7), 375–381.

Gawler, J., Bull, J., Marshall, J., & Boulay, G. Du. (1976). Computerized tomography (the EMI Scanner): a comparison with pneumoencephalography and ventriculography. Journal of Neurology, Neurosurgery & Psychiatry, 39(3), 203–211.

Goo, H. W. (2021). Hydrocephalus: Ventricular volume quantification using three-dimensional brain ct data and semiautomatic three-dimensional threshold-based segmentation approach. Korean Journal of Radiology, 22(3). https://doi.org/10.3348/kjr.2020.0671

Hendee, W. R. (1999). Physics and applications of medical imaging. Reviews of Modern Physics, 71(SUPPL. 2). https://doi.org/10.1103/revmodphys.-71.s44

Jacoby, R. J., Levy, R., & Dawson, J. M. (1980). Computed tomography in the elderly: I. The normal population. British Journal of Psychiatry, 136(3). https://doi.org/10.1192/bjp.136.3.249

Jaumah, Z. A. (2009). C. T Scan Measurements of the Lateral and Third Ventricles in Apparently Normal Iraqi Subjects. Journal of the Faculty of Medicine, Baghdad, 51(3), 320–322.

McCarley, R. W., Shenton, M. E., O'Donnell, B. F., Faux, S. F., Kikinis, R., Nestor, P. G., & Olesz, F. A. (1993). Auditory P300 Abnormalities and Left Posterior Superior Temporal Gyrus Volume Reduction in Schizophrenia. 150(3), 190.

Olarinoye-Akorede, S., Danborno, B., Jimoh, A., Fatai, O., Hamidu, A., & David, S. (2015). Third and Fourth Cerebral Ventricular Sizes among Normal Adults in Zaria-Nigeria. Sub-Saharan African Journal of Medicine, 2(2). https://doi.org/10.4103/2384-5147.157432

Prince LM, Z. (2012). Morphometric study of ventricular sizes on normal computed tomography scans of adult black zimbabweans at a diagnostic radiology centre in harare-a pilot study. University of Zimbabwe.

Riello, R., Sabattoli, F., Beltramello, A., Bonetti, M., Bono, G., Falini, A., Magnani, G., Minonzio, G., Piovan, E., Alaimo, G., Ettori, M., Galluzzi, S., Locatelli, E., Noiszewska, M., Testa, C., & Frisoni, G. B. (2005). Brain volumes in healthy adults aged 40 years and over: A voxel-based morphometry study. Aging Clinical and Experimental Research, 17(4). https://doi.org/10.1007/BF03324618

Rohlfing, T., Sullivan, E. V., & Pfefferbaum, A. (2006). Deformation-based brain morphometry to track the course of alcoholism: Differences between intra-subject and inter-subject analysis. Psychiatry Research - Neuroimaging, 146(2). https://doi.org/10.1016/j.pscychresns.2005.12.002

Shirazu, I., Mensah, Y. B., Schandorf, C., & Mensah, S. Y. (2017). Measurement of Renal Dimensions to Determine Standard Reference Renal Volume Model for Clinical Application in Ghana. 3(1), 212-224

Srijit, D., & Shipra, P. (2007). Anatomical study of anomalous posterior horn of lateral ventricle of brain and its clinical significance. Bratislavské Lekárske Listy, 108(9).

Zhang, Y., Londos, E., Minthon, L., Wattmo, C., Liu, H., Aspelin, P., & Wahlund, L. O. (2008). Usefulness of computed tomography linear measurements in diagnosing Alzheimer's disease. Acta Radiologica, 49(1). https://doi.org/10.1080/02841850701753706

Zilundu, Zhou, Y., Shi, W., Chen, W., Chen, Y.-R. Y. Y. Y. Y.-R. Y. Y. Y.-R. Y. Y. Y. Y.-R., Li, Y., Tan, L. T., Chen, D., Xia, Y., Hu, Q., Aziz, A., Nowinski, W. L., Wurthmann, C., Bogerts, B., Falkai, P., Wint, A., Watson, C., Andermann, F., GLOOR, P., … A.M., F. (2009). Ventricular Volume in Man Computed from CAT Scans. NeuroImage, 17(3), 216–223.