ORIGINAL ARTICLE

Measurement of normal ocular volume by the use of computed tomography

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Abstract

Background: Reduction or increase in ocular volume may indicate ocular pathology. Unfortunately the reference values utilized for ocular volume had been that of non-Africans. It is therefore pertinent to have a reference value of normal for Africans.

Objective: To document the computer tomography (CT) scan measured ocular volume in Benin City, which may serve as a reference for African.

Materials and Methods: The ocular volume of 200 consecutive 'normal' patients (400 eyes) who had CT scan done (using Somatom AR.T, CT scanner, and Siemens) was calculated. The dimensions were obtained at mid-ocular axial slices with maximum anterior-posterior dimension and maximum size of the eye lens.

Result: The mean (mean ± 2 SD) ocular volume for both eyes was 5282.23 mm^3 ± 1755.13 mm^3 (right eye was 5264.26 mm^3 ± 1781.12 mm^3; left eye was 5300.20 mm^3 ± 1771.57 mm^3). The mean ocular volumes was different for either eyeball and sex (in males the right eye was 5289.80 mm^3, left eye was 5224.31 mm^3; while in females the right eye was 5338.18 mm^3, left eye was 5240.79 mm^3). Ocular volume correlated with the patients' ages $P = 0.006$ for the right eye, $P = 0.008$ for the left eye and $P = 0.006$ for total eyeball volume.

Conclusion: Ocular volume correlated positively with the age of the patients to about 50 years after which some reduction was observed. We noted that males had slightly larger eyeballs in comparison to females, although not at statistical significant level.

Key words: Computed tomography, CT, eye volume, ocular volume

Date of Acceptance: 03-Sep-2012

Introduction

The eye is the sense organ for vision. The configuration of the structures of the eye and their mechanisms are set optimally for vision, such that some diseases (such as macrophthalmia, microphthalmia, hypermetropia, myopia, astigmatism and presbyopia) that affect the dimensions of the eye or its component may cause visual abnormalities. Coat's disease,[1] phthisis bulbi and persistent hyperplastic primary vitreous are examples of diseases that is associated with reduced ocular volume. While glaucoma may lead to increased ocular volume.[2] Consequently attempts were made to determine the dimensions of the eye by utilizing various methods including radiography, angiography, ultrasonography, computed tomography, magnetic resonance imaging and photography.

Other methods to measure ocular volume include gravimetric and the use of IOL master. Gravimetric method was described by Wales,[3] but it requires enucleating the eye, making it rather destructive and not practicable in most clinical situations. IOL Master can also be used in the clinic setting to determine ocular axial length measurements from which ocular volume can be calculated.[4] However it is only available in some ophthalmic clinics.

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Access this article online

Quick Response Code:

Website: www.njcponline.com

DOI: 10.4103/1119-3077.113453

PMID: *******

There is paucity of literature on ocular volume measurements involving Africans and none (to the best of our knowledge) on CT ocular volume biometry on Africans. Consequently most of the reference values utilized in Africa are based on the values obtained elsewhere. Thus we undertook this study to assess ocular volumes and document its correlation with age and sex of the patients within our environment which can serve as a reference for studies on Africans.

Materials and Methods

The medical records of two hundred and forty six patients who had cranial CT scans performed were retrospectively examined and 46 (18.69%) of the patients' records were excluded from this study based on the exclusion criteria (subjects with ophthalmic pathologies or lesions such as tumours, fractures or bony lesions involving the facial bones/orbital walls; CT images that were not clear, for example due to motion blurring; Images that showed deformity or irregularity of the eyeball contour and images with greater than 0.3 mm difference between the values obtained by the researchers). Hence the stored cranial CT scan images of 200 patients (400 eyes) were used for this study. The cranial CT examinations were conducted at the University of Benin Teaching Hospital (UBTH), Benin, Nigeria. Demographic data, including the age, sex and medical records were obtained. Approval for the study was granted by the ethical committee of UBTH.

The CT scanner used was Somatom AR.T scanner, Siemens, Germany. The CT scans were performed in axial planes at a thickness of 3 mm and a window level of 50 Hounsfield units. The slices chosen for ocular measurements were mid-ocular slices showing the maximum axial size of the eyeball, the lens and optic nerve as well as the insertions of the medial and lateral rectus muscles–Figure 1. The images of the eyeball were magnified 3 times to allow easy placement of the cursors of the measuring callipers, thereby increasing the sensitivity of the measurement.

Ocular dimensions were obtained with axial length or anterior-posterior diameter of the eyeball (defined as the distance through the visual axis from the anterior corneal surface to the posterior wall of the choroid in axial view and it included the anterior chamber depth, lens thickness, and vitreous length). The width or transverse diameter was defined as the maximum transverse distance between the temporal and nasal ends of the globe in axial view. The averages of length and width dimensions were used to calculate the total volume of the eye. The dimensions were measured twice by the 2 researchers and the average recorded.

Although the eyeball is slightly ellipsoidal, it is assumed to be spherical for volume estimation. This reduces the error margin likely to be introduced. These measurements were recorded and the largest diameters were used to estimate the volume using the following formula: [(anterior-posterior diameter + transverse diameter/2)/2]^3. (4/3π).

The statistic was performed using SPSS version 17 (Chicago, IL). The data was expressed in descriptive statistics such as frequency tables, percentages and averages. Independent T-test was used to test for differences in mean value between variables. Pearson's correlation was conducted between patients' ages and ocular volumes with the level of significance set at 0.01.

Result

The mean age of the patients was 40.5 ± 21.2 years with median of 42 years and mode 12 years. The youngest patient was 3 years old and the oldest 84 years. The ocular measurements were conducted in 122 males and 78 females. Table 1 shows the distribution of the patients' age and sex. The mean age of the males was 40.1 ± 20.9 years while that of the females was 41.0 ± 21.8 years with the females slightly older than the males (mean age difference 0.9 years), which was not statistically significant, T = 0.278, P = 0.781. The minimum age of the males was 3 years and the maximum age was 76 years while the minimum age for the females was 3 years and the maximum 84 years.

The overall mean total ocular volume of the 400 eyes (both

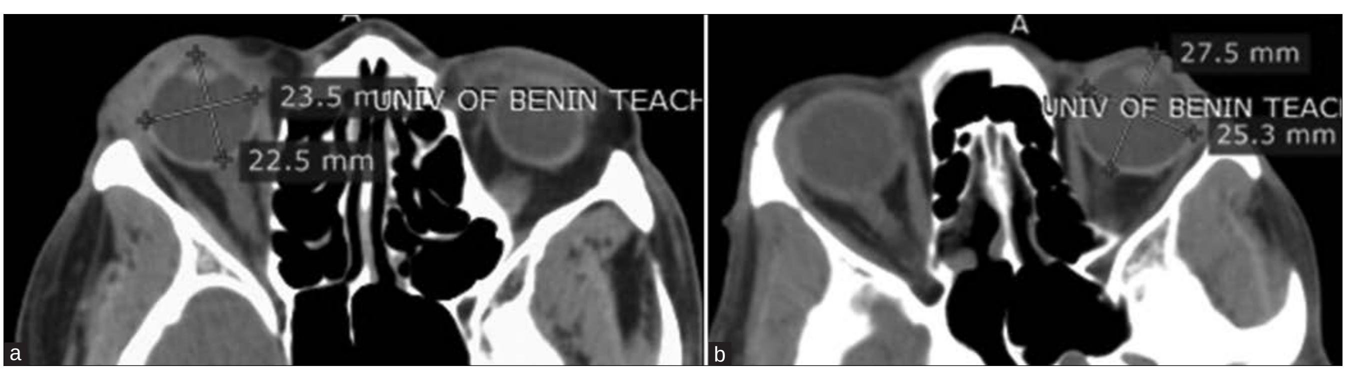

Figure 1: Axial CT scan images with measurement cursors for (a) right eye and (b) left eye

left and right eyes) was 5282.23 mm^3 ± 1755.13 mm^3 (mean ± 2 SD). The mean (mean ± 2 SD) ocular volume of the right eye was 5264.26 mm^3 ± 1781.12 mm^3 while that for the left eye was 5300.20 mm^3 ± 1771.57 mm^3 with a mean difference of 35.94 mm^3 in favour of the left eye. The median volume for the right eye was 5205.82 mm^3 while that for the left is 5577.52 mm^3 with both having the same mode of 5577.52 mm^3. The values of the minimum and maximum volumes were the same for both eyes; minimum volume = 3054.86 mm^3; maximum volume = 8184.52 mm^3 (range 5129.66 mm^3). The mean right ocular volume for the males was 5289.80 mm^3 while that for females was 5224.31 mm^3. Hence, male right eye volume was larger than for females with a difference of 65.49 mm^3 but was not statistically significant, F = 0.256, *P* = 0.613. Similar observation was noted on the left eye in which the ocular volume for the males was 5338.18 mm^3 and females 5240.79 mm^3 with a difference in volume of 97.39 mm^3 (F = 0.574, *P* = 0.450).

Table 2 demonstrates that the ocular volume in both sexes and in both eyes increases with advancing age until the patient is about 50 years of age before it starts to reduce in volume. This observation is better depicted in Figure 2. However, a sudden drop in ocular volume from about 5700 mm^3 to 5200 mm^3 occurred in patients aged between 51 and 60 years, it then rose to about 5490 mm^3 before the ocular volume starts to decrease again. Finally, the patients' ages showed significant positive correlation with ocular volumes; *r* = 0.195, *P* = 0.006 for the right eye, *r* = 0.188, *P* = 0.008 for the left eye and *r* = 0.194, *P* = 0.006 for both eyes (all the ocular variables were significant at 0.01 level, 2-tailed).

Table 1: Distribution of the subjects' by age and sex

	Male	Female	Total
Age			
<10 years	5 (62.5)	3 (37.5)	8 (100)
11–20	22 (64.7)	12 (35.3)	34 (100)
21–30	23 (62.2)	14 (37.2)	37 (100)
31–40	9 (47.4)	10 (52.6)	19 (100)
41–50	18 (58.1)	13 (41.9)	31 (100)
51–60	19 (65.5)	10 (34.5)	29 (100)
61–70	15 (78.9)	4 (21.1)	19 (100)
71–80	11 (52.4)	10 (47.6)	21 (100)
80+years	0 (0)	2 (100)	2 (100)
Total	122 (61.0)	78 (39.0)	200 (100)

NB=values are in n(the percentage within age category)

Discussion

Measurement of ocular dimensions by the use of computed tomography is non-invasive but involves exposure to ionizing radiation. Computed tomography (CT) gives accurate measurement values when compared to other imaging modalities for *in-vivo* assessment.[2,5] Although the ionizing radiation effect limits it routine

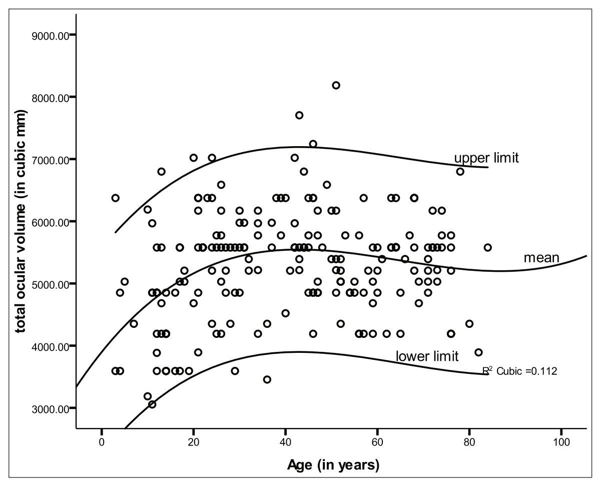

Figure 2: Scatter plots of the ocular volumes against the ages of the patients with superimposed cubic fit line at mean and 95% confidence interval lines

Table 2: The mean ocular volumes distributed among the side(s) of the eye, sex and age group of the patients. Mean values for both eyeballs is in n(mean±SD within patients' age group) while that for either eye is in n (mean within patients' sex and age group). SD=standard deviation, Eta²=Eta squared

Age group	Both eyeballs	Right eye			Left eye		
		Males	Females	Total	Males	Females	Total
<10 years	8 (4645.40±1194.37)	5 (4544.57)	3 (4860.41)	8 (4663.01)	5 (4667.88)	3 (4561.01)	8 (4627.80)
11–20	34 (4681.38±911.11)	22 (4626.32)	12 (4743.02)	34 (4667.51)	22 (4669.19)	12 (4743.02)	34 (4695.25)
21–30	37 (5445.12±792.15)	23 (5563.85)	14 (5196.51)	37 (5424.86)	23 (5636.08)	14 (5184.98)	37 (5465.39)
31–40	19 (5463.82±813.18)	9 (5381.62)	10 (5420.54)	19 (5402.11)	9 (5469.50)	10 (5575.95)	19 (5525.53)
41–50	31 (5743.13±796.92)	18 (5849.18)	13 (5582.72)	31 (5737.44)	18 (5850.10)	13 (5608.62)	31 (5748.83)
51–60	29 (5174.37±804.72)	19 (5100.89)	10 (5183.73)	29 (5129.46)	19 (5199.62)	10 (5256.62)	29 (5219.28)
61–70	19 (5498.18±698.03)	15 (5496.63)	4 (5362.39)	19 (5468.37)	15 (5549.62)	4 (5446.96)	19 (5528.01)
71–80	21 (5398.19±698.03)	11 (5436.20)	10 (5341.21)	21 (5390.97)	11 (5363.84)	10 (5339.68)	21 (5352.34)
80+years	2 (4734.58±1192.10)	0 (N/A)	2 (4884.00)	2 (4884.00)	0 (N/A)	2 (4585.17)	2 (4585.17)
Total	200 (5282.23±877.57)	122 (5289.80)	78 (5224.31)	200 (5264.26)	122 (5338.18)	78 (5240.79)	200 (5300.20)
F=0.574,	*P=0.450*	*Eta=0.054,*	*Eta²=0.003*	*F=0.256,*	*P=0.613,*	*Eta=0.036*	*Eta²=0.001*

utilization, CT may be considered essential when other means of accurate measurement of ocular dimension is contraindicated or unemployable. In addition to its dimension assessing capability, it gives anatomic details of the surrounding ocular soft tissues as well as bony structures. Furthermore in a single examination other related extra-ocular anomalies may be detected including intracranial lesions.

The volume of the eye ball changes during life as observed in this study. Our result show significant correlation between age and ocular volume for both eyes. The increase in ocular volume occurred from childhood to about 50 years of age before it starts reducing to a value comparable to those below 10 years of age for patients above 80 years. In a similar study, ocular volume was reported to rise rapidly from birth to 2 years of age and then a gradual rise until 30 years of age before it start decreasing.[5] The decline in ocular volume started later in our study, 50 years, compared with 30 years in the study by Hahn *et al.*[5]

However in a study on 1232 adult Chinese in Singapore the axial length (a major variable in the calculation of ocular volume) was noted to increase until 50 years before reduction was observed, which is in accord with our findings.[6] Nonetheless, Hahn *et al.*[5] concluded that their study supported Priestly Smith's[7] documentation that the cornea of the elderly is smaller than that of young people which might indicate that ocular volume is reduced in advanced age. Such reduction of ocular volume with increasing age may result in the shallowness of the anterior chamber in old age and may lead to closed-angle glaucoma.[8]

Although not at significant statistical level, the left ocular volume is slightly larger than the right by 0.68%. This is consistent with the observation that the difference between paired eyes is always less than 1%.[3] Consequently, if the volume of one eye is known then the volume of the other eye (if normal) can be extrapolated as it will fall within the calculated value of ±1% of the known eye volume. We reported a total average volume of both eyes of 5282 mm^3 which is smaller than that reported by Galluzzi *et al.*[1] and Acer *et al.,*[9] but less than that reported by de-Graaf *et al.*[10] (mean ocular volume of the normal eyes was put at 6,018 mm^3, 7,060 mm^3 and 5018 mm^3 respectively). Similarly, in a study in Nesbraska, USA, on CT measured ocular volume on 228 eyeballs, the value obtained was 7,181 mm^3. It appears that the values they recorded differed either because of the small sample populations (13, 36, 59 and 228 patients respectively), varied population ages and habitus or from racial differences. Unfortunately, no larger population size study on CT measured ocular volume was available for comparison.

The mean ocular volume was larger in males than females, although not at statistical significant level. This may result from human sexual dimorphism in which the male body habitus is generally bigger than that of the females [11,12] and may thus be extrapolated to concomitant increase in size of the male organs compared to females'. The difference in ocular volume between the sexes was less than 100 mm^3 which may be considered of minimal significance as it was less than 2%. But this was not the case in the study by Acer *et al.*[9] in which the percentage difference in the mean between ocular volumes of both sexes was about 3.6%. We observed that the patients in our study showed consistent increase in ocular volume in either globe of male patients than of females in those above 60 years.

Unfortunately, CT cannot be routinely used to assess ocular biometry due to its ionizing radiation dose. Instead, a patient's ocular biometry can be retrieved from their CT images that were acquired for other reasons (such as cranial CT done for headache). However, retrospectively acquired CT images may not have been obtained in optimal planes making ocular measurement rather difficult and necessitating scrutiny for the most appropriate image or utilizing image reconstruction application. CT may however be used in cadaveric ocular biometry where the effect of ionizing radiation is of no clinical consequence.

Conclusion

Normal ocular volume in our study should fall within 3527 mm^3 and 7037 mm^3. There is however variation with age and sex which should be taken into account before making an impression of microphthalmus or microphthalmia. Consequently, the reference range obtained from CT acquired ocular volume in this study can be used in our environment.

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How to cite this article: Igbinedion BO, Ogbeide OU. Measurement of normal ocular volume by the use of computed tomography. Niger J Clin Pract 2013;16:315-9.

Source of Support: Nil, **Conflict of Interest:** None declared.