A Review of Ocular Volume Measurement in Adult Humans

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Abstract:- Ocular volume (OV) estimation is important for proper diagnosis and management of eye diseases such as microphthalmos, buphthalmos, macrophthalmos, orbital tumours and refractive errors such as myopia and hypermetropia. B-scan ultrasound gives very useful information when visualizing the intra-ocular structures such as the lens, vitreous body, retina, choroid and sclera. Magnetic resonance imaging (MRI) and computed tomography (CT) of the eyeball give a clearer image compared to ultrasound images, though they are very expensive. Other methods such as radiography, angiography, photography, gravimetric methods can also be used in ocular biometry. For this manuscript, several published materials were searched for and necessary information related to the key words in this topic were sorted out and orderly written systematically. This review summarizes the most recent methods of OV measurements and estimation as well as highlighting the merits and demerits of each method. The limitations of the formulae for estimating OV was used to make recommendations for future research.

Keywords:- *Ocular Volume; Ophthalmology; B-mode Ultrasound; Magnetic Resonance Imaging; Computed Tomography.*

I. INTRODUCTION

Ultrasound Scanning of the eyeball has now become very important in diagnostic clinical practice because it is a rapid, safe and easy method of examination. This method was first employed in ophthalmology by Baum [1] using 2D B-mode application. Ultrasonic evaluation of the eyeball provides the surgeon with useful information on the size and position of the orbital tumor before surgical operations are carried out[2, 3].Magnetic resonance imaging (MRI) and computed tomography (CT) of the eyeball mostly employed for research purposes give a clearer image compared to ultrasound images, but they are very expensive [4]. Ultrasound imaging of the eye is categorized into imaging of the anterior chamber at high frequencies of 30-80 MHz and imaging of the entire eye with sector scans at 10-20 MHz to investigate the ocular fundus [5].B-scan ultrasound gives more useful information when visualizing the intra-ocular structures such as the lens, vitreous body, retina, choroid and sclera [6]. It may be used in differentiating intra-ocular tumors and rhegmatogenous from exudative retinal detachment as well as providing information about the location and extent of disorder such as proliferative diabetic retinopathy [7].

Ocular volume (OV) is an ophthalmic parameter that defines the size of the anterior and posterior eyeball segments. The anterior segment that comprises 1/6th of the eyeball volume is the fluid-filled space in the anterior compartment of the eyeball between the corneal innermost surface (endothelium) and lens [8]. The vitreous chamber is an anatomical space in the posterior part of the globe, extending between the lens anteriorly and retina posteriorly. It occupies about 5/6th of the volume of the eyeball and it is filled by a gel-like material called vitreous humour that maintains the shape of the eyeball [9]. The OVis affected in various diseases of the eye. Establishing a normal reference for ocular volume will be a basis for comparing any deviation from the normal in such disease states. A high OV above the normal value indicates the presence of congenital glaucoma (buphthalmos), ectasias, staphylomas and high myopia. In the other hand, a lower OV indicates the likelihood of pathologies such as microphthalmia and phthysis bulbi [8]. Other ocular diseases like myopia, hypermetropia, presbyopia,macrophthalmia, and astigmatism cause visual abnormalities by affecting the dimensions of the eye [9].Anthropometric measurements (age, height, weight, body mass index and fat-free mass) does not have any significant impact on the OV [10, 11, 12]. The mean OV has been found to be higher in male than in femaleboth in the right and left eyes [8, 10].

In Measuring OV, it is necessary to know about the ocular biometric dimensions. Ocular biometric dimensions such as axial length (AL), anterior chamber depth (ACD) and crystalline lens thickness (CT) are essential in determining OV as well as in clinical and research applications.The distance between the anterior and posterior poles of the eye is known as the AL. More accurately, AL is the distance from the corneal apex to an interference peak corresponding to the retinal pigment epithelium membrane [13, 14]. In an adult, the average AL of the eyeball is 23.30 mm [15] with a range of 23–25 mm [16]. The average AL in a newborn is about 16 mm. While in infants, the eye grows to a length of approximately 19.5 mm, but in adults, it remains practically unchanged [16]. These ocular biometric dimensions apart from being used to calculate OV, they can independently be used to indicates ocular pathologies. The AL can be applied clinically in calculating the intraocular lens (IOL) power before cataract and refractive surgery [17] and to diagnose other conditions like staphyloma [18], to evaluate the danger of retinal detachment [19] as well as to measure the structural and dimensional components in the studies of myopia [20]. Furthermore, a precise measurement of ACD can be applied in phakic intraocular lens(PIOL) calculation formulae and in patient selection [21], diagnosis and management of eye conditions such as acute primary angle-closure glaucoma [22], keratoconus and lenticonus [23]. In addition, LT assessment is important in biometric studies of myopia and primary angle-closure glaucoma [24].

The eyeball dimensions have different values across different continents, this information on variations among races and tribes is relevant in understanding the causes, treatment and prevention of eyeball sicknesses [25]. People from the European countries are known to have shallower ACD than their counterparts from Asia, Africa and America, therefore they are liable to having eye disease like angle-closure glaucoma [26, 27, 28]. The main aim of this manuscript is to review information on the ocular volume measurement using ultrasound, MRI, and CT methods and compare these methods as well as analyzing the weakness and strength of each method. Previous reports on OV estimations have not mention the need to perform a research using in-vitro method particularly for establishing a universal formula that combine all the existing formulae in the estimation. This review suggests the need to come up with a research using an eyeball phantom specifically designed to derive a formula that will be accepted universally for estimating the OV .

A. Search Strategy

To get a lot of useful materials, several published materials were searched for and necessary information related to the key words in this topic were sorted out and orderly writtenon the topic. Major words such as OV measurements, Ophthalmology, Ultrasound MRI and CT were searched for and important information on OV from published papers and thesis were presented. This finding was restricted OV measurements by ultrasound, MRI and CT.

II. ANATOMY OF THE HUMAN EYE

Humans have two eyes, located on the left and right of the face. The eyes sit in bony cavities called the orbits, in the skull. The eye has no definite shape, but can be seen to be a sphere, with a front and back segment [29]. The anterior segment is made up of the cornea, iris and lens. The cornea is transparent and more curved, and is linked to the larger posterior segment, composed of the vitreous, retina, choroid and the outer white shell called the sclera. The size of the eye differs among adults by only one or two millimeters. The eyeball is generally less tall than it is wide. The sagittal vertical (height) of a human adult eye is approximately 23.7 mm, the transverse horizontal diameter (width) is 24.2 mm and the axial anteroposterior size (depth) averages 22.0–24.8 mm with no significant difference between sexes and age groups [29, 30].The typical adult eye has an anterior to posterior diameter of 24 mm (0.94 in), and a volume of 6 cubic centimeters [30].The eyeball grows rapidly, increasing from about 16–17 mm diameter at birth to 22.5–23.0 mm by three years of age. By age 12, the eye attains its full size [29, 30, 31].

III. ULTRASOUND, MRI AND CT METHODS OF MEASURING OCULAR VOLUME

Ultrasonic OV measurement and analysis has been reported to be useful in managing injuries of the eye [32, 33]. An acute eye damage is easily diagnosed and prevented with the aid of the knowledge of a reduced eye volume. Furthermore, ocular injuries such as retinal detachment, vitreous heamorrhage, hyphema, ruptured globe, lens opacification and displacement can easily be identified through ultrasonography of the eyeball [33]. Ultrasound provides real-time cross-sectional image in a cost-effective manner, even in the presence of optically opaque intervening structures. The reliability of ocular and orbital diagnosis with B-scancan be seen in the identification of lesions in the posterior chamber [1]. A-scan is anaccurate technique used in identifying the anterio-posterior diameter of the eye and pre-operative lens thickness in cataracts prior to extraction [34]. Ultrasound scanning using B-mode can be applied in thedetection of unwanted objects in the eye, abnormal growth and eyeball diameters [1]. B-mode ultrasound has been found to give precise measurement of eyeball diameters and volume [8]. Ultrasound using A-mode, bio-microscopy and ultrasonography using Doppler technique do not have much application in OV estimation [8].

The value of OVreported in many articles among the same study population have remarkable variations. The reason for this noticeable differences is possibly due to the lack of a universally acceptable formula for estimating the OV. Results published by [35] shows that OV was estimated from the horizontal and verticaldiameters measured from the eyes,however, other studies [9, 36] calculated the value of OV from anterior to posterior, horizontal and vertical diameters of the ocular ball. A more accurate value of the OV is gotten by using ocular diameter measured in three dimensions of the eyeball in the estimation process [11, 36]. CT and MRI produce good cross-sectional imaging and precise examination of ocular dimensions and OV [11, 36].The problems associated with the use of MRI in most less developed countries like Nigeria are the expensive cost, scarcity and inconsistencies in measurement results. CT measurements of OV also has the limitation of cost effectiveness and radiation burdens. Table 1gives a summary of previous OV measurements using ultrasound, MRI and CT methods.

Author	Method	Ocular Volume (cm^3)	
		Male	Female
Ogbeide and Omoti (8)	B-mode ultrasonography	R=5.53± 0.25 L=5.34±0.30	R=5.41±0.35 L=5.21±0.38
Abubakar*et al*. (37)	B-mode ultrasonography	R=6.04± 0.60 L=6.03±0.61	R=5.96±0.55 L=5.94±0.54
Emmanuel O.A. (38)	B-mode ultrasonography	R=8.38± 0.57 L=8.31±0.48	R=8.31±0.58 L=8.21±0.56
Mutiu O.A. (39)	B-mode ultrasonography	R=5.71± 0.16 L=5.62±0.17	R=5.58±0.16 L=5.53±0.16
Heymsfield*et al*. (10)	MRI	R=6.35± 0.67 L=6.36±0.65	R=6.30±0.55 L=6.30±0.53
Surekha*et al*. (40)	MRI	R=6.05± 0.79 L=5.98±0.02	R=5.82±0.74 L=6.14±0.47
Park *et al*. (41)	MRI	R=19.30± 0.70	R=18.40±0.27
Chau et al. [42], Chau et al. [43]	MRI	R=6.55± 0.94	R=6.84±0.88
Ibinaiye et al. [44]	MRI	R=6.86± 0.98 L=6.97±0.99	R=6.61±1.03 L=6.52±0.86
ngbinedion and Ogbedie [9]	CT	R=5.29±0.80 L=5.22±0.31	R=5.34±0.18 L=5.24±0.79
Hahn and Chu [11]	CT	R=9.69±1.66 L=8.81±0.70	R=10.81±0.12 L=9.79±0.70
Acer et al. [45]	CT	R=7.48± 0.80 L=7.49±0.79	R=7.21±0.84 L=7.06±0.80

Table 1: Summary of Ocular Volume Measurements Using Ultrasound, MRI and CT in Adult Humans

The standard value forthe normal OV of an adult human is 6.50±1.20 cm^3 [46]. OV values in table 1 are different but most of them are within the tolerant value. The differences in these measurement values is possibly because of differences in the size of the eyeball associated with geographical locations, medium by which the eyeball diameters are measured and age group studied. OV measurement does not have a universal method due to the fact that the eyeball is mostly considered as being either spherical or an ellipse when estimations are done. In most studies, OV is calculated using only one, two or three diameters of the eyeball leading to variations in the mathematical relationships connecting the volume and diameters of the eyeball.However, researches carried out have established that calculation of OV using all three diameters have a better result[11, 37, 47]. Autopsy method of measuring OV has values within the range of 7.12±1.40 to 7.81±0.10 cm^3 [48, 49, 50].

Automatic counting and shading algorithm of MRI voxel of size 1.0 mm^3(T2-weighted) can also be used to estimate OV[51]. Most MRI, CT and ultrasound measurements of OV are done automatically. The algorithm for these machines has been embedded in the design and manufacturing of the machines. Other formulae employed in calculating OV after measuring the three diameters are as summarized below;

$$OV = \frac{\pi}{6} \times anterior - posterior\ diamater \times width \times axial\ length \quad \ldots\ 1$$

Equation 1 [39] gives OV results measured with either MRI, CT or ultrasound to be within accepted standards. Another formula used for estimating OV from CT images is given by [52]:

$$OV = t \times \left[\frac{SU \times d}{SL}\right]^2 \times \sum P \quad \ldots\ 2$$

Here, t is the thickness of each emerging section, SU is the unit scale of the film, d the separation existing between each test point of the grid, SL is the length of the film and ΣP is the sum of number of points hitting the sectioned cut surface areas of the eyeball.

In estimating the OV using MRI measurements [9, 44], a different formula from the ones above was used as seen in equation 3.

$$OV = \frac{4}{3}\pi r^3 \quad \ldots\ 3$$

Such that:

$$r = \frac{AP + TR}{4} \quad \ldots\ 4$$

Where AP is the anterior-posterior diameter in cm (axial diameter of the eyeball), and TR is the transverse diameter in cm of the eyeball. Unlike equation 1that used three (3) diameters for the OV estimation, equation 3 used only two (2) measured diameters. This discrepancy in the formulae can lead to having different estimated values of OV if the same eyeball is examined. Equation 1 can be simplified to be written as [37]:

$$OV = LD \times AD \times TD \times 0.52 \quad \ldots\ 5$$

Where LD is the longitudinal diameter, AD is the axial diameter and TD is the transverse diameter. The factor 0.52 is the result of dividing π by 6.

Comparing equations 1 and 3, it can be seen that equation 3 considers the eyeball to be a sphere, while equation 1considers the eyeball to be neither a sphere nor an ellipse. Therefore, calculating the OV of a given eyeball using these two equations will result in different values which could be misleading.

IV. LIMITATION OF THE OCULAR VOLUME ESTIMATION

Among the different methods of measuring OV, ultrasound scanning is the easiest, cheapest and harmless method. MRI and CT are not regularly employed in measuring the ocular dimensions because of their radiation/ionizing effects, but they can be applied in cadaveric ocular measurements where such effects are clinically of less impact. Other methods such as radiography, angiography, photography, gravimetric methods [53, 54] have been replaced by ultrasound, MRI and CT methods, that is the reason why they have not been discussed in this review

A. Recommendation for Future research

Considering the fact that there is no universal formula for estimating the OV, there is need for future researches to come up with a single and universally accepted equation for estimating the OV irrespective of the method involved in the imaging process. This may be done using a simple phantom of the eyeball which can be scanned using ultrasound scanners, MRI and CT. A single formula incorporating the formulae discussed in this review is recommended.

V. CONCLUSION

In this paper, a short but informative review on the methods and formulae employed in measuring and estimating the OV in adult humans. A summary on the most efficient, cheapest, harmless and recent methods have been discussed which makes it easier for researchers to access immediate information without the stress of reading plenty articles.

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