Estimation of ocular volume from axial length

Manbir Nagra, Bernard Gilmartin, Nicola S Logan

ABSTRACT

Background/aims To determine which biometric parameters provide optimum predictive power for ocular volume.

Methods Sixty-seven adult subjects were scanned with a Siemens 3-T MRI scanner. Mean spherical error (MSE) (D) was measured with a Shin-Nippon autorefractor and a Zeiss IOLMaster used to measure (mm) axial length (AL), anterior chamber depth (ACD) and corneal radius (CR). Total ocular volume (TOV) was calculated from T2-weighted MRIs (voxel size 1.0 mm³) using an automatic voxel counting and shading algorithm. Each MR slice was subsequently edited manually in the axial, sagittal and coronal plane, the latter enabling location of the posterior pole of the crystalline lens and partitioning of TOV into anterior (AV) and posterior volume (PV) regions.

Results Mean values (±SD) for MSE (D), AL (mm), ACD (mm) and CR (mm) were −2.62±3.83, 24.51±1.47, 3.55±0.34 and 7.75±0.28, respectively. Mean values (±SD) for TOV, AV and PV (mm³) were 8168.21±1141.86, 1099.40±139.24 and 7068.82±1134.05, respectively. TOV showed significant correlation with MSE, AL, PV (all p<0.001), CR (p=0.043) and ACD (p=0.024). Bar CR, the correlations were shown to be wholly attributable to variation in PV. Multiple linear regression indicated that the combination of AL and CR provided optimum R² values of 79.4% for TOV.

Conclusion Clinically useful estimations of ocular volume can be obtained from measurement of AL and CR.

INTRODUCTION

A recent comprehensive review of factors contributing to the aetiology of myopia included an analysis of the association between myopia and ocular disease.1 It was demonstrated that the risk of disease, traditionally linked to diopteric levels greater than 6D, was also significant between 1D and 3D, a level generally described as physiological myopia.2 Further, the review demonstrated that risk was not confined to myopia as hyperopia is associated with higher rates of exudative age-related maculopathy and angle closure glaucoma.3 Longitudinal axial length (AL) is the principal structural correlate for refractive error,3 4 and a recent cross-sectional study on 120 Hong Kong children used binary logistic regressions to demonstrate that after adjusting for myopia over −8D, age, gender, duration of myopia, family retinal history and intraocular pressure, an AL longer than 26.5 mm was a significant risk factor for peripheral retinal changes, optic nerve crescents and white-without-pressure.5

Ocular volume is more directly relevant than longitudinal AL to the structural and biomechanical integrity of the globe, particularly in myopia.6 If the eye is treated as a simple sphere, then a 12.8% increase in AL from 23.5 mm (typical for an emmetropic individual) to 26.5 mm (typical for a highly myopic individual) results in an increase in ocular volume of 43.4% (ie, from 6795 to 9744 mm³). A 6.4% decrease in AL to 22 mm (typical for a hyperopic individual) results in a decrease in volume of 17.9% (ie, from 6795 to 5575 mm³). A systematic analysis of in vivo measures of ocular volume and longitudinal AL has yet to be reported.

Ocular MRI has been used in ophthalmic research in areas such as accommodation7 8 and myopia.9 10 Our laboratory was the first to use 3D ocular MRI to report ocular volume in myometric and myopic eyes.9 10 The technique can also account for the differences between emmetropia and myopia in the shape of the posterior vitreous chamber.11 Our MRI studies to date have generated ocular volume data across a range of refractive error and the aim of the present study is to investigate the utility of generally available biometric measures in estimating ocular volume.

MATERIALS AND METHODS

The study was approved by the Aston University Research and Ethics Committee; all aspects of the investigation were carried out in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from all subjects.

Subjects

Sixty-seven adult subjects were recruited from the Aston University student and staff population. Subject age ranged from 18 to 40 years (mean age 26.20±6.24 years); the cohort comprised 23 males and 44 females of predominantly white European and South Asian ethnicities (54% white European; 40% South Asian; 3% African-Caribbean; 3% Chinese).

Refraction, AL, keratometry and anterior chamber depth measurements

Objective measurements of refractive error for both eyes were obtained under cycloplegia (one drop of tropicamide ophthalmic solution 0.5%, Minims Bausch and Lomb, Surrey, UK). An open-view binocular infrared autorefractor (Shin-Nippon SRW-5000, Ryusyo Industrial Co. Ltd, Osaka, Japan) was used to obtain five readings per eye and average refractive error expressed as mean spherical error (MSE, D).

Partial coherence interferometry (PCI) longitudinal AL measurements, central corneal radius (CR) and anterior chamber depth (ACD) were determined (mm) using the Zeiss IOLMaster (Carl Zeiss Meditec, Inc., Dublin, California, USA). AL was expressed as the mean of five measurements. Mean CR was expressed as the mean of the horizontal and vertical corneal radii following three
measurements, and a single capture automatically generated mean ACD based on five measurements.

Ocular volume

The MRI protocol, verification and repeatability statistics for the MRI technique employed in this study have been previously reported.9–11 Calculation of ocular volume followed the acquisition of T2-weighted MR images using a Siemens trio 3-T whole-body MR scanner (Siemens Medical Systems, Iselin, New Jersey, USA) with an eight-phase head coil (voxel dimensions 1.0×1.0×1.0 mm). Images were optimised to reveal the fluid-filled chambers of the eyes. An automatic voxel shading algorithm was applied, and if required, shading was subsequently edited manually following visual inspection of each MR slice in each of the axial, sagittal and coronal planes (approximately 25 slices per plane). The program provided a standard voxel count to calculate volume.9 10

With reference to the longitudinal visual axis, the anterior volume (AV) was defined as the region from the posterior corneal surface to the posterior pole of the lens; the posterior volume (PV) was defined as the region from the posterior pole of the lens to the retinal surface (vitreous–retinal interface). The approximate location of the posterior pole of the lens was taken to be the first MR coronal slice to fall wholly within the posterior vitreous chamber, that is, the slice that indicated the delineation of the non-fluid lens from the fluid vitreous. Shaded voxels were then removed for slices in the coronal plane between the posterior corneal surface and the posterior lens pole (ie, the AV); the remaining voxels were counted by the mri3dX program (developed by Professor Krish Singh, 2005) to generate PV in mm³. Subtracting the PV from the total ocular volume (TOV) gave values for the AV. Correlations were calculated between MSE, AL, CR, ACD and volume (PV, AV and TOV). All statistical analyses were undertaken using SPSS V21.0 (IBM, Illinois, USA).

RESULTS

A two-tailed paired Student’s t test for MSE, AL, CR, ACD, PV, AV and TOV showed no overall group difference between right and left eye data (all p>0.05). Right eye data are presented.

Mean data

MSE (D) mean -2.62±3.83 (range -10.56 to +4.38, see figure 1), mean AL (mm) 24.51±1.47 (range 21.72–28.12), mean CR (taken as the mean of the horizontal and vertical corneal radii) were (in mm) 7.75±0.28 (range 6.95–8.38) and mean ACD (in mm) 3.55±0.34 (range 2.23–4.39).

Mean TOV (mm³) was 8168.21±1141.86 (range 5036.00–11777.00); mean AV was 1099.40±139.24 (range 633.00–1422.00) and mean PV was 7068.82±1134.05 (range 4017.00–10646.00).

Pearson’s correlation coefficients

A more negative MSE was significantly correlated with a longer AL (p<0.001, R²=0.76), a steeper CR (p=0.002, R²=0.14) and a deeper ACD (p=0.046, R²=0.06). A greater TOV was also significantly correlated with a longer AL (p<0.001, R²=0.74), an increasingly negative MSE (p<0.001, R²=0.43),
a flatter mean CR (p=0.043, R²=0.06) and a deeper ACD (p=0.024, R²=0.08). Mean CR was not correlated with AL (p=0.91, R²=0.002), but a significant increase in ACD was noted with increasing AL (p=0.006, R²=0.11).

Anterior ocular volume (AV)
AV did not bear any significant correlation with MSE, AL (figures 2 and 3), CR, ACD, PV or TOV (all p>0.05)

Posterior ocular volume (PV)
An increase in PV significantly correlated with a longer AL (p<0.001, R²=0.76), an increase in negative MSE (p<0.001, R²=0.46), a larger TOV (p<0.001 R²=0.99) (figures 2 and 3) and a deeper ACD (p=0.030, R²=0.07), but the relationship with mean CR just failed to reach statistical significance (p=0.060, R²=0.06).

Regression analysis
Simple linear regressions showed that mean CR accounted for 6.2% of the variance in TOV (F=4.28, p=0.043); ACD for 7.6% (F=5.36, p=0.024), MSE for 42.6% (F=48.32, p<0.001) and AL for 73.8% of the variance in TOV (F=183.08, p<0.001).

A stepwise method of multiple regression was employed; AL and CR were automatically selected by SPSS as the predictors that created the best model of ocular volume prediction. AL alone contributed to 73.8% of the variance in TOV; mean CR contributed a further 5.6%; hence, both AL and mean CR could account for 79.4% of the variance in TOV.

Simple linear regressions showed that mean CR accounted for 5.3% of the variance in PV (F=3.67, p=0.060); ACD for 7% (F=4.91, p=0.030), MSE for 45.8% (F=55.03, p<0.001) and AL for 75.6% of the variance in PV (F=201.73, p<0.001).

Equations to determine ocular volume
From the multiple linear regression analysis, the following equation for TOV (in mm³) was derived; AL and mean CR are expressed in mm:

\[
\text{TOV} = -15.565.86 + (662.62\times AL) + (967.18\times \text{Mean CR})
\]

The robustness of the equation may be gauged from examining the difference between unadjusted and adjusted R² values, 0.794 and 0.788, respectively. The difference of 0.006 thus indicates that if the equation were derived from a larger population it would account for only 0.6% less variance.

From multiple linear regression analysis, the following equation for PV (in mm³) was derived; AL and mean CR are expressed in mm:

\[
\text{PV} = -16.155.62 + (666.41\times AL) + (889.41\times \text{Mean CR})
\]

The unadjusted R² for the PV multiple regression was 0.805 and the adjusted R²=0.798; that is, a difference of 0.007 (0.7%). The regression equations in table 1 may be used to calculate volumes in situations where only one biometric parameter may be available. Two-tailed significance p values are shown in brackets.

Table 1 Linear regression equations for both total ocular volume and posterior ocular volume based on axial length and mean spherical error (MSE)

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Posterior volume</th>
<th>Total volume</th>
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</thead>
<tbody>
<tr>
<td>Axial length (mm)</td>
<td>(y=668.70x-9319.50)</td>
<td>(y=665.11x-8132.00)</td>
</tr>
<tr>
<td>MSE (D)</td>
<td>(y=-200.65x+6543.98)</td>
<td>(y=-194.83x+7658.57)</td>
</tr>
<tr>
<td>Anterior chamber depth (mm)</td>
<td>(y=890.29x+3909.35)</td>
<td>(y=933.54x+4855.27)</td>
</tr>
<tr>
<td>Mean corneal radius (mm)</td>
<td>(y=937.17x-193.51)</td>
<td>(y=1014.66x+305.33)</td>
</tr>
</tbody>
</table>

**Clinical science**

**Figure 4** Total MRI volume (mm³) plotted as a function of axial length (AL) (mm) represented by the filled circles, and the equivalent volume of a sphere (mm³) also plotted as a function of AL, represented by the unfilled circles.

**DISCUSSION**

As expected, TOV increased with a longer AL. However, AV bore no significant relationship to either AL or to ametropia (expressed as MSE). Conversely, posterior eye volume showed a strong correlation with AL and MSE, supporting previous findings that an increase in posterior vitreous chamber depth is the main contributor to increased AL in myopia.

Whereas the correlation between linear measurements of AL and ACD was calculated solely from measurements made using the Zeiss IOLMaster, the correlation between AL and AV was calculated from a combination of PCI (AL) and volumetric data based on an MRI 1 mm³ voxel count (AV). The resolution of volumetric data will thus be significantly less than PCI data and less able therefore to reflect the significant correlation evident between AL and ACD.

Estimation of ocular volume from AL may facilitate further investigation of the effect of intravitreal injection of ophthalmic drugs on intraocular pressure (IOP). Several reports have suggested a link between AL, refractive error and IOP increase following injection, but others have found evidence to the contrary. Although injection volumes are generally small (of the order of 0.05 mL), a recent study on postmortem porcine globes demonstrated increases in IOP of approximately 15 mm Hg following 1 s 15 mL (0.015 mL) microinfusions of phosphate buffered saline. A clinical research application of this study could be, therefore, to examine whether ocular volume is a structural correlate for IOP change following intravitreal injections.

Using a similar subject group to the present study, Santodomingo et al demonstrated that AL determined using the Zeiss IOLMaster did not differ significantly from that determined by 10 MHz A-scan ultrasonography (Storz Omega Compu-Scan Biometric Ruler, Storz International, St Louis, Missouri, USA). Ultrasound measures of AL can therefore be used to estimate TOV and posterior ocular volume from Equations 1 and 2, respectively.

**Acknowledgements** We acknowledge Krish D Singh, Elizabeth Wilkinson, Jade Thai and Jon Wood for assistance with data collection. We thank Richard Armstrong and Chinyene Nzekwe-Excel for their advice on statistical analysis.

**Contributors** MN, BG and NSL contributed to the study design; the acquisition, analysis and interpretation of data, and were also involved with drafting of the manuscript.

**Funding** The College of Optometrists and The Lord Dowding Fund for Humane Research are acknowledged for funding support.

**Competing interests** None.

**Ethics approval** Aston University Research and Ethics Committee.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**REFERENCES**


**Table 2** Axial length (AL) values (mm) from 22 mm to 28 mm were inputted into the linear regression equations representing total MRI volume (mm³), and sphere formula volume (mm³) from figure 4.

<table>
<thead>
<tr>
<th>PCI AL</th>
<th>MRI regression volume</th>
<th>Sphere regression volume</th>
<th>Difference (MRI-sphere)</th>
<th>Percentage difference</th>
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<tr>
<td>22</td>
<td>6500.42</td>
<td>5360.34</td>
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<td>28</td>
<td>10 491.08</td>
<td>11 165.16</td>
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<td>–6.43</td>
</tr>
</tbody>
</table>

PCI, partial coherence interferometry.


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Br J Ophthalmol 2014 98: 1697-1701 originally published online July 1, 2014
doi: 10.1136/bjophthalmol-2013-304652

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