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Axial length, anterior chamber depth and lens thickness: Their intercorrelations in black South Africans

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Purpose: To determine means and ranges for axial length, anterior chamber depth, lens thickness values and their intercorrelations in an African population.

Methods: Six hundred participants (N = 600) were selected through stratified random cluster sampling from geographically contiguous areas of Durban, South Africa. All participants underwent height measurements and standard vision testing. Repeated measures of axial length, anterior chamber depth and lens thickness were taken with the Nidek US-500 Echoscan.

Results: Participants' ages ranged from 10 to 66 years with a mean age of 28.15 ± 13.09 years (95% confidence interval, 27.09–29.19). Of all the subjects, 295 (49.17%) were females and 305 (50.83%) were males. Axial length ranged from 20.42 mm to 27.28 mm with a mean of 23.05 mm ± 0.98 mm (95% confidence interval, 22.97–23.14), anterior chamber depth ranged from 2.38 mm to 4.13 mm with a mean of 3.21 mm ± 0.37 mm (95% confidence interval, 3.18–3.24) and crystalline lens thicknesses ranged from 2.24 mm to 4.66 mm with a mean of 3.69 mm ± 0.25 mm (95% confidence interval, 3.66–3.71). All three biometric indices were significantly higher in men than in women (all p-values < 0.05). A multivariate linear regression model indicated that axial length and anterior chamber depth decreased with age, while lens thickness increased with age. All biometric indices directly correlated with the male gender and height (all p-values < 0.001). Pearson correlation coefficient tests showed that axial length was significantly positively correlated with anterior chamber (r = 0.66, p < 0.001) and negatively correlated with lens thickness (r = -0.52, p < 0.001). A significant negative correlation was found between lens thickness and anterior chamber depth values (r = -0.68, p < 0.001).

Conclusion: Normative values for axial length, anterior chamber depth and lens thickness are determined for the first time in a black South African sample, aged 10–66 years. Age, gender and height were associated with biometric indices. While there was a positive correlation between axial length and anterior chamber depth, there was a negative correlation between lens thickness and both axial length and anterior chamber depth. These biometric data and their intercorrelations may provide some insights into the pathophysiological mechanisms of angle-closure glaucoma in this population.

Introduction

The ability to obtain accurate measurement of ocular biometric dimensions, such as axial length (AL), anterior chamber depth (ACD) and crystalline lens thickness (LT), is essential in many clinical and research applications. For example, AL is used clinically for intraocular lens (IOL) power calculation prior to cataract and refractive surgery[1] and to diagnose ocular conditions such as staphyloma[2] to evaluate the risk of retinal detachment,[3] as well as to measure the structural and dimensional components in myopia studies.[4] In addition, accurate ACD assessment is important in phakic intraocular lens (PIOL) calculation formulae and in patient selection,[5] diagnosis and management of eye conditions, such as acute or chronic primary angle-closure glaucoma,[6] keratoconus and lenticonus.[7] Furthermore, LT measurements have assumed importance in biometric studies of myopia and primary angle-closure glaucoma.[8]

Ocular biometric dimensions vary between races and ethnicities, and knowledge of their normal variations is essential to understand the pathogenesis, diagnosis and optimal management of ocular diseases.[9] For instance, Arkell et al.[10] and Wojciechowski et al.[11] demonstrated that Alaskan Eskimos had shallower ACD than Chinese, black people and white people, and thus Eskimos were particularly prone to angle-closure glaucoma. Furthermore, most data used for planning

eye care services are generated from Asian, European and American studies. These data cannot necessarily be extrapolated to South Africans as the population is culturally, ethnically and geographically diverse. Similarly, results from other African countries may not be readily comparable to results from present-day South Africa, which highlights the need for geographically and ethnically relevant studies to be conducted. This study was carried out to determine the average values of AL, ACD and LT and investigate their intercorrelations in a black South African sample with healthy eyes, as such data are not readily available.

Methods

The study was approved by the University of KwaZulu-Natal's Biomedical and Research Ethics Committee. Informed consent was obtained from each participant after the nature of the procedures had been explained to them. Research procedures adopted in this study followed the tenets of the Declaration of Helsinki. Participants were selected using a randomised, stratified, cluster sampling process from six districts of Durban, KwaZulu-Natal Province, South Africa. For logistical and operational reasons, sampling was restricted to districts within one hour's drive from the University of KwaZulu-Natal's Eye Clinic (where clinical examinations were performed). Following approval of the study protocol, two fieldworkers assisted in recruiting study participants. The fieldworkers approached the subjects in their houses and informed them of the study purpose, the procedures involved and their role as participants. Those who agreed to participate in the study were transported by one fieldworker to the University of KwaZulu-Natal Optometry Clinic for examination, while the other fieldworker moved to the next selected site.

Height was measured with a tape measure with the subject standing up without shoes and recorded in centimetres (cm). Each participant underwent non-cycloplegic autorefraction (with the Nidek AR-310A) and a full ophthalmic examination including slit-lamp biomicroscopy, intraocular pressure measurement, fundus examination and subjective refraction, which was defined as spherical equivalent (SE, sphere power + cylinder power/2). All participants that satisfied the criteria below were included in: best spectacle corrected distance Snellen acuity of 6/6 or better, no opacity of the media, no amblyopia or any ocular disease or any previous ocular surgery, and intraocular pressure lower than 21 mmHg. After instilling anaesthetic drops (proparacaine) on the cornea of each participant, AL, ACD and LT were measured with the Nidek US-500 Echoscan (Nidek, Japan). Details on how the Nidek US-500 works, its repeatability and reproducibility have been discussed in a previous study.[12] Three measurements for each variable were obtained per eye and then averaged (after ophthalmic examination and refraction). The Echoscan generates ocular biometry values of AL, ACD and LT, and acquisitions were done by one skilled operator.

Statistical analysis

Data were analysed using STATA, version 11.0, with the distributions of ocular biometry (AL, ACD and LT) being tested for normality with the Kolmogorov–Smirnov tests. Each ocular biometry index was described with the mean and its 95% confidence interval (CI) by age and gender, and the 25th, 50th and 75th percentiles were determined to demonstrate the distribution of these variables in more detail. Paired sample *t*-tests were used to analyse the differences between biometric values of the left and right eyes as well as to compare the mean ages of the participants. Independent sample *t*-tests were used to analyse any differences between the values obtained from male and female eyes. Univariate linear and multivariate regression models were constructed to establish the relationship of ocular biometric parameters with age, gender and height after adjusting variables. Pearson correlation coefficients and scatter plots were used to demonstrate intercorrelations between biometric variables (i.e. axial length and ACD, axial length and lens thickness, and ACD and lens thickness). Associations between age and biometric parameters were also assessed using Pearson correlations and scatter plots. Significance was set at the 95% CI ($p \leq 0.05$).

Results

A total of 600 ($N = 600$) participants were included in the study. Their ages ranged from 10 to 66 years, with a mean age of 28.15 ± 13.09 years (95% CI, 27.09–29.19 years). Of the participants, 295 (49.17%) were females and 305 (50.83%) were males. As there was no statistically significant difference ($p > 0.05$) in ocular biometric values between the left and right eyes, only the results from right eyes are presented here. The mean AL, ACD and LT were 23.05 mm ± 0.98 mm (range = 22.97–23.14), 3.21 mm ± 0.37 mm (range = 3.18 mm – 3.24 mm) and 3.69 mm ± 0.25 mm (range = 3.66–3.71), respectively. Details of mean and 95% CI of mean AL, ACD and LT by age and gender, 25th, 50th and 75th percentiles as well as the normal distribution indices (skewness and kurtosis) of these variables are shown in Tables 1 and 2, respectively. The results of the Kolmogorov–Smirnov tests indicated that all the biometric indices were normally distributed ($p > 0.05$) (Table 2). Significant differences were observed in the AL, ACD and LT values ($p < 0.05$) in the younger (10–39 years) and older (40 years +) age groups. On average, males in the sample were taller than females. In addition, males had higher mean AL, ACD and LT values than their female counterparts ($p < 0.05$).

Univariate regression analysis was run separately for each independent variable. For example, the change in axial length (dependent or outcome variable) was regressed against age, gender and height (independent or predictor variables). In univariate analysis, AL and ACD increased, while LT decreased with age (Table 3, Figure 1). AL, ACD and LT were significantly positively correlated with gender and height (Table 3).

TABLE 1: Means and 95% confidence intervals of axial length, anterior chamber depth and lens thicknesses. Age and gender are also included in the table distributions.

	Gender		AL (mm)		ACD (mm)		LT (mm)	
Age (years)	Male	Female	Mean	95%CI	Mean	95%CI	Mean	95%CI
10–19	90	95	23.13	23.08–23.32	3.35	3.34–3.40	3.45	3.44–3.49
20–29	100	77	23.39	23.27–23.53	3.35	3.31–3.38	3.55	3.44–3.49
30–39	57	60	23.38	23.23–23.55	3.34	3.28–3.36	3.71	3.68–3.76
40–49	38	33	21.89	21.98–22.44	2.70	2.69–2.75	4.17	4.12–4.18
50–59	20	24	21.17	21.24–21.69	2.59	2.56–2.64	4.38	4.12–4.18
60+	0	6	23.08	22.73–23.88	2.44	2.31–2.67	4.42	3.50–4.78
Total	**305**	**295**	**23.05**	**22.97–23.14**	**3.21**	**3.18–3.24**	**3.69**	**3.66–3.71**

AL, axial length; ACD, anterior chamber depth; LT, lens thickness.

TABLE 2: The percentiles, range, skewness and kurtosis of axial length, anterior chamber depth and lens thickness in this study.

	Percentiles			Ranges		Normal distribution indexes	
Parameter	25%	50%	75%	Min	Max	Skewness	Kurtosis
AL (mm)	22.43	23.05	23.76	20.42	27.28	0.00	0.07
ACD (mm)	3.01	3.21	3.44	2.38	4.13	0.00	0.00
LT (mm)	3.43	3.69	3.93	2.24	4.66	0.00	0.59

AL, axial length; ACD, anterior chamber depth; LT, lens thickness.

TABLE 3: The association of axial length, anterior chamber depth and lens thickness with age and gender according to univariate linear regression.

Ocular biometry variable	Associated factor	Coefficient	95% CI	*p*
AL (mm)	Age (years)	-0.01	-0.01 to 0.00	< 0.001
	Gender (male/female)	0.33	0.33 to 0.48	< 0.001
	Height (cm)	0.03	0.02 to 0.03	< 0.001
ACD (mm)	Age (years)	-0.01	-0.02 to -0.01	< 0.001
	Gender (male/female)	0.07	0.04 to 0.09	< 0.001
	Height (cm)	0.01	0.01 to -0.01	< 0.001
LT (mm)	Age (years)	0.02	0.01 to 0.02	< 0.001
	Gender (male/female)	0.03	0.03 to 0.05	< 0.001
	Height (cm)	0.03	0.02 to 0.03	< 0.001

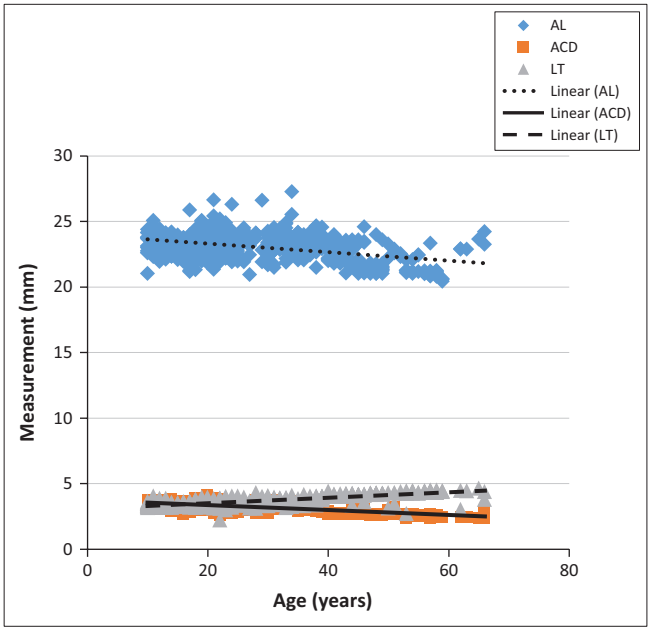
AL, axial length; ACD, anterior chamber depth; LT, lens thickness; CI, confidence interval.

TABLE 4: The association of axial length, anterior chamber depth and lens thickness with age and gender in multivariate linear regression.

Ocular biometry variable	Associated factor	Coefficient	95% CI of coefficient	*p*
AL (mm)	Age (years)	-0.01	-0.01 to 0.00	< 0.001
	Gender (male/female)	0.23	0.09 to 0.28	0.002
	Height (cm)	0.02	0.02 to 0.03	< 0.001
ACD (mm)	Age (years)	-0.01	-0.01 to -0.01	< 0.001
	Gender (male/female)	0.02	0.01 to 0.05	0.005
	Height (cm)	0.00	0.00 to 0.01	< 0.001
LT (mm)	Age (years)	0.01	0.01 to 0.01	< 0.001
	Gender (male/female)	0.02	0.02 to 0.04	< 0.001
	Height (cm)	0.02	0.02 to -0.02	< 0.001

AL, axial length; ACD, anterior chamber depth; LT, lens thickness; CI, confidence interval.

For multivariate analysis, the regression (mean change in the dependent variable for each unit of change in the independent variables of age, gender and height) was calculated. The multivariate nature of the analysis resulted from all of the independent variables being entered into the regression analysis. This provided statistics (coefficients and CIs) for each of the independent variables while adjusting for the effect of the other independent variables (the regression of age and axial length is adjusted for the effects of gender and height; the regression of gender and axial length is adjusted for the effects of age and height). According to the multivariate model, AL decreased with age (0.01 mm per year of ageing)



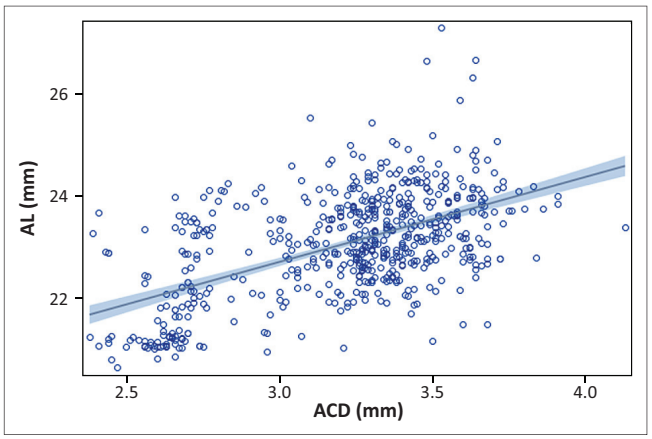
The blue diamond shapes represents the scatter plot for axial length and age; the dotted black line indicates the linear regression line of axial length with age. The regression line indicates axial length = 23.97 – 0.01Age. The orange squares show the scatter plot for anterior chamber depth and age with the corresponding linear regression line indicated by the solid black line. The regression line is: anterior chamber depth = 3.74 – 0.01 Age. The grey triangular shapes are for the scatter plot of lens thickness and age; the dashed black line is the linear regression of lens thickness with age. The regression line indicates lens thickness = 2.38 + 0.02Age.

AL, axial length; ACD, anterior chamber depth; LT, lens thickness.

FIGURE 1: Scatter plots and linear regression analysis showing the correlation between age (*x*-axis) and biometric parameters (axial length, anterior chamber depth and lens thickness) in the *y*-axis measured with the Nidek US-500 Echoscan.

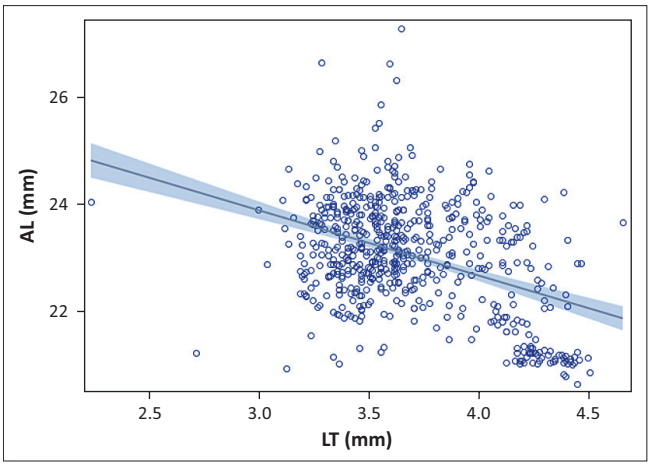
and directly correlated with the male gender and height (Table 4). If the equation of the regression line of the univariate analysis is used (AL = 23.97 – 0.01Age), one would expect a similar loss of about 0.01 mm in AL for each year of life, starting at a mean AL of 23.97 mm at 10 years of age. Similarly, ACD decreased by 0.01 mm per year of ageing, and directly correlated with the male gender and height. LT increased by 0.01 mm per year of ageing, was 0.02 mm thicker in males compared to females and showed a statistically significant increase with height (Table 4).

Pearson correlation coefficients showed that eyes with longer axial lengths tended to have deeper ACDs (r = 0.66, p < 0.001, Figure 2) and shorter lens thickness (r = -0.52, p < 0.001, Figure 3). Lens thickness was significantly negatively correlated with ACD (r = -0.68, p < 0.001, Figure 4). The 95% CIs are narrow in the three graphs because of the relatively large sample size (N = 600).



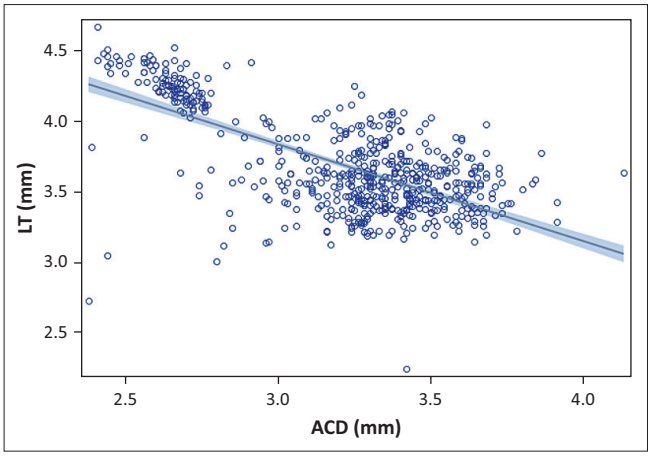
The regression line is axial length = 17.68 + 1.67 (anterior chamber depth).
AL, axial length; ACD, anterior chamber depth.

FIGURE 2: Scatter plot showing the correlation (and 95% confidence interval of the regression line) between the axial length and anterior chamber depth (R^2 = 0.306, r = 0.66, p = 0.000).



The regression line shows axial length = 27.63 – 1.24 (lens thickness).
AL, axial length; LT, lens thickness.

FIGURE 3: Scatter plot showing the relationship of axial length and lens thickness with 95% confidence interval of the regression line (R^2 = 0.17, r = -0.52, p = 0.000).



The regression line shows lens thickness = 5.65 – 0.66 (anterior chamber depth).
LT, lens thickness; ACD, anterior chamber depth.

FIGURE 4: Scatter plot showing the relationship of lens thickness and anterior chamber depth with 95% confidence interval of the regression line (R^2 = 0.46, r = -0.68, p = 0.000).

Discussion

Irrespective of ethnicity, there is a general paucity of information on the ocular biometry of the eyeballs of South Africans. Biometric data of the ocular dimensions are important because they provide insights into the pathophysiology of common ocular diseases, such as angle-closure glaucoma.[13] This, the first report on ocular AL, ACD and LT values in healthy black South Africans, provides an opportunity to compare data with other race and ethnic groups from a number of countries. Table 5 provides an overview of ocular biometric data in selected studies[14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35] among individuals of different ages, races and ethnicities compared with findings from our study.

The average AL of a newborn child is approximately 16 mm –18 mm in diameter and elongates to a range of 24 mm – 25 mm in normal adults.[36] In our study, the average AL of black South Africans was 23.05 mm, which is close to that reported in African and other ethnicities on different continents (Table 5). Iyamu et al.[16] found a mean AL of 23.50 mm in 95 Nigerian adults aged 20–69 years. However, the average AL value in our study is higher than that reported by Ogbeide and Omoti[17] and Nangia et al.[21] These differences could be because of the diverse age groups in the study samples. For instance, Ogbeide and Omoti[17] included participants aged 3–92 years, while the age range of participants in Nangia et al.'s study[21] was 30–100 years and ours was 10–66 years. The older age groups in the first two of these studies could have caused a decrease in the overall mean AL, a conclusion that supports the concept that AL decreases with age.[36] Overall, we found that AL decreased by 0.01 mm for every year of ageing (Table 4), and this was consistent with studies[18,25] that reported a decrease in AL with higher age. In contrast to our study, however, Yin et al.[19] and Nangia et al.[21] reported that AL increased with increasing age. The reasons for the discrepancies could be because of the inclusion of diverse age and racial groups in their study samples. For our sample, on average, males had longer ALs than females, which could be because of them being taller with the influence of anatomical differences, such as height on AL, having been reported in other studies.[21,22]

Mean ACD in this study was 3.21 mm, which compares well with that of American Latinos and Mexicans but is higher than that reported in Asians (Table 5). Risk factors for open-angle glaucoma include increased age and African or Latino ethnicity.[10,11] The shallow ACD in Asians may help explain their increased risk to angle-closure glaucoma.[10,11] Using the regression coefficients of the multivariate analysis (Table 4), the mean ACD decreased by 0.01 mm per year of ageing. Previous investigations[18,36] also found that ACD decreased with age, which could partly be because of the thickening of the crystalline lens over time.[37] The reduction in size of the AL may also contribute to the shallowness of the ACD in old age and in angle-closure glaucoma.[38] Deeper ACD was found in men

TABLE 5: Axial length, anterior chamber depth and lens thickness reported in subjects of different races and ethnicities as compared with findings of our study (third row below).

Study	Nationality	Instrument used	Number	Age (years)	AL (mm)	ACD (mm)	LT (mm)
Africa							
Mashige and Oduntan (2016)	Black South Africans	Nidek Echoscan	600	10–66	23.05	3.21	3.69
Albashir and Saleem[14]	Sudanese	A-scan ultrasonography	1000	18–105	23.09	NR	NR
Abdelaziz and Mousa[15]	Egyptians	IOL Master/Ultrasound	39	43–75	23.7	NR	NR
Iyamu et al.[16]	Nigerians	A-scan ultrasonography	95	20–69	23.5	NR	NR
Ogbeide and Omoti[17]	Nigerians	Ultrasound	200	3–92	21.07	NR	NR
Asia							
Hashemi et al.[18]	Iranians	LENSTAR/BioGraph	4869	40–64	23.14	2.62	4.28
Yin et al.[19]	Chinese	Optical low-coherence reflectometer	3159	50–93	23.25	NR	NR
Pan et al.[20]	Singaporean Indians	Partial coherence interferometry	2765	40–83	23.45	3.15	NR
Nangia et al.[21]	Indians	Ultrasonography	4698	30–100	22.6	NR	NR
Lim et al.[22]	Asians	Partial laser interferometry	2788	40–80	23.55	3.1	NR
He et al.[23]	Chinese	A-mode ultrasound	1269	50–93	23.11	2.67	4.44
Mallen et al.[24]	Jordanians	A-scan ultrasound	1093	17–40	23.13	3.19	3.85
Wong et al.[25]	Chinese	A-mode ultrasound	951	40–81	23.23	2.9	4.75
Osuobeni[26]	Saudi Arabians	Ultrasound	152	16–50	23.48	3.2	3.72
Americas							
Shufelt et al.[27]	American Latinos	A-scan ultrasound	5588	40+	23.38	3.41	4.38
Velez-Montoya[28]	Mexicans	A-mode ultrasound	70	54.71 ±22.33	23.33	3.25	4.52
Oceania/Australia							
Fotedar et al.[29]	Australians	IOL Master	723	59+	23.44	3.1	NR
Ip et al.[30]	Australians	IOL Master	2353	15-Nov	23.38	NR	NR
Ip et al.[31]	Australians	IOL Master	1765	6	22.61	NR	NR
Europe							
Heim et al.[32]	Norwegians	Partial coherence laser interferometry	41	43–50	23.5	NR	NR
Nagra et al.[33]	Britons	IOL Master	67	NR	24.51	3.55	NR
Olsen et al.[34]	Danish	Ultrasound	725	55+	23.74 RE	3.20 RE	4.68 RE
					23.20 LE	3.08 LE	4.65 LE
Biino et al.[35]	Italians	Optical biometry	741	5–89	23.57 RE	3.45 RE	NR
					23.51 LE	3.48 LE	

Note: Please see the full reference list of the article, Mashige KP, Oduntan OA. Axial length, anterior chamber depth and lens thickness: Their intercorrelations in black South Africans. Afr Vision Eye Health. 2017;76(1), a362. https://doi.org/10.4102/aveh.v76i1.362

AL, axial length; ACD, anterior chamber depth; LT, lens thickness; NR, not reported; RE, right eye; LE, left eye.

and persons who were tall (Table 4), which is consistent with a previous report.[18] These associations suggest that females and short black South Africans may have a higher risk of developing primary angle-closure glaucoma, a suggestion that agrees with previous reports,[39,40] in which the prevalence of primary angle-closure glaucoma was associated with shorter body stature and females.

Lens thicknesses in this study were generally lower than those reported in other studies (Table 5), possibly because of only a few participants being in the older age range in our sample. Lens thickness increased by 0.01 mm per year of ageing. As stated earlier, growth of the lens with ageing may lead to a shallowing of the ACD and can be of significance for some cases of primary angle-closure glaucoma. Hashemi et al.[18] suggested that the increase in LT with age may be because of the increase in protein fibre layers forming under the capsule. We found that men had thicker crystalline lenses than women, which contradicts the results of He et al.,[23] which found that lens thickness tended to be greater in women. Reasons for this discrepancy between the studies remain unclear. It cannot be explained by the fact that a thicker lens is associated with myopic refractive error because women in the study of He et al.[23] tended to be slightly more hyperopic.

Axial length was positively correlated with ACD and negatively correlated with LT (Figures 2 and 3). These findings suggest that smaller eyes will tend to have smaller ACD but thicker lenses, while longer eyes will tend to have larger ACD but thinner lenses. These findings are similar to those reported in other studies[26,34] and have important implications for the genesis of primary angle-closure glaucoma, as shallow ACD and increased LT are all important risk factors for this condition.[26] Mei et al.[8] suggested that these correlations were the main determinants of ACD, a major predisposing factor for developing primary angle-closure glaucoma. A strong negative correlation between crystalline ACD and LT found in this study (Figure 4) is consistent with previous reports.[8,26,41] Hashemi et al.[41] suggested that 'since part of the lens is in the anterior chamber, thinning of the lens is expected to result in increased anterior chamber depth'.

Potential limitations of our study include the omission of analysis of the association between refractive error and biometric measures. We also included only a few subjects older than 60 years because of their higher risk of ocular pathological conditions.

Conclusion

This study provides data on the distribution of AL, ACD and LT among healthy black South Africans. While mean AL and ACD values compare well with those of other races and ethnicities, LT values were generally lower. The results also support the existing views on associations between studied biometric indices with age, gender and height. Through comparison of our data with those from other studies, we suggest that older, female and shorter black South African subjects may have a higher risk of developing angle-closure glaucoma.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

Both authors (K.P.M. and O.A.O.) made equal contributions in writing this article.

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