Anterior Chamber Dimensions and Posterior Corneal Arc Length in Malay Eyes: An Anterior Segment Optical Coherence Tomography Study

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Purpose. We provided normative data of corneal and anterior segment dimensions, and a novel parameter, posterior corneal arc length (PCAL), in an adult Malay population.

Methods. The current analysis is a substudy of the Singapore Malay Eye Study (SiMES), a population-based, cross-sectional study of urban Malay adults aged 40 to 80. Subjects underwent ophthalmic and systemic examination, including imaging with anterior segment optical coherence tomography (AS-OCT). Ocular parameters subsequently were measured with the Zhongshan Assessment Program (ZAP), and included anterior chamber depth (ACD), central corneal thickness (CCT), anterior and posterior corneal curvature (ACC and PCC, respectively), and PCAL, which is a novel parameter defined as the arc-distance of the posterior corneal border between the scleral spurs. Age- and sex-adjusted analyses, and multivariate analyses were performed to determine correlations of PCAL with other ocular and systemic components.

Results. We studied 237 subjects, among whom the mean age was 56.6 ± 10.4 years and 50.2% were women. Ocular parameters (mean ± SD) included central ACD 2.78 ± 0.34 mm, CCT 550.23 ± 37.12 mm, ACC 7.43 ± 0.37 mm, PCC 6.75 ± 0.37 mm, and PCAL 13.95 ± 0.51 mm. There was moderate correlation between PCAL and ACD ($r = 0.476$, $P < 0.001$), but poor correlation with PCC ($r = 0.243$, $P < 0.001$), ACC ($r = 0.251$, $P < 0.001$), and systemic parameters, like age, body mass index (BMI), blood pressure, blood glucose levels, hemoglobin A1c (HbA1c), and refractive parameters. Multivariate analysis showed a significant association between PCAL and ACD ($P < 0.001$), PCC ($P < 0.001$), and height ($P < 0.05$).

Conclusions. Our study, to our knowledge, provides the largest baseline anterior segment parameters in an adult Asian Malay population. PCAL correlated moderately with ACD. These data are applicable clinically for assessment and surgical management of patients requiring anterior segment or corneal surgery. (*Invest Ophthalmol Vis Sci.* 2012;53:4860–4867) DOI: 10.1167/iovs.12-9787

Asia is the world's largest and most populous continent, and with approximately 4 billion people, it hosts more than half of the world's population.[1] Ocular biometric parameters are known to vary considerably across racial groups and populations.[2,3] There have been several large population-based studies of eye diseases in Asia, but largely concentrating on Chinese and Indian populations.[4] In contrast, there is little epidemiologic data on the other ethnic groups, particularly Malays, which comprise a substantial proportion of Asians. There are approximately 200 million people of Malay ethnicity living in Malaysia, Singapore, Indonesia, and other Southeast Asian countries. One major population-based survey has been done in rural villages in Central Sumatra, Indonesia, which provided some initial data on visual impairment and blindness, refractive errors, and cataract in Indonesians.[5,6] However, to our knowledge, no population-based study has provided normative ocular biometric parameters and their associations in Malay adults.

Anterior segment optical coherence tomography (AS-OCT) has allowed a noninvasive and noncontact method of rapidly imaging the anterior segment.[7–9] It permits imaging of the entire cross-section of the anterior segment in one image frame, which includes the entire cornea, both angles on one meridian including the scleral spurs, the anterior portion of the lens, and the iris surface. It has been shown to be highly reproducible in terms of repeatable image acquisition, and has excellent inter-observer and intra-observer variability.[10] However, quantification of anterior segment parameters is cumbersome as the built-in software offers limited amount of measurable parameters. It requires subjective user input, which also may compromise measurement reproducibility.[11,12]

The Zhongshan Assessment Program (ZAP) is a novel image analysis method and software for anterior chamber images obtained by the AS-OCT images. It offers a simple and straightforward quantification of anterior segment anatomy with high inter- and intra-observer agreement and repeatability.[11,13–15] Most programs used in quantification of anterior segment anatomy require user identification of the anterior chamber, and conditioning of the image's noise and contrast.[12] Inter-observer reproducibility for the measured parameters varies considerably as it is affected by subjective interpretation of visualized anatomic landmarks. In the ZAP, its preprocessing algorithm requires no user input, and conditions the images by progressively tailoring contrast thresholds and noise filters until a good pixel intensity distribution is achieved. Its image analysis then requires only the manual indication of the two scleral spurs.[14] A novel parameter that is measured and

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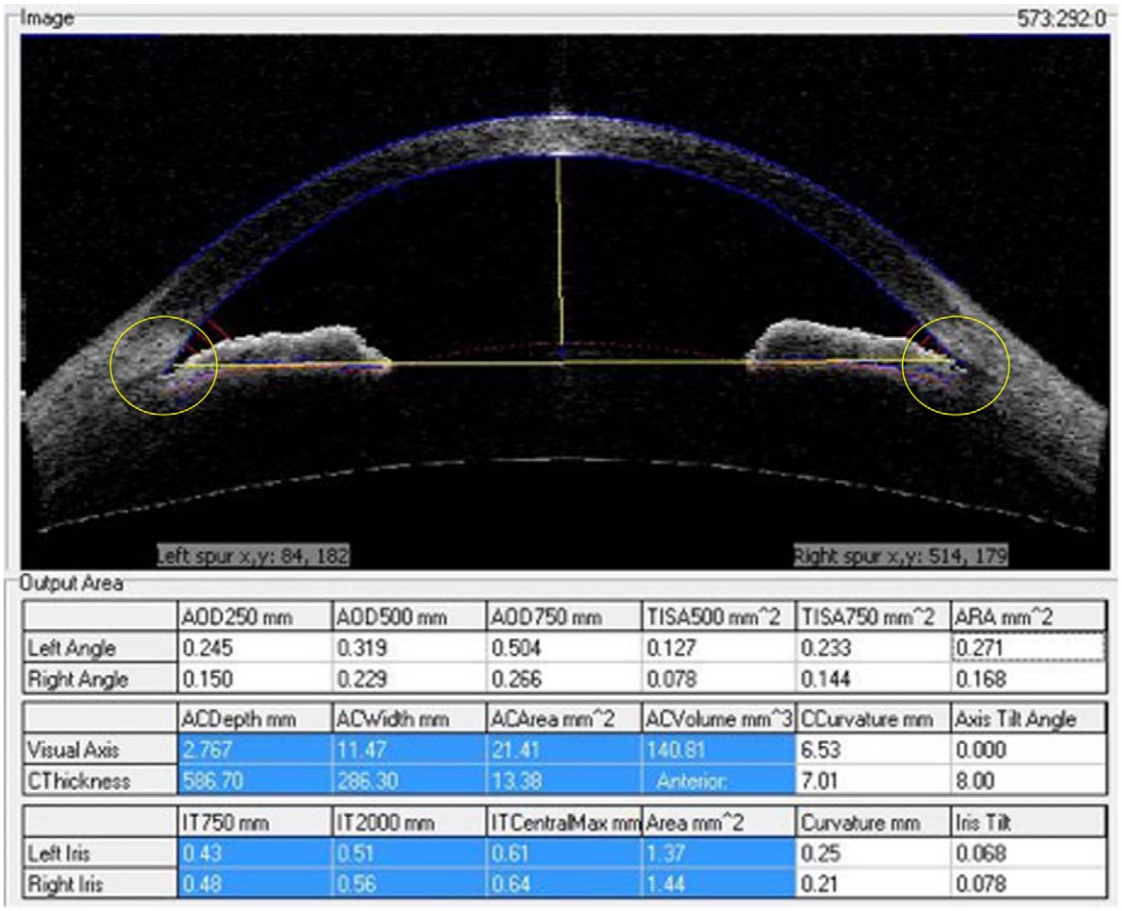

	AOD250 mm	AOD500 mm	AOD750 mm	TISA500 mm^2	TISA750 mm^2	ARA mm^2
Left Angle	0.245	0.319	0.504	0.127	0.233	0.271
Right Angle	0.150	0.229	0.266	0.078	0.144	0.168

	ACDepth mm	ACWidth mm	ACArea mm^2	ACVolume mm^3	CCurvature mm	Axis Tilt Angle
Visual Axis	2.767	11.47	21.41	140.81	6.53	0.000
CThickness	586.70	286.30	13.38	Anterior:	7.01	8.00

	IT750 mm	IT2000 mm	ITCentralMax mm	Area mm^2	Curvature mm	Iris Tilt
Left Iris	0.43	0.51	0.61	1.37	0.25	0.068
Right Iris	0.48	0.56	0.64	1.44	0.21	0.078

Figure 1. Appearance of the ZAP software using AS-OCT images; the 2 scleral spurs are identified and marked (*circled*).

evaluated in our study is the posterior corneal arc length (PCAL), defined as the arc distance of the posterior corneal border between the scleral spurs.[13] Accurate data on the shape of the posterior surface of the cornea has been limited previously.[16]

The purpose of our study was to describe the distribution and systemic determinants of ocular biometric parameters in an adult Asian Malay population residing in Singapore, and to document for the first time, PCAL data in this population, which may be a predictive parameter for anterior chamber surgery. The information from our study will form baseline normative data in this population group.

Methods

Study Population

The current analysis is a substudy of the Singapore Malay Eye Study (SiMES), a population-based, cross-sectional study of urban Malay adults aged 40 to 80 years residing in Singapore, that was conducted between August 2004 and June 2006. Using the criteria set by the Singapore Census to define "Malay" in the study, the definition included all persons of Malay or Indonesian origin (e.g., Javanese, Boyanese, and Bugis). The study methods have been described previously.[17] In brief, an age-stratified random sampling procedure was used to select Malay subjects from a national database. In total, 3280 individuals participated in the study (overall response rate 78.7% from 4168 eligible patients. For the substudy, AS-OCT was performed in 290 consecutive subjects attending the SiMES between September 12 and November 25, 2005.[18] This study was conducted in accordance with the tenets of the Declaration of Helsinki, as revised in 1989. Written informed consent was obtained from all subjects, and ethics approval was obtained from the Institutional Review Board of the Singapore Eye Research Institute.

Imaging

AS-OCT (Visante; Carl Zeiss Meditec, Dublin, CA) was used. Details of the AS-OCT imaging technology have been described previously.[12] Briefly, an infrared light of 1310 nm wavelength was used to obtain high-resolution, cross-sectional tomographic images of the anterior segment structures. The image was composed horizontally of 256 A-scans in 16 mm with 1024 points per A-scan in 8 mm of depth. Each image has a maximum transverse and axial resolution of 60 and 18 μm, respectively. Scanning at 2000 axial scans per second, the machine needs approximately an eighth of a second to scan an eye. Images were taken directly from the machine's output function as 816 × 636 pixel JPEG (lossless compression) files. The images were performed under standardized conditions of light (20 lux), and the scans were centered on the pupil and taken along the horizontal axis (nasal-temporal angles at 0–180 degrees) to maximize visibility of anatomic location and repeatability. Only consecutive images of only the right eye were used to reduce bias.

Image Processing

To obtain the best quality image, all AS-OCT images were processed with inbuilt software that adjusts for distortions arising from corneal optical properties. The images then were assessed by a single observer (WC) masked to the clinical data, whose only observer input was to determine the location of the 2 scleral spurs, defined as the anatomic

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junction between the inner wall of the trabecular meshwork and the sclera. In our study, it was defined as a change in curvature of the inner surface of the angle wall, often appearing as an inward protrusion of the sclera.

The ZAP (Zhongshan Angle Analysis Program, Guangzhou, China) software automatically extracted the 300 × 600 8-bit grey scale (intensities from 0–255) image portion of the output file, and performed noise and contrast conditioning.[11] A binary copy of the image then was produced whereby pixels were either 1′s (tissue) or 0′s (open space) depending on whether they were brighter or darker than a calculated threshold value. Algorithms defined the borders of the corneal epithelium and endothelium, and the anterior surface of the iris. These algorithms used basic edge arguments (five consecutive 0′s above five consecutive 1′s indicated an anterior surface point) to describe the borders. The corneal borders were fitted with polynomic curves, and to maintain the integrity of the corneal endothelium's original contour, fitted curves were used only for derivative data and border estimation in areas of poor border contrast. A line-smoothing algorithm that was defined explicitly by the edge-finding algorithms used the derivative data to repair step-like portions of the border.[11] Anatomic distances were calculated for anterior segment and corneal parameters, which included anterior chamber depth (ACD), central corneal thickness (CCT), anterior and posterior corneal curvatures (ACC and PCC, respectively), and PCAL (Fig. 1).

Assessment of Covariates

Participants underwent a standardized interview and examination.[17] Height was measured in centimeters using a wall-mounted measuring tape; weight was measured in kilograms using a digital scale (SECA, model 782 2,321,009; Vogel & Halke, Hamburg, Germany). Both measurements were performed on participants without shoes and excess clothing. Systolic and diastolic blood pressures (BP) were measured with a digital automatic blood pressure monitor (Dinamap model Pro Series DP110X-RW, 100V2; GE Medical Systems Information Technologies, Inc., El Paso, TX). Final refraction was determined by subjective refraction by trained and certified study optometrists. Intraocular pressure (IOP) was measured by using a Goldmann applanation tonometer (Haag-Streit, Koniz, Switzerland). Venous blood sample was collected to determine hemoglobin A1c (HbA1c) and random glucose. A detailed interviewer-administered questionnaire was administered to collect relevant socio-demographic and medical information.

Statistical Analysis

Statistical analysis was performed using SPSS (version 16; SPSS, Inc., Chicago, IL). ANOVA was conducted to evaluate the variation in different biometric components. A linear test for trend was used to investigate significance. Pearson's correlation and linear regression were used to assess factors relating to PCAL. Age- and sex-adjusted measurements were performed to determine associations of PCAL with other ocular biometric components, and with systemic and refractive components. Significant independent variables in the initial age- and sex-adjusted models were selected to be included in the multivariate models for respective outcomes. Where the variables were related closely to each other (e.g., ACC with PCC and systolic BP with diastolic BP), only the most significant one was included. Age- and sex-adjusted analyses also were performed for the other ocular biometric components with systemic and refractive components. $P < 0.05$ was considered statistically significant.

Results

A total of 290 AS-OCT images was available for analysis, of which 53 were excluded either because the scleral spurs were not clearly visible on AS-OCT images or the patients were pseudophakic. A total of 237 (81.7%) subjects was included in the study. The mean age of the patients was 56.6 ± 10.4 years and 119 (50.2%) were women.

Table 1 shows the demographics of the patients' ocular parameters, stratified by age group and sex. The mean ± SD for PCAL was 13.95 ± 0.51 mm, ACD 2.78 ± 0.34 mm, CCT 550.23 ± 37.12 μm, ACC 7.43 ± 0.37 mm, and PCC 6.75 ± 0.37 mm. Mean ACD and PCC were statistically different between the male and female subjects. ACD varied significantly with age for the population as a whole ($P < 0.001$) as well as for the men ($P = 0.001$) and women ($P = 0.003$). CCT also

Table 1. Measured Ocular Parameters, Stratified by Age and Sex

			ACD (mm)		CCT (μm)		PCC (mm)		ACC (mm)		PCAL (mm)	
		N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All persons	All ages	237	2.78	0.34	550.23	37.12	6.75	0.37	7.43	0.37	13.95	0.51
	40–49	66	2.93	0.27	558.16	35.44	6.75	0.33	7.49	0.44	13.96	0.53
	50–59	86	2.78	0.32	551.93	36.65	6.79	0.35	7.45	0.31	13.99	0.54
	60–69	48	2.64	0.33	546.04	37.75	6.73	0.46	7.35	0.36	13.94	0.51
	70–80	37	2.68	0.39	537.59	37.69	6.68	0.33	7.39	0.35	13.88	0.38
	P for trend		**<0.001**		**0.005**		0.218		0.099		0.396	
	P value*		**<0.001**		0.930		**0.009**		0.116		0.065	
Men	All ages	118	2.87	0.31	550.45	34.09	6.81	0.38	7.47	0.33	14.02	0.50
	40–49	38	3.01	0.21	555.69	30.96	6.77	0.35	7.50	0.38	14.01	0.49
	50–59	37	2.83	0.27	552.90	34.87	6.79	0.27	7.46	0.26	14.01	0.52
	60–69	24	2.80	0.27	552.23	34.19	6.92	0.53	7.37	0.35	14.11	0.56
	70–80	19	2.74	0.46	532.93	35.50	6.80	0.35	7.54	0.27	13.93	0.42
	P for trend		**0.001**		**0.022**		0.493		0.902		0.76	
Women	All ages	119	2.69	0.34	550.02	40.03	6.69	0.35	7.39	0.40	13.89	0.51
	40–49	28	2.83	0.29	561.51	41.11	6.73	0.30	7.48	0.51	13.90	0.58
	50–59	49	2.75	0.35	551.19	38.28	6.80	0.39	7.44	0.34	13.97	0.57
	60–69	24	2.49	0.32	539.86	40.78	6.53	0.26	7.33	0.38	13.78	0.40
	70–80	18	2.61	0.30	542.51	40.30	6.55	0.27	7.24	0.36	13.83	0.33
	P for trend		**0.003**		0.070		**0.011**		**0.029**		0.425	

Bold values represent values that are statistically significant.

* *P* value for differences between sex.

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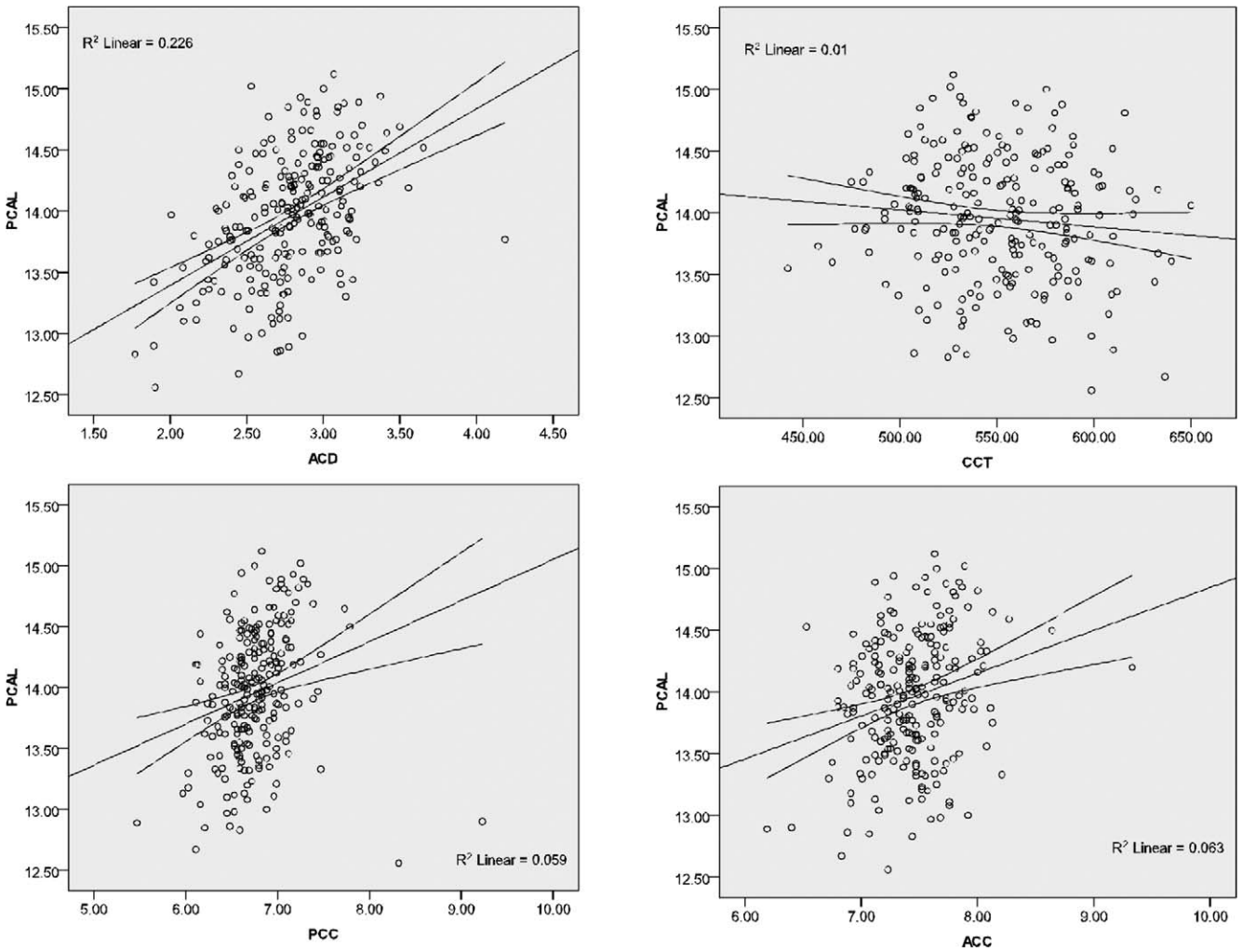

Figure 2. Scatter plots of PCAL and corneal parameters: ACD ($r = 0.476$, $P < 0.001$), CCT ($r = -0.100$, $P = 0.125$), PCC ($r = 0.243$, $P < 0.001$), and ACC ($r = 0.251$, $P < 0.001$).

varied significantly with age across the population ($P = 0.005$), but not PCC, ACC, or PCAL.

The variables were distributed normally, and PCAL was correlated positively with ACD, ACC, and PCC, and negatively with CCT (Fig. 2). Table 2 shows the relationship of PCAL in quartiles with measured corneal and anterior segment parameters. The positive associations between ACD, PCC, and ACC with higher measurements of PCAL were statistically significant ($P < 0.001$ for ACD and PCC, $P = 0.002$ for ACC).

Table 3 shows the Pearson's correlation coefficient between the corneal parameters, and with the systemic and refractive variables. There were poor ($r < 0.3$) to moderate ($r = 0.3$–0.59) correlations between PCAL and the other corneal parameters: ACD ($r = 0.476$, $P < 0.001$), CCT ($r = -0.100$, $P = 0.125$), PCC ($r = 0.243$, $P < 0.001$), ACC ($r = 0.251$, $P < 0.001$). Overall, there was a poor correlation between PCAL, and the systemic and refractive parameters. There was a significant positive relationship between all the cornea parameters with height and weight, except for CCT with height ($P = 0.076$).

In age- and sex-adjusted analysis of PCAL with the other corneal, systemic, and refractive parameters (Table 4), longer PCAL was associated with increasing ACD ($\beta = 0.770$, $P < 0.001$), and increasing PCC and ACC ($\beta = 0.316$ and 0.329, respectively, $P < 0.001$ for both). Taller and heavier subjects ($\beta = 0.017$ and 0.006, $P = 0.003$ and 0.019, respectively), and

Table 2. Relationship of PCAL (in Quartiles) with Measured Corneal and Anterior Segment Parameters

		ACD (mm)		CCT (μm)		PCC (mm)		ACC (mm)	
PCAL (mm)	*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
First quartile (<13.615)	59	2.54	0.32	557.82	39.92	6.68	0.52	7.35	0.37
Second quartile (13.615–13.970)	60	2.77	0.35	545.56	35.38	6.69	0.28	7.39	0.33
Third quartile (13.971–14.320)	60	2.83	0.26	549.39	41.93	6.72	0.26	7.42	0.38
Fourth quartile (>14.320)	58	2.97	0.26	548.22	29.65	6.92	0.30	7.56	0.36
P for trend		**<0.001**		0.25		**<0.001**		**0.002**	

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Table 3. Pearson's Correlation Coefficient between PCAL and Other Ocular Parameters, and Systemic and Refractive Variables

		PCAL	ACD	CCT	PCC	ACC	Age	Height in cm	Weight in kg	BMI	Diastolic BP	Systolic BP	Blood Glucose	HbA1c	IOP	Spherical Equivalent
PCAL	Pearson correlation	1	0.476	−0.100	0.243	0.251	−0.057	0.219	0.173	0.052	0.186	0.096	−0.015	0.030	−0.077	−0.053
	Sig. (2-tailed)		**<0.001**	0.125	**<0.001**	**<0.001**	0.384	**0.001**	**0.008**	0.427	**0.004**	0.140	0.821	0.646	0.236	0.422
	N	237	237	237	237	237	237	236	236	236	237	237	232	232	236	233
ACD	Pearson correlation	0.476	1	0.030	0.000	0.070	−0.301	0.285	0.160	0.016	0.184	−0.067	−0.008	0.015	−0.025	−0.288
	Sig. (2-tailed)	**<0.001**		0.644	0.994	0.284	**<0.001**	**<0.001**	**0.014**	0.805	**0.005**	0.304	0.900	0.816	0.706	**<0.001**
	N	237	237	237	237	237	237	236	236	236	237	237	232	232	236	233
CCT	Pearson correlation	−0.100	0.030	1	0.080	−0.029	−0.178	0.116	0.239	0.187	0.040	−0.025	0.127	0.145	0.235	0.011
	Sig. (2-tailed)	0.125	0.644		0.222	0.658	**0.006**	0.076	**<0.001**	**0.004**	0.542	0.696	0.054	**0.028**	**<0.001**	0.873
	N	237	237	237	237	237	237	236	236	236	237	237	232	232	236	233
PCC	Pearson correlation	0.243	0.000	0.080	1	0.516	−0.036	0.256	0.231	0.107	0.091	−0.036	−0.029	0.015	−0.173	0.045
	Sig. (2-tailed)	**<0.001**	0.994	0.222		**<0.001**	0.578	**<0.001**	**<0.001**	0.100	0.164	0.586	0.658	0.816	**0.008**	0.495
	N	237	237	237	237	237	237	236	236	236	237	237	232	232	236	233
ACC	Pearson correlation	0.251	0.070	−0.029	0.516	1	−0.103	0.226	0.163	0.060	0.120	0.026	−0.002	0.027	−0.170	−0.006
	Sig. (2-tailed)	**<0.001**	0.284	0.658	**<0.001**		0.114	**<0.001**	**0.012**	0.361	0.064	0.695	0.977	0.678	**0.009**	0.923
	N	237	237	237	237	237	237	236	236	236	237	237	232	232	236	233

Sig, significance.

patients with higher systolic and diastolic BP ($\beta = 0.004$ and 0.007, $P = 0.016$ and 0.011, respectively) had longer PCAL.

The multivariate adjusted influences of different corneal, systemic and refractive parameters are shown in Table 4. After adjustment for age, sex, height, and blood pressure, increasing PCAL was associated with increasing ACD ($\beta = 0.789$, $P < 0.001$), increasing PCC ($\beta = 0.317$, $P < 0.001$), and increasing height ($\beta = 0.013$, $P = 0.009$).

Table 5 shows the age- and sex-adjusted model of the other corneal parameters. Increasing ACD was associated with younger age and being male ($\beta = -0.010$ and -0.172, respectively, $P < 0.001$ for both). Persons with more myopic spherical equivalence ($\beta = -0.051$, $P < 0.001$), and higher systolic and diastolic BP ($\beta = 0.002$ and 0.004, $P < 0.050$ and 0.032, respectively) had longer ACD. Increasing CCT was associated with younger age ($\beta = -0.636$, $P = 0.006$), heavier weight ($\beta = 0.557$, $P = 0.002$), higher IOP ($\beta = 2.798$, $P < 0.001$), and persons with diabetes ($\beta = 2.091$, $P = 0.015$) or higher measured blood glucose and HbA1c ($\beta = 4.277$ and 14.628, $P = 0.013$ and 0.015, respectively). Increasing PCC is associated with being male ($\beta = 0.124$, $P = 0.009$), taller and heavier ($\beta = 0.012$ and 0.006, $P = 0.003$ and 0.001, respectively), and having lower IOP ($\beta = -0.028$, $P = 0.018$). Taller persons and lower IOP also are associated with increasing ACC ($\beta = 0.013$ and -0.018, $P = 0.003$ and 0.016, respectively).

Discussion

In this population-based study, we have shown a significant positive correlation of PCAL with ACD, PCC, and ACC in urban Malay adults. This association is consistent with previous reports in adult ethnic Chinese and Indians.[13,15] Our study provides the baseline normative data of corneal and anterior segment dimensions, such as ACD, ACC, PCC, CCT, and PCAL, in the Malay population. It also records associations and correlations of ocular with systemic parameters, such as age, height, and weight, spherical equivalence, and systemic disorders, like diabetes, hypertension, and cardiovascular diseases.

In this Malay study, PCAL was 13.95 ± 0.51 mm. Compared to a previous study on Chinese,[13] this was higher despite comparable dependent variables, such as ACD, PCC, and ACC (in the previous study on Chinese PCAL was 12.92 ± 0.54 mm, ACD 2.68 ± 0.31 mm, PCC 6.65 ± 0.34 mm, and ACC 7.36 ± 0.37 mm). A similar finding was found in a study on Indians,[15] where PCAL 13.85 ± 0.54 mm also was higher than in the Chinese. However, this must be confirmed in larger, direct comparative studies between the different ethnicities. A significant correlation was observed between PCAL and ACD ($r = 0.476$, $P < 0.001$), PCC ($r = 0.243$, $P < 0.001$), and ACC ($r = 0.251$, $P < 0.001$), and this was similar to results found in Chinese and Indian eyes.[13,15] The linear relationship and moderate correlation between PCAL and ACD was found in all 3 ethnicities, which suggests that ACD may be a surrogate index of PCAL, and may be used as a predictive parameter for anterior segment surgery independent of race. PCAL gives a good estimation of the internal diameter of the cornea, and its potential utility is relevant particularly to endothelial keratoplasty (EK) procedures, for example Descemet's stripping automated endothelial keratoplasty (DSAEK), where accurate preoperative measurement of PCAL in a recipient can guide an appropriate choice of donor graft diameter and optimum donor graft size.[19] Currently, to our knowledge, there is no method for optimal selection of donor graft size and most surgeons estimate the appropriate EK graft size from measurement of the anterior cornea surface. Optimal graft sizing from

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Table 4. Age- and Sex-Adjusted and Multivariate Analysis of PCAL

		Age-Sex Adjusted			Multivariate		
PCAL	**Unit**	**Beta Coefficient**	**SE**	***P* Value**	**Beta Coefficient**	**SE**	***P* Value**
ACD	Per mm increase	0.770	0.095	**<0.001**	0.789	0.091	**<0.001**
CCT	Per μm increase	−0.002	0.001	0.083			
PCC	Per mm increase	0.316	0.089	**<0.001**	0.317	0.078	**<0.001**
ACC	Per mm increase	0.329	0.088	**<0.001**			
Height	Per cm increase	0.017	0.006	**0.003**	0.013	0.005	**0.009**
Weight	Per kg increase	0.006	0.002	**0.019**			
BMI	Per kg/m^2 increase	0.009	0.007	0.178			
Spherical equivalent	Per diopter increase	−0.016	0.018	0.385			
IOP	Per mm Hg increase	−0.010	0.010	0.337			
Systolic BP	Per mm Hg increase	0.004	0.002	**0.016**			
Diastolic BP	Per mm Hg increase	0.007	0.003	**0.011**	0.004	0.002	0.124
Hypertension	Yes vs. no	0.130	0.074	0.082			
Blood glucose	Per mmol/L increase	−0.001	0.012	0.950			
HbA1c	Per % increase	0.015	0.024	0.542			
Diabetes	Yes vs. no	−0.024	0.084	0.780			

accurate measurement of the posterior cornea surface will allow the largest possible diameter graft to be inserted feasibly, which will have a direct impact on the amount of endothelial cells transplanted. Another potential use of PCAL and ACD is the accurate calculation of the size of an anterior chamber phakic intraocular lens (IOL) preoperatively, and postoperative follow-up in determining if the implant has been placed in an optimal position.[20]

The radius of ACC was significantly different between the sexes in the Chinese study as well as previous studies involving predominantly Caucasian and Chinese populations.[2,13] There was no significant difference in ACC between the sexes in our study as well as in the Indian study.[15] The reason for this is unclear, but it is notable that some studies also did not find an association between sex and biometric parameters.[21,22] The mean radius of PCC in our study was 6.75 ± 0.37 mm, which was greater than that of Chinese (6.65 ± 0.34 mm) and Indian (6.45 ± 0.35 mm) studies, but more similar to the schematic Gullstrand eye of 6.8 mm.[23] Increasing PCC is associated with increasing hyperopia. However, this was not statistically significant in our study ($P > 0.05$). Although PCC and PCAL are dimensions of the posterior cornea, there was poor correlation between them ($r = 0.243$, $P < 0.001$) and this was similar to that found in Chinese and Indian eyes.[13,15] As cornea curvatures are measured for the central 3 mm of the cornea, this result could suggest that the deviation from mean PCAL was due to the variation beyond the central 3 mm of the cornea to the scleral spurs.

The mean CCT 550.23 ± 37.12 μm in our study was less than that in the Chinese (562.39 ± 31.85 μm) and Indian (561.40 ± 34.1 μm) cohorts.[13,15] This may be significant, as CCT has been found to be a prognostic factor for glaucomatous progression in patients with ocular hypertension in the Ocular Hypertension Treatment Study.[24] Our mean CCT was greater, but not statistically different than in a similar cohort of Malay patients.[25] This may be due to the way the CCT was calculated

Table 5. Age- and Sex-Adjusted Analysis of ACD, CCT, PCC, and ACC with Systemic and Refractive Variables

		ACD			CCT			PCC			ACC		
	Unit	**Beta Coefficient**	**SE**	***P* Value**	**Beta Coefficient**	**SE**	***P* Value**	**Beta Coefficient**	**SE**	***P* Value**	**Beta Coefficient**	**SE**	***P* Value**
PCAL	Per mm increase	0.287	0.035	**<0.001**	−8.189	4.708	0.083	0.161	0.046	**<0.001**	0.171	0.046	**<0.001**
ACD	Per mm increase	–	–	–	−3.204	7.758	0.680	−0.071	0.077	0.352	0.017	0.077	0.829
CCT	Per μm increase	0.000	0.001	0.680	–	–	–	0.001	0.001	0.254	0.000	0.001	0.455
PCC	Per mm increase	−0.052	0.056	0.352	7.571	6.615	0.254	–	–	–	0.512	0.057	**<0.001**
ACC	Per mm increase	0.012	0.055	0.829	−4.908	6.565	0.455	0.503	0.056	**<0.001**	–	–	–
Age	Per year increase	−0.010	0.002	**<0.001**	−0.636	0.229	**0.006**	−0.001	0.002	0.592	−0.004	0.002	0.117
Sex	Female vs. male	−0.172	0.040	**<0.001**	−0.285	4.765	0.952	−0.124	0.047	**0.009**	−0.074	0.047	0.119
Height	Per cm increase	0.000	0.004	0.963	0.613	0.424	0.149	0.012	0.004	**0.003**	0.013	0.004	**0.003**
Weight	Per kg increase	0.001	0.002	0.331	0.557	0.176	**0.002**	0.006	0.002	**0.001**	0.004	0.002	0.046
BMI	Per kg/m^2 increase	0.005	0.004	0.257	1.338	0.472	**0.005**	0.012	0.005	**0.010**	0.006	0.005	0.190
Spherical equivalent	Per diopter increase	−0.051	0.010	**<0.001**	0.596	1.307	0.649	0.005	0.012	0.657	−0.001	0.013	0.934
IOP	Per mm Hg increase	0.001	0.006	0.844	2.798	0.734	**<0.001**	−0.018	0.007	**0.018**	−0.018	0.007	**0.016**
Systolic BP	Per mm Hg increase	0.002	0.001	**0.050**	0.118	0.119	0.321	0.000	0.001	0.955	0.002	0.001	0.132
Diastolic BP	Per mm Hg increase	0.004	0.002	**0.032**	0.118	0.210	0.575	0.002	0.002	0.375	0.003	0.002	0.122
Hypertension	Yes vs. no	0.016	0.046	0.734	8.603	5.377	0.111	0.001	0.053	0.990	0.033	0.054	0.538
Blood glucose	Per mmol/L increase	0.005	0.007	0.505	2.091	0.852	**0.015**	−0.003	0.009	0.747	0.002	0.009	0.819
HbA1c	Per % increase	0.012	0.015	0.422	4.277	1.705	**0.013**	0.007	0.017	0.701	0.011	0.017	0.546
Diabetes	Yes vs. no	0.089	0.051	0.084	14.628	5.941	**0.015**	−0.037	0.060	0.537	−0.028	0.061	0.645

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(manual versus automated) from the AS-OCT scans in the two different studies and the difference in patient characteristics. There was no correlation or statistically significant association between CCT and PCAL, suggesting parameter independence. This also was found in the Chinese and Indian studies.[13,15] We also found that CCT decreased with age ($\beta = -0.636$, $P = 0.006$), and this phenomenon has been reported in other population-based studies,[26,27] as well as our Chinese and Indian cohorts.[13,15]

ACD (2.78 ± 0.34 mm) in our Malay study population was greater than that reported in the Chinese (2.68 ± 0.31 mm) and Indian (2.72 ± 0.37 mm) populations.[13,15] This AS-OCT parameter in Malay eyes has been described previously, and has been found to be comparable in our study.[28] Similar to that described in the Chinese population, there was significant difference in ACD between males and females in our study ($P < 0.001$). This difference was not found in the Indian population.[15] Increasing ACD was associated with younger age and being male ($P < 0.001$ for both). Persons with more myopic spherical equivalent ($P < 0.001$) and higher BP ($P < 0.050$) also had deeper ACD.

General systemic disorders may affect corneal physiology, and in our study, diabetes and hypertension were included as part of the systemic determinants of ocular biometric parameters, as they were among the more important public health challenge in many nations; the global prevalence of both diseases is increasing rapidly as a result of ageing, and urbanization.[29,30] Diabetes, higher blood glucose, and HbA1c were associated with increased CCT in our study. This association has been described previously[31] and, while the reason for this association is unclear, some studies have suggested that hyperglycemia may cause corneal endothelium dysfunction with resultant corneal stromal hydration and swelling.[32] This association is important clinically, and should be taken into consideration while obtaining accurate IOP measurements in diabetics.

Similar to the Chinese and Indian studies, we did not find any association of PCAL to systemic disorders, such as hypertension, diabetes mellitus, or cardiovascular disease. We found significant association between PCAL with age, sex, and height. Increasing PCAL was associated with increasing age, being female, and increasing height ($P < 0.05$ for all). This was not found in the Indian study and, in contrast, in the Chinese study increasing PCAL was associated with being male, and there was a significant inverse correlation of PCAL with age. The reasons for this apparent discrepancy are unclear and these findings may need to be studied further in direct, comparative studies.

Ocular biometric parameters and their physiologic determinants are known to vary considerably across racial groups and populations.[2,3] There also is emerging evidence in some populations that biometric parameters are influenced by anthropometric measurements.[33–35] People of Malay ethnicity comprise a substantial proportion of Asians. A survey of rural villages in Central Sumatra, Indonesia, has provided some data on visual impairment and blindness, cataract, and refractive errors in Indonesians.[5,6,36] However, these data may be limited to the rural environment in which the survey was conducted. To date, data on ocular biometric parameters in the adult Malay population have been limited. As such, to our knowledge, our study would be the first to provide the baseline normative data of corneal and anterior segment dimensions in an adult urban Malay population.

One limitation of our study was its cross-sectional nature, which limited causal inferences. A cohort study may have been helpful to determine if the changes occur for the individual subject. Our study also was limited in that only cross-section images of the nasal-temporal AS-OCT scans were evaluated, as these have been shown to be the most consistent with respect to obtaining high-quality images for ZAP software to analyze.[37] This may result in an under-representative assessment of the parameters in the vertical quadrants. Other limitations included the inability to detect the scleral spur on AS-OCT images; that the ZAP software image processing was dependent on manual identification of the scleral spur as a measurement reference point, and the difficulty of this practice have been well recognized.[7,15,38] However, to overcome this limitation, the ZAP software has an inbuilt magnification window that can be moved over the scleral spurs to aid in determining their exact position. One advantage of the ZAP program is that once the scleral spurs are identified, the rest of the measurements are produced automatically.

Conclusions

Our study served to provide the baseline normative data of corneal and anterior segment dimensions, as well as a novel parameter, PCAL, in an adult Asian Malay population. We believe these data will be applicable clinically for assessment and surgical management of patients requiring anterior segment or corneal surgery. Further studies with comparisons to other ethnic populations would be useful.

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