

# Variation of the Contribution from Axial Length and Other Oculometric Parameters to Refraction by Age and Ethnicity

Jenny M. Ip,<sup>1</sup> Son C. Huynh,<sup>1</sup> Annette Kifley,<sup>1</sup> Kathryn A. Rose,<sup>2</sup> Ian G. Morgan,<sup>3</sup> Robit Varma,<sup>4,5</sup> and Paul Mitchell<sup>1</sup>

**PURPOSE.** To compare the distribution of spherical equivalent refraction (SER) and other ocular parameters and to assess the contribution from oculometric parameters to SER in two age-specific, cross-sectional samples of children, and in two ethnic groups (European Caucasian and East Asian).

**METHODS.** A random-cluster design was used to recruit predominantly 6-year-old (1765 participants, 78.9% response) and 12-year-old children (2353 participants, 75.3% response) from schools across Sydney, Australia. Data collection included questionnaires and eye examination (keratometry, biometry, and cycloplegic autorefractometry). Results of three analytical methods (Pearson correlation, partial correlation coefficient, and linear regression analyses) are reported for 6- and 12-year-old children.

**RESULTS.** Kurtosis for SER and axial length (AL) in the 12-year-old children (14.3 and 2.1, respectively) was similar to that previously reported for the 6-year-old children (11.3 and 0.5). AL showed high correlation ( $r$ ) with SER in the 6- ( $r = -0.44$ ) and 12-year-old ( $r = -0.61$ ) children. Lower correlations for SER with corneal radius ( $r \leq 0.09$ ) and with lens power ( $r \leq 0.13$ ) were noted in both samples. In multivariate models, AL accounted for 24% and 49% of the variations in SER for the 6- and 12-year-old children, respectively. In these older children, correlations between AL and SER were greater in the East-Asian ethnic group ( $r = -0.79$  vs.  $-0.47$ ), and multivariate analyses showed that AL accounted for a greater proportion of the variation in refraction in East-Asian children (68%) than in European-Caucasian children (24%).

**CONCLUSIONS.** In the samples of predominantly 6- and 12-year-old children, the main determinant of SER was AL. The greater

contribution of AL in the older sample and in East-Asian children corresponds well with recently proposed models of continuing axial elongation in the absence of compensatory lens changes. (*Invest Ophthalmol Vis Sci.* 2007;48:4846-4853) DOI:10.1167/iov.07-0101

Since the classic studies of ocular biometry and the relationship with spherical equivalent refraction (SER) were reported,<sup>1-4</sup> it has been widely accepted that the age-related myopic shift in refraction in school children is due to axial elongation. In initial studies, Sorsby et al.<sup>2,4</sup> reported ambiguous findings for corneal power; however, recent studies using more precise instrumentation and detailed analytical methods have established that after the first 2 years of life, corneal power is relatively stable throughout development, whereas axial length (AL) continues to increase, with a corresponding shift in refraction in the myopic direction.<sup>5-8</sup> There is also a gradual reduction in lens power with age.<sup>5,9,10</sup>

Other studies have shown that there is an early phase of refractive development spanning approximately the first 2 years of life that is characterized by a rapid reduction in predominantly hyperopic refractive errors in conjunction with changes in AL and corneal and lens power.<sup>11-13</sup> Also evident during this phase is the transformation of the distribution of refractive error from a normal distribution at birth into a tight and peaked distribution. Such change is generally interpreted as reflecting active processes that are intended to achieve emmetropia by matching the AL to the optical power of the eye. Formal statistical analyses of skew and kurtosis for the distributions of refraction and ocular components, however, have rarely been reported.

In this study of two cross-sectional population-based samples of 6- and 12-year-old children, we compared the skew and kurtosis of refraction and ocular biometric parameters and assessed the contribution of ocular biometry to the variability in SER by age and ethnicity.

## MATERIALS AND METHODS

### Study Population

The Sydney Myopia Study is a population-based survey of eye health in children attending primary and high schools across the metropolitan area of Sydney, Australia. This project forms part of the larger Sydney Childhood Eye Study. The present report focuses on the findings in high school students, who were predominantly 12 years of age, referred to hereafter as 12-year-old children. Some of the findings in primary school children (predominantly 6 years of age) are also included for comparison. Approval for the study was obtained from the Human Research Ethics Committee of the University of Sydney, the New South Wales Department of Education, and the Catholic Education Office. The study adhered to the tenets of the Declaration of Helsinki.

Details of the sampling method, examination procedures and characteristics of the participating 6- and 12-year-old children have been

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From the <sup>1</sup>Centre for Vision Research, Department of Ophthalmology and the Westmead Millennium Institute, the <sup>2</sup>School of Applied Vision Sciences, Faculty of Health Sciences, University of Sydney, Sydney; the <sup>3</sup>ARC Centre of Excellence in Vision Science and Research School of Biological Sciences, Australian National University, Canberra, Australia; the <sup>4</sup>Department of Preventive Medicine, and the <sup>5</sup>Doheny Eye Institute and Department of Ophthalmology, Keck School of Medicine, University of Southern California, Los Angeles, California.

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Corresponding author: Paul Mitchell, Department of Ophthalmology, Centre for Vision Research, University of Sydney, Westmead Hospital, Hawkesbury Road, Westmead, NSW, Australia, 2145; paul\_mitchell@wmi.usyd.edu.au.

described.<sup>8,14,15</sup> In brief, stratified random cluster sampling was used to select primary and secondary schools across the Sydney metropolitan region for participation. A total of 55 schools, with a proportional mix of public and private/religious schools were included. Examinations in the 6-year-old children were conducted from August 2003 to October 2004, and in the 12-year-old children, between November 2004 and November 2005. Informed consent from at least one parent and verbal assent from each child was obtained before examination.

Overall, 1765 6-year-old children (78.9% response) and 2353 12-year-old children (75.0% response) had parental permission to participate. Of these, 38 children (24 6-year-old children and 14 12-year-old children) were not examined due to absence during the in-school examination period. The mean ages of participants in the two samples were 6.7 years and 12.7 years, respectively. Ethnic origins of the participating children were predominantly European Caucasian (60.0% of 6-year-olds; 64.5% of 12-year-olds) and East Asian (17.2% and 15.0%, respectively).

### Questionnaire Data

Parents completed a comprehensive 193-item questionnaire that addressed basic sociodemographic factors such as ethnicity, parental education, and occupation. The determination of ethnicity was based on self-identification by the parents, together with information about the child's place of birth. Children whose parents reported different ethnicities were categorized as having mixed ethnicity. The present study adopted ethnic categories based on the genetic relatedness of human populations defined using modern molecular biology,<sup>16</sup> which are largely consistent with the categories used in the Australian Standard Classification of Cultural and Ethnic Groups (available at [www.abs.gov.au](http://www.abs.gov.au); document 1249.0). The term East Asian includes people originating from China, Myanmar, Thailand, Laos, Cambodia, Vietnam, Malaysia, Singapore, Indonesia, the Philippines, Japan, and Korea.

To obtain information on risk factors for myopia, parents were asked to estimate the amounts of time their children spent in near-work and outdoor activities each day. Details of any spectacle or contact lens use in the parents were also collected, and spectacle prescriptions were obtained from parents or their prescribers when possible. The classification of parental myopia was based on spectacle prescriptions, or if unavailable, on age at first use (at 30 years or younger) and the purpose of use (distance viewing only, or both distance viewing and near work).<sup>17</sup>

### Examination

Cycloplegic autorefractometry was performed with an autorefractor (model RK-F1; Canon, Tokyo, Japan). This instrument generated five reliable readings of refraction in each eye; the median reading was used for analysis. Cycloplegia was induced using cyclopentolate 1% (1 drop), 2 minutes after corneal anesthesia with amethocaine 0.5%. Tropicamide 1% (1 drop) and phenylephrine 2.5% (1 drop) were also used in some children to obtain adequate mydriasis (a minimum pupil diameter of 6 mm). Autorefractometry was repeated 25 minutes after the last drop.

Measurement of ocular biometric parameters was performed with an optical biometer (IOLMaster; Carl Zeiss Meditec, Oberkochen, Germany). AL was measured as the distance from the anterior corneal vertex to the retinal pigment epithelium along fixation, automatically adjusted for retinal thickness. The validity of AL increments was assessed using the signal-to-noise ratio (SNR), where  $SNR \geq 2.0$  indicated a reliable result. Corneal radius of curvature, determined from the reflection of a hexagonal array of lights on the cornea, was measured along the flattest and steepest meridians. Three consistent keratometry readings were used in analysis, with consistency based on a variation of 0.1 D or less in corneal astigmatism. Anterior chamber depth was measured as the distance from the anterior corneal surface to the anterior lens surface by image analysis of an optical section. These

measurements were considered valid if individual measurements varied by no more than 0.15 mm.

Anthropometric measures in the children included assessment of height and weight. The child's height was measured with shoes off, using a freestanding height rod. Body mass index (BMI) was calculated ( $BMI = \text{weight in kilograms}/\text{height in square meters}$ ).

### Definitions

Average corneal radius of curvature was the average of the steepest and flattest meridians. Axial length/corneal radius (AL/CR) ratio was defined using the average corneal radius of curvature. Calculated lens power ( $F_L$ ) was based on the Gullstrand-Emsley schematic eye.<sup>18</sup>

### Data Analysis

Data were analyzed with commercial software (SAS software ver. 9.1.3; SAS, Cary, NC). As biometric data for the right and left eyes were highly correlated, analyses were performed using data for the right eye only. The overall distributions of refraction and ocular biometric parameters were assessed for kurtosis and skew. Kurtosis is a measure of how data points are concentrated around the mean of a distribution; higher kurtosis values indicate a sharper peak than the normal distribution.

The associations of ocular biometric parameters to SER were assessed using three methods: Pearson correlation, partial correlation coefficient (PCC), and  $\beta$  coefficient from linear regression models. The PCC was used to describe the relative contribution of individual biometric parameters to the variability in SER, adjusting for demographic variables such as age, gender, and ethnicity. Linear regression models were used to assess the impact of a unit change in biometric parameter on the SER. Analyses were performed in all participants and separately for children from the two major ethnic groups in the study (European Caucasian and East Asian). Confidence intervals (CI) are 95%.

## RESULTS

### Ocular Biometric Parameters

Ocular biometric data for the two samples of 6- and 12-year-old children are compared in Table 1, showing more myopic refractions, deeper anterior chambers, weaker lens power, and greater AL in the older children, despite the similarity in the corneal radius of curvature. Similar age patterns were seen in the data for the European Caucasian and East Asian ethnic groups (Table 1).

In the sample of 12-year-old children, kurtosis was greatest for the distribution of SER (kurtosis = 11.3) with broader, more normal distributions for all other ocular biometric parameters (kurtosis = 0.5–2.1). Kurtosis for AL/CR was 3.9. Skew for SER was  $-1.6$  and ranged from  $-0.2$  to  $0.6$  for the other ocular biometric parameters.

### Refraction and Ocular Biometric Parameters

Overall, in the 6- and 12-year-old children, correlations between SER and individual biometric variables were all statistically significant (all  $P < 0.05$ ). The strongest biometric correlations for SER in the two samples of children were with AL/CR ratio, AL, and anterior chamber depth, in terms of both Pearson correlation coefficients and PCCs (Table 2).

In the sample of 12-year-old children, linear regression analyses showed that an increase of 1.0 mm in AL or anterior chamber depth would be associated with a myopic shift of 0.96 to 0.97 D. AL accounted for 37% of the variability in SER, after adjustment for age, gender, and ethnicity. Models that included AL, age, gender, and ethnicity explained 49% of the variation in SER. Other parameters, such as corneal radius of curvature and lens power explained smaller proportions of the

TABLE 1. SER and Ocular Biometric Parameters in Children Aged 6 and 12 Years with Stratification into the Two Major Ethnic Groups

	6-Year-Olds*			12-Year-Olds†		
	Whole Group	European Caucasian	East Asian	Whole Group	European Caucasian	East Asian
SER (D)	1.26 ± 0.88	1.40 ± 0.84	0.90 ± 0.76	0.48 ± 1.34	0.83 ± 1.00	-0.69 ± 1.92
Average corneal radius (mm)	7.78 ± 0.25	7.78 ± 0.26	7.80 ± 0.25	7.78 ± 0.25	7.77 ± 0.25	7.79 ± 0.27
Anterior chamber depth (mm)	3.53 ± 0.21	3.55 ± 0.21	3.43 ± 0.20	3.67 ± 0.25	3.67 ± 0.24	3.62 ± 0.24
Lens power (D)	24.01 ± 1.37	23.92 ± 1.38	24.35 ± 1.46	22.15 ± 1.46	22.18 ± 1.46	22.03 ± 1.45
AL (mm)	22.61 ± 0.69	22.58 ± 0.70	22.65 ± 0.64	23.38 ± 0.85	23.23 ± 0.75	23.86 ± 1.07
AL/CR ratio	2.91 ± 0.07	2.91 ± 0.07	2.90 ± 0.06	3.01 ± 0.09	2.99 ± 0.08	3.06 ± 0.13

Data are the mean ± SD.

\* Nonstratified results for SER, anterior chamber depth, AL, and AL/CR for the whole group published in Ojaimi et al.<sup>15</sup>

† Results for SER, corneal radius, and AL published in Ip et al. (Published online February 2, 2007).

variability in SER after adjustment for age, gender, and ethnicity (PCC < 0.12).

In the two ethnic groups within the 12-year-old sample, the correlation between AL and SER was higher for children of East Asian ethnicity than for children of European Caucasian ethnicity ( $r = -0.79$  vs.  $-0.47$ ). Linear regression analyses also predicted greater myopic shifts in refraction for increases in AL within the East Asian ethnic group ( $\beta$  coefficient =  $-1.42$  vs.  $-0.61$ ). Other notable differences between the two ethnic groups were evident in linear regression analyses of anterior chamber depth and lens power (Table 2).

In the sample of 6-year-old children, per unit increases in AL had a significantly lower impact on SER ( $\beta$  coefficient =  $-0.53$ ) and accounted for a smaller proportion of the variability in refraction (PCC = 0.19) than that reported for the

12-year-old children. For the two ethnic groups in this younger sample, correlation coefficients were quite similar, with substantial overlap of the confidence intervals for the  $\beta$  coefficients in linear regression analyses.

**Myopia and Ocular Biometry**

Multivariate models constructed for the sample of 12-year-old children showed that each 1.0-mm increase in AL was associated with a sixfold greater odds ratio (OR) for myopia (OR 5.9, 95% CI 4.6-7.5), after adjustment for age, gender, and ethnicity (Table 3). The corresponding ORs for myopia in children with European Caucasian and East Asian ethnicity were 5.0 (95% CI 3.4-7.5) and 9.9 (95% CI 6.0-16.3), respectively. The interaction term, ethnicity × AL did not reach statistical significance for odds of myopia ( $P = 0.08$ ).

TABLE 2. Association of Ocular Biometric Parameters and AL/CR with SER

	6-Year-Olds				12-Year-Olds			
	Pearson Correlation Coefficient	$\beta$ Coefficient (CI)*	PCC†	Model $R^2$	Pearson Correlation Coefficient	$\beta$ Coefficient (CI)	PCC	Model $R^2$
AL								
Whole group	-0.44‡	-0.53 (-0.59--0.46)	0.19	0.24	-0.61‡	-0.96 (-1.01--0.91)	0.37	0.49
European	-0.42‡	-0.50 (-0.56--0.43)	0.18	0.19	-0.47‡	-0.61 (-0.67--0.55)	0.24	0.24
East Asian	-0.40‡	-0.37 (-0.50--0.23)	0.13	0.13	-0.79‡	-1.42 (-1.54--1.31)	0.65	0.68
Corneal radius§								
Whole group	0.04	0.23 (0.06-0.41)	0.01	0.07	0.09‡	0.44 (0.22-0.66)	0.009	0.21
European	0.05	0.19 (-0.01-0.40)	0.01	0.03	0.09	0.35 (0.14-0.57)	0.009	0.01
East Asian	0.07	0.42 (0.04-0.80)	0.03	0.03	0.07	0.52 (-0.26-1.31)	0.002	0.07
ACD								
Whole group	-0.20‡	-0.81 (-1.01--0.60)	0.11	0.16	-0.18‡	-0.97 (-1.19--0.75)	0.08	0.24
European	-0.31‡	-1.20 (-1.42--0.99)	0.10	0.12	-0.22‡	-0.86 (-1.07--0.65)	0.09	0.05
East Asian	-0.28‡	-1.09 (-1.52--0.67)	0.10	0.11	-0.28‡	-2.25 (-3.08--1.42)	0.12	0.16
Lens power								
Whole group	0.06	0.05 (0.01-0.08)	0.006	0.07	0.13‡	0.12 (0.09-0.16)	0.02	0.21
European	0.08	0.06 (0.02-0.10)	0.004	0.02	0.08	0.05 (0.02-0.09)	0.005	0.008
East Asian	0.06	0.04 (-0.03-0.11)	0.003	0.01	0.29‡	0.39 (0.25-0.52)	0.09	0.15
AL/CR ratio								
Whole group	-0.66‡	-8.59 (-9.09--8.09)	0.47	0.50	-0.81‡	-11.50 (-11.85--11.15)	0.64	0.70
European	-0.66‡	-8.52 (-9.12--7.93)	0.46	0.47	-0.71‡	-9.08 (-9.56--8.59)	0.52	0.52
East Asian	-0.63‡	-7.60 (-8.72--6.47)	0.45	0.45	-0.90‡	-13.26 (-13.97--12.55)	0.79	0.81

The model  $R^2$  shows the variation in SER explained by multivariate models that include ocular biometric parameter, age, and gender as explanatory variables. The analyses for the whole group are also adjusted for ethnicity. ACD, anterior chamber depth.

\* In regression models, SER was the dependent variable with each biometric variable as an independent variable. In this sample, a 6-year-old child with 1.0 mm longer AL would be expected to have 0.53 D more myopic SER.

† Indicates the variability in SER explained by each biometric variable, after adjustment for age and gender. Analysis for whole group also adjusted for ethnicity, showing that in the 6-year-old children, AL accounted for 19% of the variability in SER.

‡  $P < 0.0001$ .

§ Corneal radius is the average of the maximum and minimum radii of curvature.

||  $P < 0.05$ .

TABLE 3. Logistic Regression for Myopia (Dichotomous Variable) in 12-Year-Old Children

	Univariate Model			Multivariate-Adjusted Model*		
	Odds Ratio (CI)	Crude Model $R^2$	Max Rescaled† $R^2$	Odds Ratio (CI)	Multivariate Adjusted Model $R^2$	Max Rescaled† $R^2$
AL (per 1.0 mm)						
Whole group	5.8 (4.7-7.1)	0.17	0.33	5.9 (4.6-7.5)	0.24	0.47
European	4.3 (3.0-6.3)	0.05	0.15	5.0 (3.4-7.5)	0.05	0.17
East Asian	7.1 (4.7-10.9)	0.37	0.51	9.9 (6.0-16.3)	0.43	0.58
Corneal radius (per 1.0 mm)‡						
Whole group	0.4 (0.2-0.6)	0.01	0.01	0.3 (0.2-0.6)	0.14	0.27
European	0.2 (0.1-0.6)	0.006	0.02	0.2 (0.1-0.6)	0.007	0.02
East Asian	0.6 (0.3-1.4)	0.004	0.005	0.8 (0.3-1.8)	0.07	0.10
ACD (per 1.0 mm)						
Whole group	3.9 (2.3-6.6)	0.01	0.02	11.4 (6.0-21.8)	0.15	0.29
European	6.2 (2.2-18.0)	0.008	0.03	6.6 (2.2-20.0)	0.009	0.03
East Asian	12.8 (4.6-36.3)	0.08	0.10	36.2 (11.2-112.9)	0.16	0.24
Lens power (per 1.0 D)						
Whole group	0.8 (0.7-0.9)	0.01	0.02	0.7 (0.7-0.8)	0.15	0.29
European	1.0 (0.8-1.2)	0.00	0.0001	1.0 (0.8-1.2)	0.0009	0.003
East Asian	0.6 (0.5-0.7)	0.10	0.14	0.6 (0.5-0.7)	0.17	0.23
AL/CR ratio (per unit)§						
Whole group	14.9 (11.1-20.0)	0.30	0.59	15.5 (11.1-21.6)	0.34	0.66
European	12.5 (7.7-20.3)	0.13	0.41	13.7 (8.3-22.8)	0.13	0.43
East Asian	15.7 (8.6-28.7)	0.52	0.70	16.7 (9.0-31.2)	0.53	0.72

$R^2$  represents the proportion of the total variability explained by univariate and multivariate models which include ocular biometric parameters and AL/CR. ACD, anterior chamber depth.

\* Adjusted for age and gender; analysis for the whole group also adjusted for ethnicity.

† Strength of association (range 0-1); 1 indicates the strongest association.

‡ Average of the maximum and minimum radii of curvature.

§ Normalized distribution of AL/CR ratio used for analysis.

Further evaluation by AL showed that for a given AL band, an equal or greater proportion of children had myopia in the East Asian ethnic group, than in the European Caucasian ethnic group (Fig. 1). In the two ethnic groups, longer AL was associated with flatter corneas, deeper anterior chambers, and weaker lens power (Fig. 2). Linear regression analysis of the data suggested that the relationship of AL with corneal curvature, anterior chamber depth, and lens power was steeper in

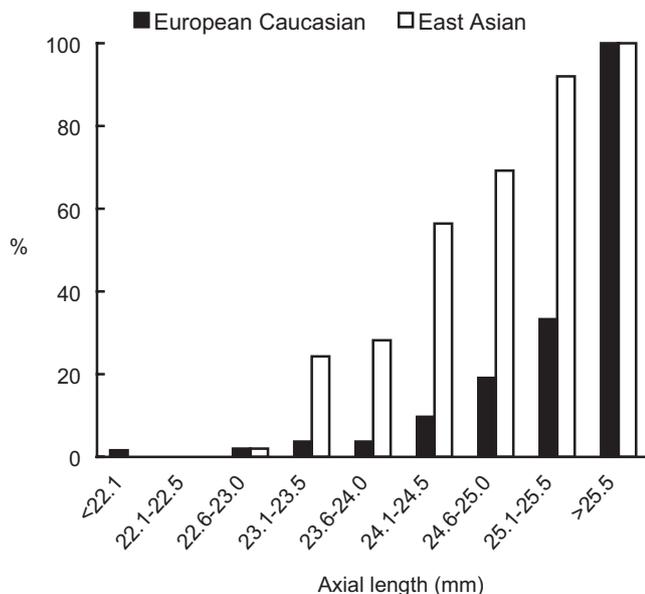


FIGURE 1. Proportion with myopia in 12-year-old children (European Caucasian and East Asian ethnic groups) as a function of AL.

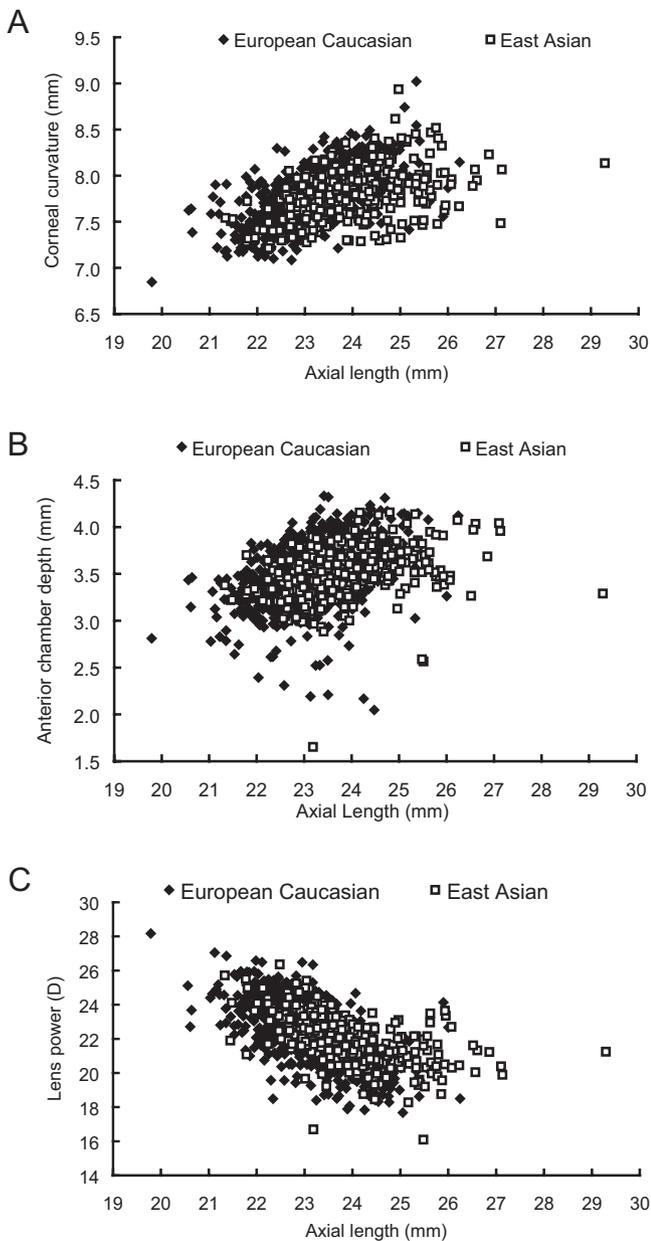
the European Caucasian ethnic group than in the East Asian group (data not shown). However, linear regression analysis excluding those children who were myopic showed no substantial difference between the ethnic groups (Fig. 2).

### AL/CR Ratio

In the 12-year-old children, the AL/CR ratio was strongly correlated with SER ( $r = -0.81$ ,  $P < 0.0001$ ); this parameter was strongly associated with increasing odds of myopia (OR 15.5, 95% CI 11.1-21.6, per unit increase in AL/CR). The AL/CR ratio accounted for a greater proportion of the variation in SER than did AL alone (PCC = 0.64 vs. 0.37; adjusted for age, gender, and ethnicity). Substantial overlap of the CIs in the odds for myopia in the European Caucasian (OR 13.7; 95% CI 8.3-22.8) and East Asian (OR 16.7; 95% CI 9.0-31.2) subgroups, however, suggests that the ethnic difference was not statistically significant (Table 3).

### Myopia and Other Risk Factors

The impact of nonbiometric factors (parental myopia, demographic measures of socioeconomic status, BMI, outdoor activity, and near work) on childhood refraction was also assessed individually and in combined models using linear regression in the 12-year-old sample. Unadjusted linear models showed that parental myopia alone accounted for up to 8.6% of the variability in refraction (PCC for at least one myopic parent = 0.015; for two myopic parents = 0.086), and that demographic measures (home ownership, parental employment, and parental education) each accounted for less than 2.0%. The contributions from near work and outdoor activity were 0.9% and 3.5%, respectively, while childhood BMI accounted for less than 0.1% of the variability in refraction.



**FIGURE 2.** Relationship between AL and (A) corneal curvature, (B) anterior chamber depth, and (C) lens power in 12-year-old children of European Caucasian and East Asian ethnicity. Linear regression equations after excluding myopic children in the European Caucasian and East Asian groups, respectively, are as follows: (A) corneal curvature:  $y = 0.2428x + 2.1432$ ,  $y = 0.2708x + 1.4824$ ; (B) anterior chamber depth:  $y = 0.1506x + 0.02$ ,  $y = 0.1196x + 0.6508$ ; (C) lens power:  $y = -1.3329x + 53.102$ ,  $y = -1.1655x + 49.58$ .

A multivariate model of statistically significant nonbiometric parameters (age, gender, ethnicity, parental myopia, parental employment, near work, and outdoor activity) explained 27.3% of the variation in childhood refraction. The addition of childhood AL to the model increased the proportion to 56.2%. According to this final model, a 1.0-mm increase in AL was associated with a  $-0.91$ -D difference in refraction ( $P < 0.0001$ ), whereas 1 hour spent out of doors each week was associated with a difference in refraction of  $+0.13$  D ( $P < 0.0001$ ). Near work did not have any discernible effect on refraction in this multivariate model (0.00 D;  $P = 0.97$ ), al-

though a significant impact from East Asian ethnicity persisted ( $\beta$  coefficient =  $-0.75$ ,  $P < 0.0001$ ).

## DISCUSSION

The findings in this large population-based study of ocular biometry in children provide evidence supporting a predominant role for AL in determining refraction at ages 6 and 12 years. Although data from the two cross-sectional samples of children in the present study are not longitudinal findings, our age-specific data provide some insight into patterns of change, which will require confirmation from longitudinal studies. The correlation of refraction with AL and most other biometric parameters was greater in the older sample of children. Separate analyses for the two ethnic groups in the sample of 12-year-old children showed a greater correlation of refraction with AL, anterior chamber depth, and lens power in East Asian than European Caucasian children.

### Axial Length and Refraction

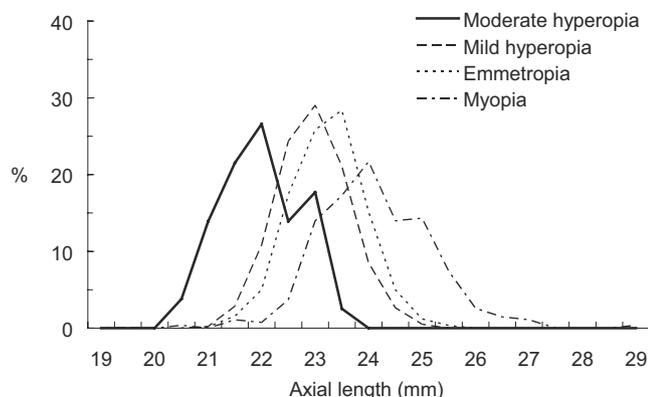
The three analytical methods described in this report provide some quantitative estimates of the impact of ocular biometric parameters on refraction with older age. AL was better correlated with refraction in the older (12-year-old) children than in the younger sample, a finding that corresponds well with the age-related myopic shift in refraction and the previously described changes in ocular biometry among school children that include marked increases in AL but relatively smaller changes in anterior chamber depth and lens thickness, and little change in corneal radius of curvature or power.<sup>5-10</sup> Although linear regression models in the present study predict that increases in anterior chamber depth would be associated with a substantial change in refraction, there was only low correlation between anterior chamber depth and refraction; anterior chamber depth only accounted for 10% to 12% of the variability in SER. These findings can be explained by the relatively small intra- and intersample variations in anterior chamber depth and confirm that the axial elongation associated with more myopic refractions is predominantly posterior.

Our results are consistent with findings from a sample of Singapore children aged 6 to 12 years with myopia ( $n = 252$ ), which showed that the degree of myopia was significantly associated with vitreous chamber depth, lens thickness, and gender.<sup>19</sup> A multiple regression model including these three variables explained 36.5% of the variability in SER.<sup>19</sup> In our study, the model that included AL, age, gender, and ethnicity as explanatory variables accounted for 49% of the variability in SER.

In adult studies, the variability in refraction attributed to AL is similar to these estimates in children. AL was reported to account for 33% of the variation in refraction in one sample of Latino adults aged 40 years or older.<sup>20</sup> However in adults, there is an age-related hyperopic shift that is followed by a myopic shift in older age,<sup>20-22</sup> thought to result, at least in part, from increasing lens opalescence.<sup>20,23</sup>

### AL/CR Ratio and Myopia

Although greater AL was associated with a greater likelihood of myopia in this sample of schoolchildren, myopic refractions were also found in shorter eyes. Figure 3 shows that there was considerable overlap in the distribution of AL between myopia, emmetropia, and hyperopia in the sample of 12-year-old children. AL/CR ratio was found to correlate better with refraction than AL alone. Because the AL/CR ratio provides a rough measure of the degree of matching between AL and corneal power, it is possibly a more useful marker of progress toward



**FIGURE 3.** Distribution of AL in 12-year-old children with moderate hyperopia ( $\text{SER} \geq +2.00$  D) mild hyperopia ( $+0.50$  D  $\leq$   $\text{SER} < +2.00$  D), emmetropia ( $-0.50$  D  $<$   $\text{SER} < +0.50$  D), and myopia ( $\text{SER} \leq -0.50$  D).

myopic refractions than absolute ocular biometric values such as AL.

### Other Ocular Biometric Parameters and Refraction

In some studies, corneal characteristics, including corneal curvature, peripheral corneal curvature, and corneal toricity, have been associated with myopia,<sup>24-28</sup> or are thought to predispose to its development.<sup>28</sup> Our cross-sectional data showed that there was little difference in the mean corneal curvature between the ages of 6 and 12 years, with minimal difference between the two ethnic groups in each age sample. While our cross-sectional analyses need confirmation from longitudinal data, increases in myopia prevalence throughout childhood<sup>14,29-33</sup> seem to occur over a period during which only minimal age-related differences in corneal curvature or corneal power have been reported.<sup>4,5,7</sup>

Calculated lens power was only weakly correlated with SER in our samples of 6- and 12-year-old children, where weaker lens diopter power was associated with a more myopic refraction. Longitudinal studies report that lens thinning occurs throughout childhood (a reduction of 0.2 mm in lens thickness has been reported between ages 6 and 14 years<sup>10</sup>), acting as possible compensation for the myopigenic effects of axial elongation. Some studies have suggested that myopia may occur when further compensation by flattening of the crystalline lens is no longer possible.<sup>34-36</sup> In our sample of 12-year-old children, children of East Asian ethnicity generally had weaker lens power than did children of European Caucasian origin, and East Asian children were more myopic. Lower lens powers in the 12-year-old sample were noted in both ethnic groups.

### Distribution of SER and Axial Length

In our two cross-sectional samples, the kurtosis for the distribution of SER was similar (14.4 vs. 11.3; 6- and 12-year-olds respectively), whereas kurtosis for AL was higher in the 12-year-olds (2.1 vs. 0.5). These data suggest that there is little further active matching of AL to corneal curvature during this period of development. In a study of children aged 1 through 48 months,<sup>12</sup> the distribution of refraction as a function of age showed a decline in the level of hyperopia and a narrower distribution of refraction with age, providing a graphic representation of the emergence of kurtosis in the distribution of refraction during infancy. Similar changes in distribution of

refractive error, with developing kurtosis can also be seen in the Berkeley Infant Biometry Survey over the period from 3 to 9 months.<sup>15</sup>

### Ethnic Comparisons

Oculometric differences between other ethnic groups have been reported. In a study of Malay ( $n = 904$ ) and Melanesian ( $n = 753$ ) children aged 6 to 17 years, Garner et al.<sup>37</sup> reported that the individual correlations of SER with AL, anterior chamber depth, and lens power were higher in the Malay than in the Melanesian children; however, correlations for corneal power were similar. The sample of Melanesian children, however, was somewhat younger than the sample of Malay children, and so age may have been a confounding variable. Measurement bias was also possible in this comparison of Malay and Melanesian children, since different measurement instruments were used in the two samples.

Among the 6-year-old children, we found that the correlation between SER and AL was similar in both the European Caucasian and the East Asian ethnic groups. The variability in refraction attributed to AL was also similar (19% and 13%, for European Caucasian and East Asian children, respectively). These findings suggest that the factors underlying ethnic differences in refraction most likely occur after the age of 6 years.

Overall, our results in the 12-year-old children confirm that in the two ethnic groups of East Asian and European Caucasian ethnicity, AL was the main contributor to SER, although there were various degrees of impact. Recently presented data suggest that the relationship between AL and SER is nonlinear and that at longer AL there is a greater impact on SER (Rose KA et al. *IOVS* 2007;48:ARVO E-Abstract 1535). The longer mean AL in the East Asian children, may therefore account for some of the stronger associations in this ethnic group.

In the 12-year-old sample, longer AL in the East Asian ethnic group also appear to explain the apparent ethnic differences in other ocular biometric parameters, since linear regression analyses excluding myopic children were quite similar between the two ethnic groups (Fig. 2). Continuing axial elongation, which appears to be more common in the East Asian ethnic group, was found to be associated with greater variability in corneal curvature, but little further increase in anterior chamber depth and/or reduction in lens power. Overall, these results suggest that the underlying processes of refractive development are similar in the two ethnic groups.

### Strengths and Limitations

Our cross-sectional study showed differences in two age-specific samples of children, but inferences about age-related changes should be made with caution. Longitudinal measurements are needed to confirm the inferred changes. Lens power was not directly measured in our study but calculated using the Gullstrand-Emsley schematic eye, which is based on adult proportions. For all other ocular biometric parameters, however, direct measurements were obtained using partial coherence interferometry (IOLMaster; Carl Zeiss Meditec) which provides more precise and repeatable measures, particularly for AL, than those obtained with ultrasound.<sup>38</sup> We also used cycloplegic refraction and standardized instrumentation and protocols across the two samples of children.

In summary, this study of ocular biometry confirmed that variability in AL was a major determinant of refraction among the 6- and 12-year-old children, in both the East Asian and the

European Caucasian ethnic groups. The contributions from corneal curvature, anterior chamber depth, and lens thickness were less prominent. Our findings of higher correlations between AL and SER in the older children and in the East Asian ethnic group correspond well with a refractive development model of continuing axial elongation in the absence of compensatory lens changes.

The major gap in the literature on refractive development in children now concerns changes in refraction and ocular biometry after the first year of life up to the commencement of schooling. This period was covered in the studies of Sorsby and Leary,<sup>2</sup> but there have been considerable advances in both instrumentation and analytical techniques over the past decades. Data from the on-going Sydney Pediatric Eye Disease Study, the Multi-ethnic Pediatric Eye Disease Study, the Baltimore Pediatric Eye Study, the Berkeley Infant Biometry Study, and the Study on Refractive Error, Amblyopia, and Strabismus in Singaporean Chinese Preschoolers should provide information on the development of refraction and ocular biometry, as well as kurtosis in the distribution of refraction during this largely undocumented developmental phase, to complement the very limited data currently available.<sup>3,9,10,12</sup> Filling this gap is important, since the increasingly early onset of myopia in urban East Asia<sup>39-41</sup> suggests that critical developmental changes are taking place before the commencement of formal schooling.

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