Refractive Error and Biometry in Older Chinese Adults: The Liwan Eye Study

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Purpose. To assess the prevalence of refractive error and describe the distribution of ocular biometry and its association with refraction in adult Chinese.

Methods. Random clustering sampling was used to identify adults aged ≥50 years in Liwan District, Guangzhou. Refraction was determined by subjective refraction that achieved the best corrected vision based on monocular measurement. Ocular biometry was measured by A-mode ultrasound using a handheld applanation probe.

Results. Among 1405 participants in the study, data from 1269 phakic right eyes were available for analysis. The prevalence of myopia (SE < -0.5 D), hyperopia (SE $> +0.5$ D), and astigmatism (cylinder > 0.75 D) was 32.3% (95% confidence interval [CI], 27.8%–34.6%), 40.0% (95% CI, 37.3%–42.7%), and 48.3% (95% CI, 45.6%–51.1%), respectively. The spherical equivalent tended to become hyperopic at 60 years and shifted toward myopia at 75 years. Axial length did not change with age but was consistently shorter in women. Lens thickness increased with age and tended to be greater in women.

Conclusions. The prevalence of myopia and biometric distribution in this urban Chinese cohort are similar to those observed in Singaporean Chinese but greater than in Mongolians and Europeans. Further studies are needed to clarify the role of environmental factors in the myopia rates. (*Invest Ophthalmol Vis Sci.* 2009;50:5130–5136) DOI:10.1167/iovs.09-3455

Uncorrected refractive error is increasingly recognized as a significant cause of avoidable visual disability worldwide and has been included as one of the priority areas of Vision 2020.[1] Similar to other quantitative biological traits, considerable interracial variability has been observed in the prevalence of refractive error. Myopia is reportedly more common in East Asian than in European[2–6] and African populations.[3,7] This difference is particularly noted when younger people in more industrialized areas are considered, such as Singapore,[8,9] Hong Kong,[10,11] Taiwan,[12] and Japan.[13] Although numerous epidemiologic data on refractive error are available for the adult populations in European and some East Asian nations, data from mainland China remain limited, hindering our understanding of the magnitude of this disease in one fifth of the world's population.

A refractive error may be defined as a state in which the optical system of the nonaccommodating eye fails to bring parallel rays of light to focus on the fovea. Therefore, refractive error is likely a consequence of a mismatch of the biometric parameters of the eyes (i.e., AL, corneal curvature, anterior chamber, lens thickness, vitreous chamber depth) and the refractive power of these structures.[10,14–17] If biometric data are not examined, the distribution and risk factors of refractive error may not be fully appreciated. In a recent study in Beijing the prevalence of refractive error was reported in adults living in northern China[18]; however, refraction data were obtained only for those with visual impairment. This limitation in the data may lead to substantial underestimation of both myopia and hyperopia. The biometric data were not described in that study. Furthermore, the situation in urban southern China remains largely unknown.

We therefore performed a population-based study of refractive error in the city of Guangzhou in southern China. The distribution of refraction and biometric data, as well as the association between them, are reported.

Methods

Approval for study of human subjects was obtained from the Ethics Committee of the Zhongshan Ophthalmic Center, Guangzhou Liwan District government, and the Research Governance Committee of Moorfields Eye Hospital (London, UK). The work was conducted in accordance with the tenets of the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from all subjects.

Detailed study procedures have been reported elsewhere.[19] In brief, cluster sampling was used to enroll 1405 subjects aged ≥50 years from Liwan District, Guangzhou. Noncycloplegic refraction data were collected with a handheld autorefractor (ARK-30; Nidek Corp., Gamagori, Japan). The autorefractor produced eight refraction values, each with a machine-calculated confidence index, along with an average weighted value. If the autorefractor did not generate valid readings, the examiner recorded a failure. The autorefractor also provided the corneal power (CP) index in diopters. Subjective refraction and best corrected visual acuity were measured by an optometrist in those with presenting visual acuity <20/40 in either eye, in which the optometrist used the autorefractor data as the starting point and then further refined the refraction in an attempt to achieve the best visual acuity based on monocular measurement. Distance visual acuity was measured using an ETDRS logMAR E chart (Precision Vision, Villa Park, IL) with a standard illumination box, according to standard protocol.

Anterior chamber depth (ACD), lens thickness (LT), and axial length (AL) of the globe were measured by using A-mode ultrasound (Echoscan US1800; Nidek, Corp.) before pharmacologic dilation of the

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Supported by a UCL Graduate School Research Scholarship and UCL Overseas Research Scholarship 2001061054, Grant 2005B30901008 from the Scientific and Technology Foundation of Guangdong Province, and Grant NCET-06-0720 from the Program for New Century Excellent Talents in University, Ministry of Education (all to MH), Grant G0401527 from the Medical Research Council, Grant 075110 from the Wellcome Trust, and the Richard Desmond Charitable Foundation (via Fight for Sight) (all PJF).

Submitted for publication January 24, 2009; revised March 25, and May 5 and 24, 2009; accepted July 31, 2009.

Disclosure: **M. He**, None; **W. Huang** , None; **Y. Li**, None; **Y. Zheng**, None; **Q. Yin**, None; **P.J. Foster**, None

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Table 1. Prevalence of Refractive Error in Adult Chinese

Age Group	*n*	Myopia (< −0.5 D)	High Myopia (< −5.0 D)	Hyperopia (> +0.5 D)	Astigmatism (>0.75 D)
Men					
50–59	207	31.4 (25.0–37.8)	6.3 (2.9–9.6)	30.9 (24.6–37.3)	33.8 (27.3–40.3)
60–69	162	36.4 (28.9–43.9)	8.0 (3.8–12.3)	47.5 (39.8–55.3)	50.0 (42.2–57.8)
70–79	154	32.5 (25.0–39.9)	1.9 (0–4.1)	46.8 (38.8–54.7)	63.6 (60.0–71.3)
80–93	32	40.6 (22.6–58.6)	3.1 (0–9.5)	37.5 (19.8–55.2)	68.8 (51.8–85.8)
All	555	33.7 (29.8–37.6)	5.4 (3.5–7.3)	40.5 (36.4–44.6)	48.8 (44.7–53.0)
Women					
50–59	260	31.9 (26.2–37.6)	4.6 (2.0–7.2)	24.6 (19.3–30.1)	29.6 (24.1–35.2)
60–69	214	27.1 (21.1–33.1)	5.6 (2.5–8.7)	50.9 (44.2–57.7)	54.2 (47.5–60.9)
70–79	197	30.5 (24.0–36.9)	4.6 (1.6–7.5)	48.7 (41.7–55.8)	60.4 (53.5–67.3)
80–93	43	51.2 (35.6–66.7)	0 (0)	30.2 (15.9–44.5)	69.8 (55.5–84.1)
All	714	31.2 (27.8–34.6)	4.6 (3.1–6.2)	37.5 (35.9–43.1)	47.9 (44.2–51.6)
Men and women					
50–59	467	31.7 (27.5–35.9)	5.3 (3.3–7.4)	27.4 (23.3–31.5)	31.5 (27.2–35.7)
60–69	376	31.1 (26.4–35.8)	6.6 (4.1–9.2)	49.5 (44.4–54.5)	52.4 (47.3–57.5)
70–79	351	31.3 (26.4–36.2)	3.4 (1.5–5.3)	47.9 (42.6–53.1)	61.8 (56.7–66.9)
80–93	75	46.7 (35.1–58.2)	1.3 (0–4.0)	33.3 (22.4–44.3)	69.3 (58.7–9)
All	1269	32.3 (29.7–34.9)	5.0 (3.8–6.2)	40.0 (37.3–42.7)	48.3 (45.6–51.1)
P (age)*		0.056	0.099	<0.001	<0.001
P (sex)*		0.352	0.524	0.706	0.563

* By χ^2 trend test.

pupils. The patients were examined in the sitting position. A handheld probe (applanation) was used for the measurement. The best trace from 10 individual measurements for each parameter was taken. If the standard deviation was greater than 0.13 mm for ACD, the readings with greatest variation were deleted, and the measurements were repeated. The ACD reading obtained from this measurement included the corneal thickness according to the operation manual.

Statistical Analysis

Refraction data were determined based on subjective refraction data if they were available (if presenting VA ≤ 20/40); otherwise, the objective autorefraction data were used. Since the refraction data of the left and right eyes were similar ($r = 0.804$, $P < 0.001$), the right eyes were arbitrarily chosen to represent a specific individual. Eyes with iatrogenic or pathologic conditions that compromised a reliable refraction measurement were excluded—for example, previous cataract surgery, media opacities, significant retinal problems, and optic atrophy. The refraction data were converted to the spherical equivalent (SE: sphere + ½ cylinder). Myopia was defined as SE < −0.5 D, among which, high myopia was further defined as SE < −5 D. Hyperopia was defined as SE > +0.5 D, and astigmatism was defined as cylinder power >0.75 D. These definitions were chosen to compare the data with other available data.

The multiple linear regression model was used to investigate the independent effects of ocular biometry and other demographic factors on spherical equivalents. Since the SE data, as a dependent variable, were not normally distributed, a Box-Cox conversion was conducted to minimize the skewness and kurtosis. The converted SE was approximate to normal distribution ($P_{skweness} = 0.998$, $P_{kurtosis} = 0.224$). Logistic regression was also used to identify risk factors for refractive error when it was classified as dichotomous variables, such as myopia, high myopia, and hyperopia.

Results

A total of 1405 subjects aged ≥50 years were examined, representing 75.3% of those eligible. Refraction data were considered inappropriate for analysis and thus were excluded in 136 right eyes, which included aphakia/pseudophakia (47 eyes), significant cataract that led to best corrected VA ≤ 20/40 (46 eyes), significant retinal problems where VA did not improve with refraction correction (such as retinal detachment and vascular proliferation, 9 eyes; high myopic retinopathy was not excluded), corneal opacity or transplantation (2 eyes), glaucoma with significant postoperative complication and vision loss (7 eyes), poor cooperation due to mental retardation, Alzheimer or Parkinson disease (6 eyes), and other causes (19 eyes). After these exclusions, data for 1269 eyes remained available for analysis. Those excluded tended to be older (*t*-test, $P < 0.001$) but with no difference in sex (χ^2 test, $P = 0.808$).

Among these 1269 subjects, the mean age was 64.4 ± 9.6 years, and 714 (56.3%) were women. The mean ages of the men and women were not significantly different (*t*-test, $P = 0.775$). The prevalence of myopia, high myopia, hyperopia, and astigmatism is summarized in Table 1. The prevalence of overall myopia (SE < −0.5 D), high myopia (SE < −5 D), hyperopia (SE > +0.5 D), and astigmatism (cylinder > 0.75 D) were 32.3% (95% confidence interval [CI], 27.8%–34.6%), 5.0% (95% CI, 3.8%–6.2%), 40.0% (95% CI, 37.3%–42.7%), and 48.3 (95% CI, 45.6%–51.1%), respectively. The χ^2 trend test suggests that the prevalence of myopia and high myopia was not associated with age, whereas these associations are statistically significant for hyperopia and astigmatism. The sex of the individual was not associated with any refractive error (Table 1).

Figure 1 illustrates the distribution of refraction (SE) in this population. The distribution was non-Gaussian, with a skew toward myopia (SK test, $P_{skewness} < 0.001$, $P_{kurtosis} < 0.001$). The mean, SD, median, and 25% and 75% percentiles were −0.36, 2.67, 0.25, −0.88, and 1.06 D, respectively. The SE tended to be more hyperopic in those aged 60 to 75 years but then became more myopic in older age groups. Although men and women did not differ in overall prevalence of myopia, women tended to be more myopic in the older age group. The median and 25th and 75th percentiles are summarized in Table 2.

Table 2 also summarizes the median and 25th and 75th percentiles for ultrasound biometric parameters, including AL, ACD, LT, and CP. In general, AL did not change with age, but was consistently shorter in women by an average of 0.51 mm. Mean ACD decreased with age in an approximately linear fashion. In the men, ACD tended to be deeper in those aged >80 years, although this trend in very old people was not

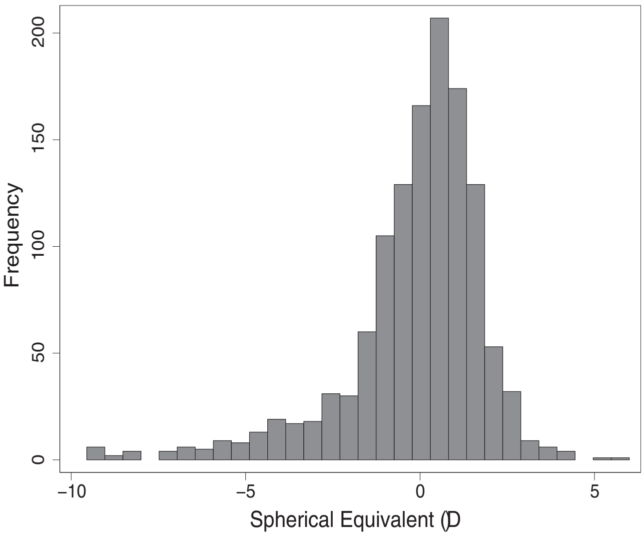

FIGURE 1. Distribution of SE on phakic right eyes.

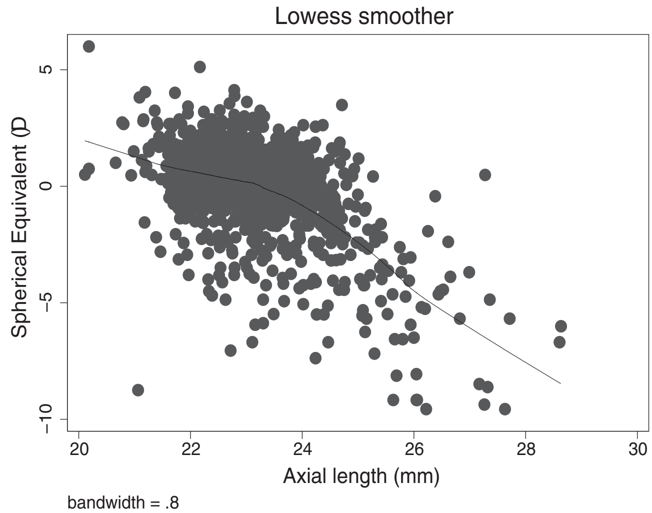

FIGURE 2. Lowess curve illustrates the association of SE and AL.

apparent among the women. AC depth was shallower in the women than in the men by an average of 0.14 mm. Converse to the patterns in ACD, lenses tended to be thicker in the older people and women. CP did not change with age but was consistently greater in the women, with a mean sex difference of 0.74 D.

Figure 2 illustrates the association between SE and AL, appearing to show a break point when AL was approximately 23 mm. Thus, two sections of linear regression were fit to the data: the regression coefficients suggested that SE decreased by −0.94 D for every 1 mm increase of AL when AL ≤ 23 mm (n = 556, R^2 = 0.12, P = 0.02), whereas this number was −2.04 D when AL > 23 mm (n = 640, R^2 = 0.70, P < 0.001).

A linear regression model was used to investigate the independent effects of ocular biometric components on refraction after adjustments were made for age and sex. The coefficient of the LT parameter was not statistically significant (P = 0.217), and ACD was highly co-linear with AL; therefore, they were not included from the regression model. Since the associations of AL and SE were substantially different in those with AL ≤ 23 mm and ≥23 mm, linear regression was fitted separately for these two groups. Table 3 summarizes the results of linear regression: When AL ≤ 23 mm, the regression model explained 12% of the SE variation, whereas the standardized regression coefficient (SRC) suggested that AL and CP contributed similarly to the SE variation; when AL > 23 mm, the model explained approximately 70% of the SE variation, and SRC suggested that AL (−0.81) was at least twice as important as CP (−0.30) in determining SE variation. Age and sex were not significant. We estimated that a 0.94-D myopic shift occurred for every 1-mm increase in AL and a 0.37-D myopic shift occurred for every 1-D increase of CP when AL ≤ 23 mm. These two shifts were 2.04 and 0.72 D when AL > 23 mm.

TABLE 2. Distribution of Ocular Biometry in Adult Chinese

Age Group	*n*	SE (D)	AL (mm)	ACD (mm)	LT (mm)	CP (D)
Men						
50–59	191	0.06 (−0.81, 0.81)	23.37 (22.72, 23.95)	2.83 (2.57, 3.11)	4.14 (3.61, 4.63)	43.50 (42.62, 44.44)
60–69	159	0.50 (−1.06, 1.25)	23.41 (22.83, 24.25)	2.71 (2.53, 2.94)	4.38 (3.56, 4.88)	43.40 (42.38, 44.19)
70–79	144	0.50 (−0.75, 1.19)	23.31 (22.86, 23.87)	2.68 (2.47, 2.88)	4.39 (3.60, 4.93)	43.56 (42.81, 44.62)
80–93	27	−0.10 (−1.00, 1.19)	23.65 (22.55, 24.19)	2.70 (2.38, 3.05)	4.49 (3.72, 5.21)	43.37 (41.75, 44.38)
All	521	0.25 (−0.88, 1.06)	23.38 (22.83, 24.00)	2.75 (2.53, 3.00)	4.32 (3.58, 4.82)	43.50 (42.56, 44.37)
Women						
50–59	243	−0.01 (−0.81, 0.50)	22.83 (22.31, 23.43)	2.72 (2.46, 2.95)	4.30 (3.59, 4.62)	44.06 (43.25, 45.06)
60–69	208	0.59 (−0.75, 1.37)	22.87 (22.32, 23.60)	2.59 (2.42, 2.82)	4.53 (3.54, 4.87)	44.25 (43.19, 45.19)
70–79	186	0.50 (−1.00, 1.43)	22.79 (22.32, 23.35)	2.56 (2.37, 2.73)	4.74 (3.82, 5.04)	44.44 (43.19, 45.25)
80–93	38	−0.63 (−1.56, 0.93)	22.98 (22.43, 23.36)	2.50 (2.30, 2.70)	4.69 (4.18, 5.12)	44.13 (43.38, 45.12)
All	675	0.25 (−0.87, 1.06)	22.83 (22.32, 23.46)	2.61 (2.42, 2.84)	4.50 (3.64, 4.84)	44.25 (43.25, 45.19)
Men and women						
50–59	434	0.00 (−0.81, 0.63)	23.08 (22.44, 23.74)	2.79 (2.53, 3.03)	4.26 (3.59, 4.62)	43.88 (42.94, 44.83)
60–69	367	0.50 (−0.88, 1.25)	23.14 (22.51, 23.84)	2.65 (2.44, 2.88)	4.47 (3.54, 4.88)	43.88 (42.81, 44.81)
70–79	330	0.50 (−0.87, 1.31)	23.08 (22.48, 23.60)	2.60 (2.41, 2.81)	4.64 (3.69, 5.00)	43.91 (43.12, 45.06)
80–93	65	−0.31 (−1.25, 1.00)	23.11 (22.54, 23.86)	2.57 (2.35, 2.80)	4.65 (3.78, 5.21)	43.87 (42.56, 44.62)
All	1196	0.25 (−0.88, 1.06)	23.11 (22.48, 23.74)	2.67 (2.45, 2.91)	4.44 (3.61, 4.84)	43.88 (42.94, 44.88)
Adj. β (Age)*		0.02	0.00	−0.007	0.013	0.003
P (Age)		0.054	0.513	<0.001	<0.001	0.507
Adj. β (F/M)*		0.08	−0.51	−0.136	0.095	0.743
P (Sex)		0.617	<0.001	<0.001	0.014	<0.001

Median (25th, 75th percentiles).

* Adjusted regression coefficient suggested by multiple linear regression model where age and sex were included as independent variables.

TABLE 3. Linear Regression Model for the Determinants of Spherical Equivalent*

Parameters	Nonstandardized Regression Coefficient (95% CI)	Standardized Regression Coefficient†	*P*
AL ≤ 23 mm (*n* = 556); R^2 = 0.12‡			
Age	0.00 (−0.01 to 0.02)	0.03	0.527
Female	−0.32 (−0.60 to −0.03)	−0.10	0.029
AL, mm	−0.94 (−1.24 to −0.64)	−0.30	<0.001
CP, D	−0.37 (−0.48 to −0.25)	−0.31	<0.001
AL > 23 mm (*n* = 640); R^2 = 0.70‡			
Age	0.01 (0 to 0.03)	0.04	0.071
Female	−0.24 (−0.54 to 0.06)	−0.04	0.118
AL, mm	−2.04 (−2.16 to −1.92)	−0.81	<0.001
CP, D	−0.72 (−0.83 to −0.60)	−0.30	<0.001
All; R^2 = 0.61			
Age	0.01 (0 to 0.02)	0.05	0.019
Female	−0.34 (−0.55 to −0.12)	−0.06	0.002
AL, mm	−1.79 (−1.88 to −1.70)	−0.87	<0.001
CP, D	−0.67 (−0.75 to −0.60)	−0.38	<0.001

* Spherical equivalent is the dependent variable in the model.

† Beta, standardized regression coefficient, calculated after converting all independent variables to standard distribution (mean, 0; standard deviation, 1).

‡ Adjusted R^2 in a linear regression model.

DISCUSSION

This is the first study to provide population-based data on refraction and ocular biometric parameters in a representative cohort of adult Chinese living in mainland China. We found that the men consistently had longer eyes, flatter corneas, deeper anterior chambers, and thinner lenses than did the women of all ages. However, the distributions of refractive errors were similar in both sexes. The overall prevalence of myopia (SE < −0.5 D) was 32.3% (95% CI, 29.7%–34.9%). The prevalence of myopia was slightly greater in older age groups. AL and CP were the most important determinants for refraction. The precise nature of the association between biometry and refraction differed between those with AL ≤ 23 mm and AL > 23 mm. In contrast to data from Singapore and Mongolia, we did not observe any age-specific differences in AL among our participants.

It has been believed that East Asians suffer the highest rates of myopia, people of African descent have low rates, and Europeans occupy an intermediate position in the spectrum.[20] However, this supposition was not fully supported by the existing data, at least in the adult population. Table 4 summarizes the age-specific rates of myopia and hyperopia in adults, derived from population-based studies with available published data based on similar definitions of refractive error and age categories. In people aged 50 to 59 years, where the subjects are less often affected by nuclear cataract, the rates of myopia are not remarkably different in the Guangzhou, Singapore, white Baltimore, and white Beaver Dam populations. This highlights that the prevalence of myopia may not always be higher in Chinese people. On the other hand, the higher rates of myopia in older populations (≥60 years) in Guangzhou in comparison to white populations may, in part, result from timely cataract surgery in developed areas that removes the nuclear cataract. In addition, the prevalence of myopia in Chinese living in Singapore[9] and Guangzhou (the present study) was very similar in those age ≥50 years—approximately 30%. However, this rate of myopia was much lower in the rural Mongolian population,[16] particularly in younger people (40–59 years) when the subjects are presumably less affected by nuclear cataracts in this age range. The reasons for this difference are not clear. However, notable lifestyle differences include the start of formal education at an older age—typically between 5 and 8 years of age in Mongolia—compared with greater, early exposure to preschool at the age of 2 to 5 years, as well as the much more intensive education systems in Singapore and Guangzhou. Dietary and metabolic factors have also been proposed as possibly influencing refractive error.[21] Since the age-specific prevalence of myopia was not given in the published data of the Beijing Eye Study, nor were details about the sampling technique and refractive assessment,[18] a valid comparison is difficult. However, based on the age-specific distribution (the median of spherical equivalent), the refractive error distribution in northern and southern China is, in general, similar, although a lower overall prevalence of myopia (21.8%) was reported in Beijing. Taking all these data together, East Asians living in urban settings, whether in Singapore, Japan, urban Guangzhou, or Beijing, have similar magnitude of myopia, which is much greater than in people living in rural Mongolia. This finding suggests that the observed variation in the myopia rates may also be attributable to significant environmental impact.

The variation in refractive error with age among adults has been reported in previous studies. Significant higher rates of myopia were found in younger Chinese Singaporeans (48.7% in 40–49 vs. 26.4% in 50–59 years),[9] Japanese (70.3% in 40–49, 49.6% in 50–59 vs. 20.8% in 60–69 years),[13] African-Americans in Baltimore (28.9% in 40–49 vs. 18.4% in 50–59),[3] and white Americans in Baltimore (42.1% in 40–49 vs. 26.5% in 50–59).[3] These observations suggest higher rates of myopia ametropia in younger people. However, the competing effects of increasing lens nuclear sclerosis and greater AL both driving refraction toward myopia make a definitive explanation of the etiology of the refractive changes problematic without biometric data. Fortunately, two previous population studies that reported the prevalence of refractive error in adult East Asians also reported ultrasound biometric data, in populations in Mongolia,[16] Singapore,[22] and, currently, Guangzhou. The AL means were similar (~23 mm) and did not differ among people of different ages in the Singapore, Mongolia, and Guangzhou cohorts among people aged ≥60 years. However, significantly longer eyes were observed in younger Singaporeans (23.60 mm in 40–49 years vs. 23.35 mm in 50–55 years). This finding is consistent with data from studies of younger populations in industrialized regions of East Asia.[12,23,24] The explanation for

Table 4. Comparison of Age-Specific Prevalence of Myopia and Hyperopia in Selected Population-Based Studies with Comparable Data

Ethnicity	Selected Studies	Age Categories (y)				
		40–49	50–59	60–69	70–79	80+
Myopia (SE < −0.5D)						
Chinese	Liwan (Urban/China)	—	31.7	31.1	31.3	46.7
Singaporean Chinese	Tanjong Pagar (Singapore)*	48.7	26.4	30.0	36.4	—
Chinese	Shihpai (Taiwan/China)	—	—	12.8	21.6	23.3
Mongolian	Mongolia	15.6	12.5	21.4	26.5	—
Japanese	Tajimi (Japan, Male)†	70.3	49.6	20.8	13.5	21.6
Japanese	Tajimi (Japan, Female)	67.8	42.4	22.1	18.6	24.6
Blacks	Baltimore (US, Female)†	28.9	18.4	13.8	12.5	25.5
Blacks	Baltimore (US, Male)	34.0	25.2	16.0	12.6	10.5
Black	Barbados (West indies)	17.0	11.1	20.7	41.8	55.1
White	Baltimore (US, Female)	42.1	26.5	17.5	18.6	12.9
White	Baltimore (US, Male)	39.3	23.0	19.2	19.0	12.8
White‡	Beaver Dam (US)	42.9	25.1	14.8	14.4	—
White§	Blue Mountain (Australia)	25.4	14.4	11.0	11.5	10.3
Hyperopia (SE > +0.5 D)						
Chinese	Liwan (Southern Urban)		27.4	49.5	47.9	33.3
Singaporean Chinese	Tanjong Pagar (Singapore)*	11.3	45.2	46.9	38.6	—
Chinese	Shihpai (Taiwan/China)			62.9	59.2	50.7
Mongolian	Mongolia	24.0	31.0	44.6	51.5	—
Japanese	Tajimi (Japan, Male)†	2.1	18.4	47.2	56.5	56.8
Japanese	Taijimi (Japan, Female)	2.9	19.8	47.4	63.8	60.9
Black	Baltimore (US, Female)†	16.7	42.5	59.3	65.9	61.7
Black	Baltimore (US, Male)	11.8	24.4	38.8	54.1	57.9
Black	Barbados (West indies)	28.8	64.9	58.9	39.4	29.9
White	Baltimore (US, Female)	14.7	43.9	61.2	63.0	60.2
White	Baltimore (US, Male)	16.7	42.6	51.5	63.9	68.1
White‡	Beaver Dam (US)	22.1	50.2	67.2	68.5	—
White§	Blue Mountain (Australia)	26.9	53.5	68.0	68.6	74.4

* In the published data, age-specific rates (%) were reported for those aged 70 years and over but data were not available specifically for 80+ years.

† Data were presented separately for males and females; information in the article do not allow calculate age-specific rates regardless of sex.

‡ Age group was categorized as 43-54, 55-64, 65-74, 75+ years.

§ Age group was categorized as 49-54, 55-64, 65-74, 75-84, 85+ years.

the dramatic apparent increase in myopic refractive error in urban East Asians is not clear. It has been shown there is an association between greater myopia and greater exposure to near work in both children and adults.[25,26] Other lifestyle and environmental factors have been proposed as possible determinants of refractive error.[21] The present study was performed in 2003, and we enrolled subjects aged 50 years and older; therefore, most subjects were born before the 1950s. At that time, when most of our participants should have received a high school and college education, the education system was significantly weakened by the effects of the Japanese War (1938–1945), the Civil War (1945–1949), postwar recovery (1950–1960), and the Cultural Revolution (1966–1976). Therefore, it seems possible that the subjects in the present study were not exposed to the effects of a well-resourced and competitive education system. However, unfortunately, the present study did not include those aged 40 to 49 years or even younger—in which the rate of myopia might be greater. This limitation may explain why a higher prevalence of myopia was not observed in younger cohorts. On the other hand, given our recent data that indicated that approximately 80% of Chinese children have myopia at the age of 15 years,[27] one may reasonably expect this group of myopic children to remain myopic into adulthood. Furthermore, one has to be cautious that the refractive error was determined with noncycloplegic refraction and subjective refraction in the present study, which may overestimate the prevalence of myopia in younger people, although this effect is probably small for those aged 50+ years.[28]

The prevalence of hyperopia exhibits a different pattern with age. In our study, the rates of hyperopia started to increase in those aged 60 to 69 years (49.5% in 60–69 vs. 27.4% in 50–59 years). This apparent increase in hyperopia occurs at similar ages in Japanese but earlier in Singaporean Chinese and white and black Baltimore populations. Based on the median value of spherical equivalent, in our study, the 60- to 69-year cohort had an approximately 0.50-D hyperopic shift in comparison with the 50- to 59-year cohort. Since the AL and CP were similar in these two age groups, the difference in refraction is likely due to changes in the lens. In fact, our data suggest that people aged 60 to 69 years had a 0.20-mm-thicker lens than the younger age group, which is similar to the studies conducted in Singapore, Mongolia, and elsewhere.[16,22] Since a thicker lens will create myopic refractive error, the observed hyperopic shift is most likely a consequence of a decrease in the lens refractive index, which has been suggested by Mutti and Zadnik[29] and Hemenger et al.[30]

Sex differences in refractive error have been reported previously, but the data are not consistent. Studies conducted in Baltimore,[3] Singapore,[9] Sydney,[6] and Barbados[7] did not identify significant sex differences, while studies conducted in Shihpai[31] and Beijing[18] found that women were likely to be more hyperopic. The present study did not identify a sex difference in spherical equivalent distribution based on the univariate linear regression model and logistic regression models (for both myopia and hyperopia). However, when the ocular biometric indexes were adjusted for, women tended to be slightly more hyperopic (Table 3).

The rate of high myopia (defined as SE < -5 D) was 5.0% in the present study, which is slightly lower than in the studies in Singapore (7%),[9] but greater than those conducted in Beijing (2.6% if SE < -6 D),[18] Baltimore (1.4%, SE < -6 D),[3] and the Blue Mountains in Sydney (3.0%, SE < -4.0 D).[6] The fact that those with high myopia also had high rates of blindness and low vision (6.5% for both) based on best corrected VA, found in the present study, highlights the importance of identifying the etiology of myopia, and investigating strategies to prevent the onset and progression of myopia.

Refractive astigmatism was found to increase with age but was not associated with the sex of the individuals in our study. This age pattern has also been consistently found in other studies.[3,6,9,13,16,32] The age-specific prevalence of astigmatism in Guangzhou was similar to reports in Japanese,[13] Singaporean Chinese,[9] and Singapore Malay populations,[8] but greater than those found in Bangladeshi,[32] white, and black populations.[3] Since the presence of astigmatism is associated with the degrees of ametropia (myopia),[33] the difference in prevalence may largely be attributable to the different level of spherical refractive error in the populations, although age, sampling, definition, and genetic differences may also be considered.

The analysis of the association between refractive error and biometric measures is complicated by the presence of coexisting lens nuclear sclerosis in older adults. The current analysis excluded eyes with significant cataracts (indicated by best corrected VA $<$ 20/63) or coexisting eye diseases (significant retinal disorders and glaucoma) since both objective and subjective refraction examinations were either difficult or not possible. After adjustment for the effects of age and sex, we found that AL is the major determinant of refractive error (2.04-D myopic shift per 1-mm AL increase, and 0.81 myopic shift per 1 SD increase of AL), followed by CP (0.72 myopic shift per 1-D increase in CP, and 0.30 myopic shift per 1-SD increase in CP), whereas variation in LT was not significantly associated with refraction. It was also interesting to find that the association of refraction and biometry appeared to differ between those with AL $\leq$ 23 mm versus AL $>$ 23 mm. The R^2 of linear regression was only 0.12 in people with AL $\leq$ 23 mm (compared with 0.70 when AL $>$ 23 mm), which suggests that refraction tends to be less AL-dependent and may be more related to lens power change when eyes are emmetropic or hyperopic. This pattern of association between AL and refraction has been consistently found in Sydney children (Rose KA, et al. *IOVS* 2007;48:ARVO Abstract 1535). Higher rates of myopia in older people have been documented in other studies, and attributed to proportionally higher rates of lens nucleus sclerosis (and hence refractive index) occurring with older age.[8,9,34] This myopic shift in the older age group was consistently found in the present study, although we were not able to gather lens opacity data.

The principal strength of our study was that the findings were based on both refraction and biometric data in a population-based random sample. The weaknesses, as already mentioned, include the use of noncycloplegic refraction that may overestimate the myopia rate in some younger subjects. Our study did not include those younger than 50 years and therefore may not cover the young myopic cohort well. Finally, further studies examining environmental factors may help in understanding the differences in refractive error in a genetically similar population, such as Chinese, Singaporean Chinese, and Mongolian.

In summary, our data describe the distribution of refractive error by age and sex in older adults in the People's Republic of China. In addition, we present biometric data associated with refraction and identify a possible role of variation in LT in the emmetropization process of ocular development. Comparison of our data with those from other major urban centers in East Asia may offer new and important insights into the etiology of myopia, particularly with respect to the unique lifestyle and environmental factors to which the Chinese population has been exposed over the past 50 years.

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