Abstract

Purpose: To characterize astigmatism as a function of age in a Hong Kong clinical population.

Methods: All new clinical records during 2007 at a university optometry clinic were used. Only data from subjects with visual acuity ≥6/9 in both eyes and with completed subjective refraction were analyzed. The subjects were divided into seven age groups (i.e., 0-10yrs, 11-20yrs, ..., >60yrs). Refractive errors were decomposed into spherical-equivalent refractive error (M), J0 and J45 astigmatic components for analyses. Internal astigmatism was calculated by subtracting corneal astigmatism from refractive astigmatism.

Results: Of the 2759 cases that fulfilled our selection criteria, 58.9% had myopia (M≤−0.75D) and 28.4% had refractive astigmatism (Cyl≥1.00D). The prevalence of refractive astigmatism increased from 17.8% in 0-10yrs age group to 38.1% in 21-30yrs age group but remained high in >60yrs age group (41.8%). Among the astigmats, almost all children (92.6%) had with-the-rule astigmatism but a majority of the elderly (63.0%) had against-the-rule astigmatism. For a subset of subjects who had both subjective refraction and keratometric readings (n=883), refractive astigmatism was more strongly correlated with corneal (r=0.35~0.74) than with internal astigmatism (r=0.01~0.35). More importantly, the magnitudes of both refractive and corneal J0 were consistent with synchronized in phase (-0.14D per 10yrs) after age of 30.

Conclusions: In this Hong Kong Chinese clinical population, the prevalence rates of myopia and astigmatism were high and shared similar trend before the young adulthood. The manifest astigmatism was mainly corneal in nature, bilaterally mirror symmetric in axis, and shifted from predominantly WTR to ATR over age.

Keywords: Astigmatism, Refractive errors, Hong Kong Chinese, Myopia, Prevalence

Introduction

Astigmatism is a common refractive error that affects both normal and diseased eyes. Of particular concern are the findings that significant amounts of astigmatism are more prevalent in adults after the age of forty,[1-3] and astigmatism is highly prevalent in school-age children (28%[4] in United States (see also ref 5); 23-58% in urban areas of Asian countries[6-9]), populations of Native American,[10-12] and those with ocular diseases such as albinism and retinitis pigmentosa.[13, 14] Even with spectacle corrections, some members of the affected populations were frequently found to have abnormal retinal electrophysiology,[15] abnormal refractive development,[6, 16] amblyopia[17-19] and migraine headache.[20]

Astigmatism, particularly high amounts of astigmatism, is frequently associated with significant spherical ametropias in humans[21] and in animal models.[22, 23] People with low degrees of spherical ametropia usually exhibit small amounts of astigmatism while subjects with high amounts of spherical ametropia (i.e., myopia or hyperopia) frequently exhibit high amounts of astigmatism.[21, 24-28] In this regard, it has been reported that the magnitude of astigmatism and the amount of myopia are linearly correlated in both children[29] and young adults.[27, 30]. Indeed, significant astigmatism and/or against-the-rule astigmatism have been speculated to alter the emmetropization process and promote myopia development.[16, 25, 27, 31]

Unlike hyperopic or myopic refractive errors, the optical effects of which can be reduced by accommodation or changing in viewing distance, astigmatism constantly degrades eye's image quality and adversely affect the quality of life.[20] However, although the prevalence of refractive errors has been reported in several different populations worldwide, studies reporting the characteristics of astigmatism in Chinese population were either focusing on particular age cohorts and/or adopting different definition of astigmatism.[6, 7, 9, 33-37] The primary goal of this study was to determine the prevalence of common refractive errors, in particular astigmatism, as a function of age in a Hong Kong Chinese clinical population. The secondary goal was to characterize the properties of astigmatism in this affected Chinese population.

Methods

All refraction and ocular biometry records of new clinical cases of Chinese patients (n=5138) who attended Primary Care Clinic at the Optometry Clinic of The Hong Kong Polytechnic University during 2007 were used for analysis. The optometry clinic on campus provides clinical training for optometry students and primary eye care to the Hong Kong public from different age, occupation and social levels. Each clinical case was a result of diagnostic eye examinations done by a registered Clinical Optometrist or a working pair of a student optometrist and an experienced clinical supervisor. The biometric data, including patients' demographic information (gender and age), unaided and aided visual acuity, refractive errors determined by subjective refraction (specified in minus-cylinder correcting lens form), and the keratometric readings measured by auto-keratometers, were retrieved for analysis. The exclusion criteria were incomplete demographic information (n=87, 1.7%), incomplete/absent subjective refraction recording (n=438, 8.5%), and aided visual acuity worse than 6/9 (n=1854, 36.1%). Poor visual acuity was mainly found in the youngest and oldest age groups because of the inability to identify letters, under-development of visual function in infants; and the age-related ocular pathologies such as cataract and ARMD in elderly. Data from the remaining 2759 subjects were used in further data analyses.

Statistical analyses were done using Minitab 15.1.30.0 (Minitab Inc., USA) with significance level set at $\alpha<0.05$. To do this, each refractive error was first decomposed into spherical-equivalent refractive error (M), J0 and J45 astigmatic components according to Fourier analysis.[38] We defined myopia and hyperopia as spherical-equivalent refractive error (M) ≤–0.75D and ≥0.75D, respectively. Refractive astigmatism (RA) and high RA were defined as astigmatic errors (Cyl) ≥1.00D and ≥2.00D, respectively. Internal astigmatism (IA) was calculated by subtracting corneal astigmatism (CA) from the manifest astigmatism (RA). In addition, RA was further classified as with-the-rule (WTR axis: 0°-15° or 165°-180°), against-the-rule (ATR axis: 75°-105°) and oblique astigmatism (axis: 16°-74° or 106°-164°). Symmetries between axes of right and left eyes were determined by the "reflected difference" in astigmatic axes for subjects who had ≥1.00D of astigmatism in both eyes. Reflected differences were calculated individually by subtracting the reflected axis in the left eye from the axis in the right eye, *i.e.*, right astigmatic axis − (180°−left astigmatic axis). Data were stratified into seven age groups (0-10yrs, 11-20yrs, 21-30yrs, 31-40yrs, 41-50yrs, 51-60yrs and >60yrs). Two-way ANOVA was applied to evaluate the effect of age and gender on the amount of myopia and the magnitude of astigmatism. Multivariate logistic regression was conducted to test the association between refractive errors (myopia, hyperopia or astigmatism) and age or gender. Chi-square test for trend was used to test significance of the change in the orientation of the astigmatism (WTR, ATR or OBL) over age. Spearman correlation coefficient was computed to determine the levels of correlation between spherical refractive error (M and principal power meridians) and components of astigmatism (Cyl, J0 and J45).

Results

Effects of Age and Gender on refractive errors

Of the 2759 cases included for analysis, there were 1573 (57.0%) females and 1186 (43.0%) males. Subjects were aged 3 to 84 years with M and Cyl ranged from +3.18D to –19.00D and from 0.00D to 6.50D, respectively. Since M and Cyl in the right and left eyes were highly correlated (Spearman correlation's r: M= 0.94; Cyl= 0.66, all $p<0.001$), the following analyses will only present data from right eyes unless otherwise stated. Table 1 summarizes refractive errors in the seven age groups by gender. Overall the magnitudes of M varied significantly with age (Two-way ANOVA, age effect, $p<0.001$). There was also a significant interaction between age and gender for M component ($p=0.002$). Females appeared to be more myopic between 11 to 40 years while males appeared to be more myopic after age of 40 years with significantly more myopia observed in the 51-60 year-old males. The magnitude of Cyl was also age dependent (Two-way ANOVA, age effect, $p<0.001$) but there was no significant interaction between age and gender for Cyl ($p=0.64$). The mean Cyl were similar between females and males (Cyl: female= 0.68±0.73D, male= 0.65±0.72D; all $p>0.50$).

Prevalence of Myopia, Hyperopia & Astigmatism

The overall prevalences of myopia, hyperopia and refractive astigmatism (≥1.00D) were 58.9% (95% CI=57.0%-60.7%), 10.9% (95% CI=9.8%-12.1%) and 28.4% (95% CI=26.7%-30.1%), respectively. As shown in Table 2, the prevalence of myopia increased from 19.1% in the youngest age group (0-10yrs), peaked (84.7%) in the 21-30yrs age group, stayed high before 40 years and dropped to 28.2% in the oldest age group (>60yrs). In contrast, the prevalence of hyperopia started at 20.7% in the youngest age group and decreased to single digits in 11-12yrs, 21-30yrs and 31-40yrs age cohorts, it then climbed back and peaked at 36.7%% in the oldest age group. Interestingly, the prevalence of refractive astigmatism (≥1.00D) appeared to show two peaks, one in 21-30yrs age cohort and the other one in the oldest age cohort (>60yrs), although the prevalence was slightly higher in the later group (38.1% vs. 41.8%). However, if astigmatism was defined as a magnitude ≥2.00D, then the prevalence of astigmatism followed the trend of those for myopia, i.e., increased from the youngest age group to a peak at 21-30yrs age cohort, and decreased afterwards. As shown in Table 3, the prevalence of myopia, hyperopia and refractive astigmatism were significantly related to age (logistic regressions, all $p<0.001$) but not gender (all $p>0.20$). Compared with 0-10yrs age group, all the other age groups had an increased risk of having myopia and the odd ratio (OR) was highest in the 21-30yrs age group (OR= 23.81, $p<0.001$). However, compared to the 0-10yrs age group, the risk of having hyperopia decreased in almost all older age groups except those who were older than 50 years. The lowest and highest ORs for hyperopia were found in 11-20yrs (OR= 0.10, $p<0.001$) and >60yrs age groups (OR= 2.18, $p<0.001$), respectively. Older age groups also had increased risks of having significant amounts of astigmatism (either Cyl>=1D or Cyl>=2D (data not shown)). The risk was the highest in >60yrs age group (OR= 3.29, $p<0.001$) and was second highest in 21-30yrs age group (OR= 2.82, $p<0.001$).

Characteristics of astigmatism

Types of astigmatism

Figure 1 showed the proportion of WTR, ATR and oblique RA (≥1.00D) in the seven age cohorts. There was a significant increase in the prevalence of WTR astigmatism and a decrease in prevalence of ATR astigmatism with age (Chi squared for trend, p<0.001). WTR astigmatism was highly dominant in 0-10yrs age group (92.6%, CI=83.7%-97.6%) but gradually reduced to 2.7% (CI=0.3%-9.4%) in the >60yrs age group. In contrast, the proportion of ATR astigmatism increased from 2.9% (CI=0.4%-10.2%) in 0-10yrs age group to 79.7% (CI=68.8%-88.2%) in >60yrs age group. On the other hand, the proportion of oblique astigmatism changed less dramatically across the age cohorts compared to those of ATR and WTR astigmatism, it increased from 4.4% (CI=0.9%-12.4%) in the youngest age group to a peak at 23.6% (CI=17.7%-30.2%) in 41-50yrs age groups, and later reduced to 17.6% (CI=9.7%-28.2%) in >60yrs age group.

Correlations between refractive, corneal and internal astigmatism

To characterize the relationship between refractive, corneal and internal astigmatism, a total number of 883 cases which had both subjective refraction and keratometric readings were used for analyses. Our results showed that the correlation coefficients between refractive and corneal astigmatic components (Spearman correlation's r: Cyl= 0.35; J0= 0.74; J45= 0.52, all p<0.001) were higher than those between refractive and internal astigmatic components

(Spearman correlation's r: Cyl= 0.01, p= 0.67; J0= 0.33; J45=0.35, all p<0.001). Figure 2 illustrate the changes in astigmatic error (Cyl), J0 and J45 astigmatic components for refractive, corneal and internal astigmatisms. It should be noted that whereas the magnitudes of J45 components were fairly stable over time, the changes in J0 components for both RA and CA appeared to be synchronized in different age groups. Consequently, when corneal J0 finally reduced to zero in the eldest age group, the manifest J0 astigmatic component was solely contributed by the internal astigmatism.

Symmetry of Astigmatic Axis

Both refractive and corneal astigmatic axes were frequently bilaterally mirror symmetric. Figure 3 shows the frequency distribution of these reflected differences in astigmatic axes for refractive (n = 509) and corneal astigmatisms (n= 102). The fact that the majority of cases had reflected differences clustered around zero (e.g., within the range –20°~+20°: refractive= 64.0%; corneal: 57.8%) indicate that the axes in both eyes were frequently mirror symmetric.

Correlations of astigmatic components with principal powered meridians

Table 4 summarizes the correlations of the manifest astigmatic components with spherical components for myopes and hyperopes. In general, although all correlations between spherical ametropia and refractive astigmatism were small except those between MHM and Cyl in hyperopes, they were statistically significant. In both myopic and hyperopic groups, the strongest correlations with astigmatic components were always found along the most ametropic meridians. Furthermore, much stronger correlations were found between spherical components with J0 component when compared to J45 component. Indeed, the J45 astigmatic components had only very weak or no correlations with the spherical components.

Discussion

In this clinical population, we have found that: 1) age but not gender had significant impacts on M and Cyl; 2) the most prevalent astigmatism was in the oldest age group (>60yrs); 3) WTR astigmatism was predominant in children and ATR astigmatism was predominant in the elderly; and 4) the manifest astigmatism was mainly corneal in nature, bilaterally mirror symmetric in axes and correlated more strongly with the more ametropic meridian.

As shown in Figure 4A, the age-related changes in the prevalence of myopia were very similar in the current (gray area: 95% confidence intervals) and previous studies (open symbols) conducted in Hong Kong.[34, 35, 39-47] Specifically, the prevalence of myopia increased rapidly over the first two decades, reached a peak in the thirties, then decreased gradually afterwards. This rapid increase in the first two decades was found not only in Hong Kong population but also in other studies of Chinese population. For instance, in Shunyi District of China, the prevalence of myopia (<–0.50D) increased from zero in 5 year-old children to 36.7% and 55.0% in 15 year-old male and female teenagers, respectively.[48] In Taiwan, the prevalence of myopia (<–0.25D) has also been shown to increase from 21% at the age of 7 to 81% at the age of 15.[49] In addition, a longitudinal study conducted in Japan also reported an increase in the prevalence of myopia (≤–0.5D) from 43.5% at the age of 12 to 66.0% at the age of 17.[50] It is worth noting that, in the current study, after the prevalence of myopia reached its peak at 21-30yrs, it decreased at a slower rate in the later adulthoods (mean prevalence rates >40yrs: 28.2%-65.5%) when compared to a previous study conducted in 1994 for a Hong Kong population (>40yrs: 8.6%-46.2%).[35] One possibility for this difference might be a birth cohort effect. It appears that the increased prevalence of myopic adults (>40yrs) in the current study (Fig. 4A) is a result of the data from a previous study[35] being shifted horizontally to the right of the figure. The other possibility might be the differences in characteristics between the sample from a clinical population in our study and the sample from the previous study. For instance, our Optometry Clinic is well known to local society in providing comprehensive eye care services to the public. It is possible that people with comparatively complicated refractive status are self-selected to receive eye examinations from our clinic. However, given the facts that strict exclusion criteria was applied and that the prevalence of myopia in the younger age groups were very similar in the current and previous studies, we believe this self-selected bias would be minimal especially in the younger age groups. Thus, as reflected from the comparison between current and previous studies, the prevalence of myopia remained high for younger age cohorts across different studies but tends to be higher for older age cohorts in the current study.

Figure 4B illustrates the prevalence of refractive astigmatism in our study and previous studies using similar definition of refractive astigmatism for Hong Kong Chinese populations. Among the seven age cohorts, the prevalence of RA (≥1.00D) was the lowest in children (0-10yrs: 17.8%). This prevalence rate is similar to those reported in Singaporean children (19.2%)[36], but is either higher than those reported in Australian (4.8%)[51] and Indian children (0.2%)[52], or lower than that found in Native American children (42%).[53] However, when adopting lower magnitudes for the definitions of astigmatism, the prevalence of refractive astigmatism in this study (Cyl≥0.75D, 24.9%; Cyl≥0.50D, 41.9%) was similar to those reported in other Asian populations including southern China (Cyl≥0.75D, 26.3%),[7] Malaysia (Cyl≥0.75D, 21.3%),[33] and Taiwan (Cyl≥0.50D, 42.5%).[9]

The two surges in the prevalence of manifest astigmatism, one in young adults (20-30 year) and the other in elderly (>60-year) groups, are worrisome (Fig. 4B). The high prevalence of refractive astigmatism in the older age group (>60 years) observed in our study agree with several previous studies focusing on Asian populations. In particular, the prevalence of refractive astigmatism increased from 39.9% (40-49yrs) to 91.3% (>80yrs) in Japan (Cyl>0.50D),[54] from 67.8% (65-69yrs) to 84.9% (>80yrs) in Taiwan (Cyl>0.50D)[55] and from 21.0%-25.2% (40-49yrs) to 58.5%-67.1% (70-80yrs) in Singapore Malays (Cyl>0.50D).[56] Likewise, the Tehran Eye Study (Iran, Cyl≥0.50D) and the Botucatu Eye Study (Brazil, Cyl≥0.50D) have also reported an age-related increase in the prevalence of refractive astigmatism (Iran[57]: 36.5% at 5-15yrs to 81.2% at >56yrs; Brazil[58]: 25.8% at <10 yrs to 71.1% at ≥70yrs), and a shift in astigmatic axis from with-the-rule (WTR) to against-the-rule (ATR) when aging.[57] On the other hand, the higher prevalence of refractive astigmatism in adulthood has also been reported in the Botucatu Eye Study, but the surge was observed in the 4th decade of life (30-39 years) rather than the 3rd decade as found in our study.[58] What causes the surges in the prevalence of astigmatism in these two age groups is an urgent question of clinical and biological significance. It should also be reminded that because the astigmatic blur could not be alleviated by changing in working distance or eye's accommodative effort, financial burden due to the expenses on ophthalmic aids would certainly be increased with aging population.

The characteristics of astigmatism we found from this population, including the age-related shift (WTR to ATR) in astigmatic axis,[59, 60] bilateral symmetry in axis direction,[61] and the correlations between astigmatic components with the most ametropic principal power meridian,[21] were in close agreement with previous studies. One important aspect for the age-related shift in astigmatic axis is that because the prevalence of oblique astigmatism was quite stable after teenage (Fig. 1), the shift in astigmatic axis with age is probably a consequence of the changes related to horizontal and/or vertical meridians only. This speculation is supported by the finding that both refractive and corneal J0 components, but not J45 components, showed a synchronized decrease in magnitudes when aging (Fig. 2); thus, when the contribution of corneal J0 component finally reduced to zero in elderly, the internal astigmatism dominated the manifest astigmatism. These characteristics of astigmatism with age, while waiting for further confirmation from longitudinal data, provide important foundation when developing ophthalmic aids and designing refractive surgery for this affected clinical population.

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Figures

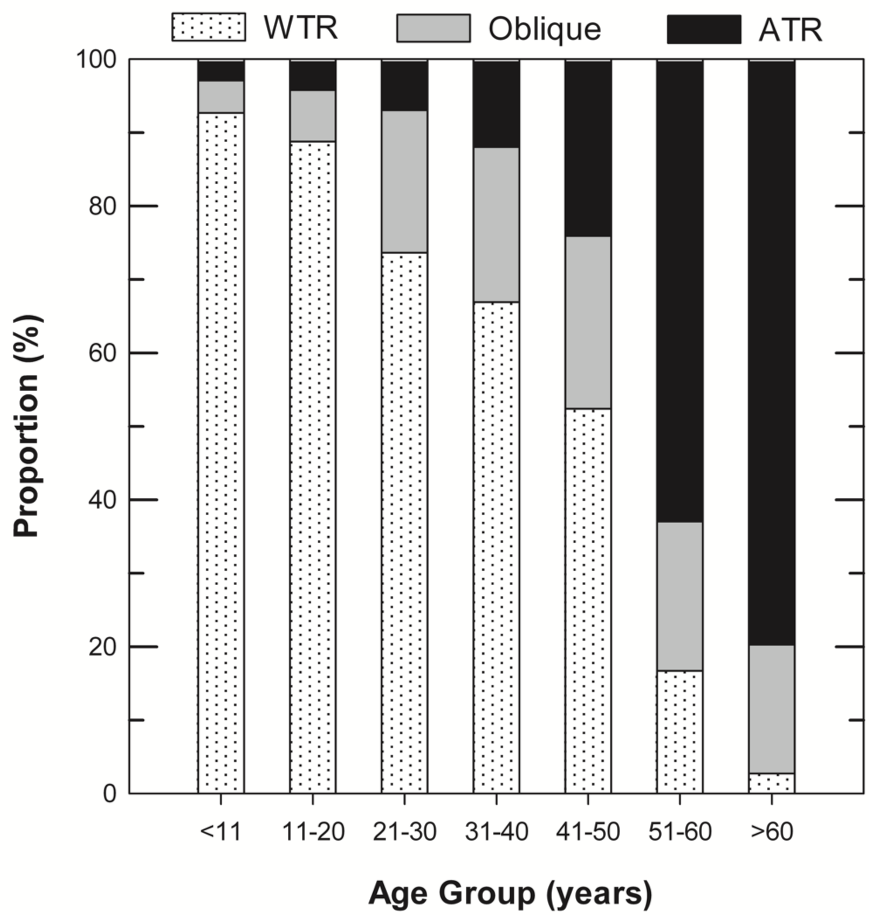

Figure 1. Proportion of WTR, ATR and oblique refractive astigmatism (≥1.00D) in the seven age groups.

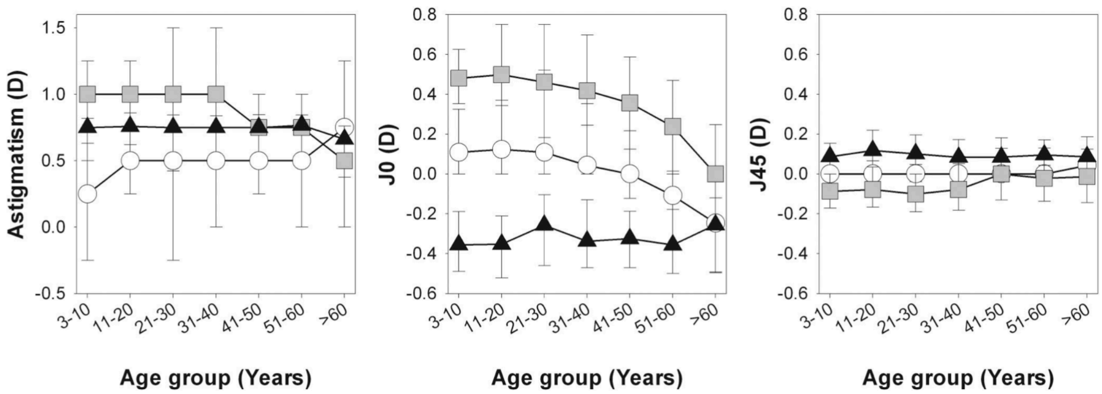

Figure 2. The magnitudes (mean±SE) of cylinder (left), J0 (middle) and J45 astigmatic components (right) as a function of age for refractive (○), corneal (■), and internal astigmatism (▲).

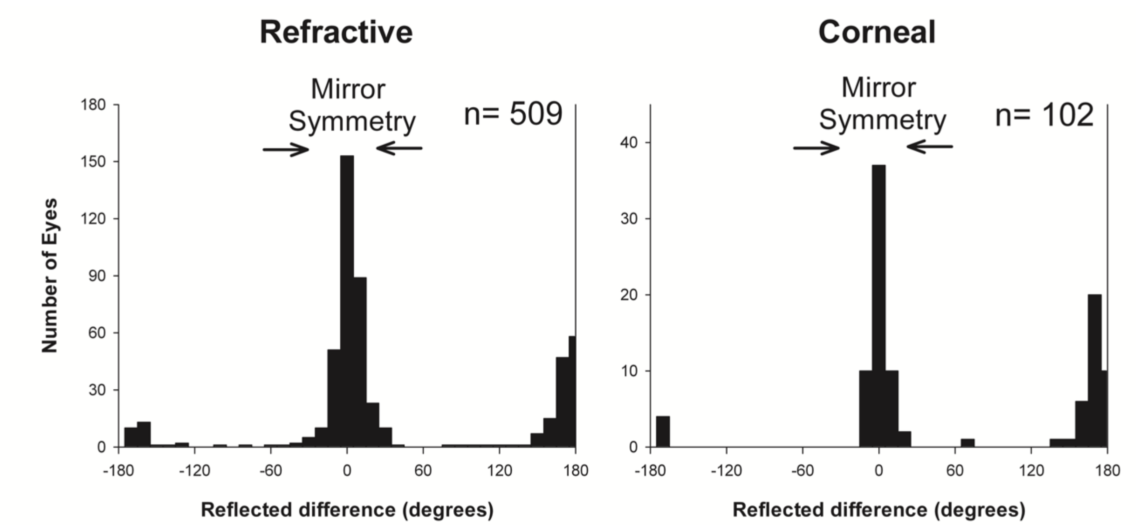

Figure 3. Frequency distributions of reflected differences (right axis － (180°－left axis)) in refractive (n=509) and corneal (n=102) astigmatic axes.

Table 1. Demographic information and refractive errors in the seven age groups.

Age Groups	Gender	Number	Age (mean±SE)	M (mean±SE)	Cyl (mean±SE)
<11	F	161	6.88±1.93	−0.21±2.18	0.49±0.80
	M	221	7.03±1.86	−0.28±1.78	0.47±0.66
11-20	F	121	14.87±3.31	−2.94±2.62	0.85±0.87
	M	105	14.85±3.00	−2.68±2.32	0.68±0.70
21-30	F	197	25.79±2.78	−4.53±3.20	0.84±0.74
	M	142	25.75±2.93	−3.94±3.13	0.86±0.95
31-40	F	326	35.92±2.84	−4.01±3.30	0.69±0.81
	M	163	35.77±2.91	−3.40±3.15	0.73±0.78
41-50	F	428	45.01±2.80	−2.75±2.96	0.63±0.67
	M	313	45.13±2.62	−2.86±3.01	0.61±0.64
51-60	F	238	55.04±2.82	−1.09±2.74	0.61±0.54
	M	167	55.14±2.56	−2.08±3.34**	0.62±0.59
>60	F	102	65.91±4.86	−0.07±2.22	0.80±0.58
	M	75	66.95±5.94	−0.26±1.99	0.86±0.67

** $p<0.01$, male vs. female.

Table 2. Prevalence (95% CI) of myopia, hyperopia and astigmatism in the seven age groups.

Age groups	n	Prevalence			
		Myopia M≤-0.75D	Hyperopia M≥0.75D	Astigmatism Cyl≥1.00D	Astigmatism Cyl≥2.00D
<11	382	19.1 (15.3-23.4)	20.7 (16.7-25.1)	17.8 (14.1-22.0)	5.8 (3.6-8.6)
11-20	226	75.2 (69.1-80.7)	2.7 (1.0-5.7)	31.4 (25.4-37.7)	10.6 (6.9-15.4)
21-30	339	84.7 (80.4-88.3)	3.2 (1.6-5.7)	38.1 (32.9-43.5)	11.5 (8.3-15.4)
31-40	489	78.1 (74.2-81.7)	3.3 (1.9-5.3)	29.0 (25.1-33.3)	7.0 (4.9-9.6)
41-50	741	65.5 (61.9-68.9)	5.9 (4.3-7.9)	25.8 (22.8-29.2)	4.9 (3.5-6.8)
51-60	405	44.0 (39.1-48.9)	19.8 (16.0-24.0)	26.7 (22.4-31.3)	4.0 (2.3-6.3)
>60	177	28.2 (21.7-35.5)	36.7 (29.6-44.3)	41.8 (34.5-49.4)	5.6 (2.7-10.1)

Table 3. Spearman correlations between refractive astigmatic and spherical components for myopes and hyperopes.

	Myopes (n=1625)			Hyperopes (n=301)		
	Spherical-equivalent (M)	Least-Myopic Meridian (LMM)	Most-Myopic Meridian (MMM)	Spherical-equivalent (M)	Least-Hyperopic Meridian (LHM)	Most-Hyperopic Meridian (MHM)
Cylinder	+0.21***	+0.08**	+0.34***	−0.27***	+0.16***	−0.58***
J0	−0.32***	−0.25***	−0.37***	−0.08	+0.07	−0.18**
J45	−0.04	−0.03	−0.05*	+0.01	−0.06	+0.05

* p<0.05; ** p<0.01; *** p<0.001