Peripheral Refraction in Different Ethnicities

Pauline Kang, Paul Gifford, Phitolomena McNamara, Jenny Wu, Stephanie Yeo, Bonney Vong, and Helen Swarbrick

PURPOSE. Peripheral refraction is commonly used to infer retinal shape. Because of the different prevalence of myopia in the white compared with East Asian populations, peripheral refraction along the horizontal meridian was compared in white and East Asian young adults with emmetropic, low myopic, and moderately myopic refractive errors.

METHODS. Thirty-five white and 37 East Asian subjects were recruited with central refraction between +1.00 DS and −5.50 DS and ≤ −1.50 DC. Central and peripheral noncycloplegic autorefraction was measured along the horizontal meridian at 5° intervals up to ±35°, and corneal topography maps were also quantified.

RESULTS. There were no significant differences between whites and East Asians in peripheral refraction profiles in the emmetrope and low myope groups, which had peripheral myopic and emmetropic refraction, respectively. However, in the moderate myope group, there was a statistically significant difference between whites and East Asians in peripheral refraction, which was generally hyperopic. East Asian moderate myopes had more relative peripheral hyperopia than did whites of similar central refractive error. Corneal shape and power were comparable between white and East Asian subjects in the three refractive groups.

CONCLUSIONS. East Asian moderate myopes have a greater degree of relative peripheral hyperopia and hence a more prolate ocular shape than do white subjects of similar central refractive error. Differences in ocular shape may play a role in the greater propensity for East Asians to develop and progress in myopia compared with whites. (Invest Ophthalmol Vis Sci. 2010;51: 6059 – 6065) DOI:10.1167/iovs.09-4747

The prevalence of myopia has increased dramatically over the past decade and substantially higher prevalence rates have been repeatedly documented in the East Asian1–5 compared with the white6,7 population. There appears to be a higher risk of development of myopia in individuals of East Asian ethnicity, in Asia and elsewhere.6,7 The age of myopia onset is becoming younger8 and faster progression rates have been associated with earlier age at onset.9,9 This onset at earlier age not only contributes to increased severity of myopia, but to an increased prevalence within the population.2,8–10

Myopia not only carries a financial11–12 and social burden for the individual, but it also increases the risk of development of several ocular complications such as glaucoma,14–16 macular degeneration,14 and various pathologic retinal changes.17,18 Myopia is one of the most significant causes of blindness19–25 and therefore much research continues to be conducted to determine methods to slow down or arrest its progression.

Recently, there has been a surge of interest in peripheral refraction subsequent to animal24,25 and human studies26,27 that have demonstrated a significant influence of peripheral retinal defocus on the development of central refraction. The idea that peripheral refraction may influence the development of myopia stemmed from early studies by Hoogerheide et al.,20 who noted that emmetropic trainee pilots in whom myopia subsequently developed had a relatively hyperopic peripheral refraction. It was proposed that the eye responds to hyperopic defocus by increasing in axial length to bring the peripheral retina in focus with the peripheral image despite a consequent increase in foveal myopic defocus.28–32 In addition, eye diseases affecting peripheral or foveal vision, such as vitreous hemorrhages, congenital cataracts, and retinitis pigmentosa have been found to lead to myopia,33–38 whereas diseases affecting only foveal vision including maculopathy and rod monochromacy have been found to result in mild hyperopia.36–39 This finding further highlights the significance of image quality received at the peripheral retina in the development of refractive error.

Numerous studies have demonstrated characteristic peripheral refraction patterns along the horizontal meridian in different refractive groups, and the shape of the eye has been commonly inferred from the measured peripheral refraction.31,41–46 Emmetropes and hyperopes have been found typically to have a relatively myopic peripheral refraction. This myopic shift is more evident in hyperopes31,44,47 and indicates a more oblate ocular shape. Myopes, particularly those greater than −2.50 DS,48 have been found in general to have a relatively hyperopic peripheral refraction corresponding to a more prolate ocular shape.31,42,44

There have been some studies in which differences in ocular biometry between white and Asian myopic eyes were investigated.7,42,48 To date, there have been no comparisons of peripheral refraction profiles between whites and Asians across different refractive groups. In this article, we report peripheral refraction profiles measured in emmetropic, low myopic, and moderately myopic white and East Asian subjects and compare corneal shape and power between the two ethnic groups.
MATERIALS AND METHODS

Subjects

Seventy-two subjects (35 white and 37 East Asian) were enrolled from the University of New South Wales community (age range, 18–38 years) by word of mouth and advertisements placed on notice boards in the School of Optometry and Vision Science. This study adhered to the tenets of the Declaration of Helsinki (2000), and approval was obtained from the institutional Human Research Ethics Advisory (HREA) Panel before study commencement. All subjects gave their informed written consent to study participation after being informed about the nature and possible consequences of this study. Subjects were required to be non–rigid gas-permeable (GP) lens wearers and were instructed to cease lens wear for at least 24 hours before measurements were to be taken. To be eligible for the study, central refraction had to measure between ±0.50 D, with ≤±1.50 DC and good ocular health. Subjects were not eligible if they were aware of a change in their refractive error within the past year. They were divided into three groups, depending on their central refraction. Those with spherical equivalent (M) between ±1.00 and ±0.49 D formed the emmetrope group, those between <−0.50 and −2.49 D the low myope group, and those between <−2.50 and −5.50 D the moderate myope group. Measurements were taken only in the right eye unless it did not meet the inclusion criteria, in which case the left eye was used.

Measurement Techniques

Peripheral Refraction. An autorefractor (NVision K5001; Shin-Nippon, Tokyo, Japan) was used to measure both central and peripheral refraction across the horizontal meridian out to 35° in the nasal and temporal visual fields. A fixation device that projected a green monochromatic laser spot target was used to ensure accurate fixation at 5° intervals with minimal accommodative effect. No cycloplegic or mydriatic drug was used, and five measurements were taken at each location and averaged. The spherical (S) and cylindrical power (C) and cylindrical axis (θ) of the spherocylindrical refractive error measured by the autorefractor were converted into power vectors M, J180, and J45 to allow for statistical analysis using the following equations derived by Thibos et al.92:

\[ M = S + C/2 \]

\[ J_{180} = -C \cos 2\theta/2 \]

\[ J_{45} = -C \sin 2\theta/2 \]

where M is the mean spherical equivalent error, J180 is the 90° to 180° astigmatic component, and J45 is the 45° to 135° astigmatic component. Relative peripheral M refraction was calculated by subtracting central M values obtained in primary gaze from M values measured at each respective eccentric fixation point. Peripheral refraction is commonly used to infer retinal shape in human eyes.31,31–45 M has been a frequently used value to describe ocular shape. M has been approximated to lie quite close to the retina (within 0.75 D) out to 60° in the visual field through optical equations (ray tracing)31 and therefore was deemed most appropriate to use in this study to describe retinal shape.

Corneal Topography. A videokeratoscope (E300; Medmont Pty. Ltd., Melbourne, Victoria, Australia) was used to capture corneal topography, and the data were analyzed with the accompanying software (Studio 4, version 4.12.2; Medmont Pty. Ltd.). Four images of each eye were obtained at each visit and data were averaged. Tangential power (assumed corneal refractive index, 1.3375) along the horizontal chord at 0.5-mm intervals over a chord of 5 mm was plotted from the averaged values. A chord length of 5 mm was an approximation of the horizontal corneal chord over which autorefraction measurements (≥35°) were taken. Corneal eccentricity (e) and apical radius (rA) were also extracted and averaged.

Data Analysis

MANOVA and repeated-measures ANOVA were performed on relative refraction and corneal power data, to allow for comparison between East Asian and white subjects in each refractive group. Based on planned comparisons, analyses of refraction data were performed at center and ±30° in the periphery,44,49 whereas analysis of corneal power was conducted at the center and at ±2.5 mm. For the relative refraction data in different refractive groups, MANOVA with serial deletion of central refractive data points was also used to isolate differences in peripheral refraction from central refraction results in the two ethnic groups. Post hoc Student’s t tests with Bonferroni correction were used to compare e and rA between East Asian and white subjects in each of the refraction groups (SPSS ver. 15; SPSS, Chicago, IL). The P values were adjusted by the software, according to the Bonferroni correction, such that P < 0.05 denoted statistical significance.

RESULTS

Central and Peripheral Refraction

Table 1 shows the average central distance refraction of the East Asian and white subjects in the different refractive groups.

<table>
<thead>
<tr>
<th>White</th>
<th>F/M (D, mean ± SD)</th>
<th>East Asian</th>
<th>F/M (D, mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emmetrope</td>
<td>0.73 ± 0.94</td>
<td>8/4</td>
<td>0.57 ± 0.50</td>
</tr>
<tr>
<td>Low myope</td>
<td>−0.97 ± 0.51</td>
<td>7/4</td>
<td>−1.17 ± 0.87</td>
</tr>
<tr>
<td>Moderate myope</td>
<td>−3.82 ± 1.00</td>
<td>12/2</td>
<td>−3.42 ± 0.81</td>
</tr>
</tbody>
</table>

TABLE 1. Objective Central Distance Refraction

As is evident in Figure 1b, there was a statistically significant difference in relative M refraction profiles between the three refractive groups (F = 6.416, P = 0.003), when analyzing data at center and ±30° and also when analyzing all data points except temporal 15° (F = 19.36, P = 0.046). Emmetropes had relatively myopic peripheral refraction that was significantly more myopic than that of the low myopes and moderate myopes in the nasal visual field (P = 0.019; P = 0.002) but not in the temporal visual field (P = 0.842; P = 0.408). Low myopes had a relatively emmetropic peripheral refraction that was not significantly different from moderate myopes in both the temporal and nasal visual fields (P = 0.555; P = 0.540; Fig. 1a).

As is evident in Figure 1b, there was a statistically significant negative increase in J180 with eccentricity in the nasal and temporal visual fields (F = 125.011, P < 0.001). However, there was no difference in J180 refraction profiles between the different refractive groups (F = 2.168, P = 0.122) or between ethnicities (F = 0.298, P = 0.745). Temporal–nasal asymmetry was evident (F = 5.637, P = 0.02) with greater astigmatism in
the nasal than in the temporal visual field. No decrease in asymmetry was found with increasing myopia in either white or East Asian subjects ($F_{w} = 2.709, P_{w} = 0.082; F_{EA} = 2.725, P_{EA} = 0.080$).

Similarly, there was no difference in $J_{25}$ refraction profiles between the three refractive groups ($F = 2.428, P = 0.096$) or between ethnicities ($F = 0.965, P = 0.386$). There was a statistically significant tendency toward a positive increase in $J_{25}$ with increasingly positive eccentricities ($F = 52.384, P < 0.001$; Fig. 1c).

Relative $M$ refraction profiles in whites and East Asians in the three refractive groups are shown in Figures 2a–c. MANOVA analysis at the center and at $\pm 30^\circ$ indicated significantly different interactions between the peripheral refraction profiles between whites and East Asians ($F = 4.360, P = 0.017$). There were no statistically significant differences in refraction profiles between whites and East Asians in the emmetrope and low myope groups ($F_{c} = 0.241, P_{c} = 0.788; F_{lm} = 1.167, P_{lm} = 0.334$). However, there was a significant difference in refraction profile between the center and $\pm 30^\circ$ between whites and East Asians in the moderate myope group ($F = 5.204, P = 0.014$). East Asians had a significantly greater amount of relative hyperopia at $30^\circ$ in the temporal visual field ($F = 10.571, P = 0.003$) but not in the nasal visual field ($F = 1.368, P = 0.254$). Moreover, MANOVA analyzing all data except at $15^\circ$ temporal also indicated a significant interaction between ethnicity and visual field eccentricity ($F = 2.058, P = 0.034$). MANOVA with serial deletion of central data points indicated that the peripheral refraction profiles for moderate myopes showed differences between the two ethnicities at $\pm 25^\circ$ ($F = 3.375, P = 0.019$) and beyond.

**Corneal Topography**

Apical radius ($r_o$) and corneal eccentricity ($e$) across the central 5-mm corneal chord were extracted from corneal topography maps, and average values are shown in Table 2. There were no significant differences in apical radius between whites and East Asians in the three different refractive groups ($t_e = 1.195, P_e = 0.245; t_{lm} = -1.977, P_{lm} = 0.064; t_{mm} = -0.226, P_{mm} = 0.823$). Similarly, there were no significant differences in corneal eccentricity between whites and East Asians in the three groups ($t_e = 0.018, P_e = 0.986; t_{lm} = -1.010, P_{lm} = 0.327; t_{mm} = -1.724, P_{mm} = 0.096$).

Tangential corneal power across the central 5-mm corneal chord was compared between whites and East Asians; relative average values at the center and at $\pm 2.5$ mm are shown in Figures 3a–c for emmetropes, low myopes, and moderate myopes, respectively. Corneal tangential power across the central 5-mm chord was similar between each of the three refractive groups ($F = 1.779, P = 0.109$) and across whites and East Asians ($F = 0.859, P = 0.468$).

**DISCUSSION**

There has been a surge of interest in peripheral refraction of human eyes after evidence in animal and human studies
showed that the peripheral retina appears to play a significant role in the development of central refraction. It has been assumed, because of the high density of cells in the central retina, that information from retinal cells in the periphery is of less influence. With increasing retinal eccentricity, the spatial density of most retinal cell types generally decreases with the exception of rods. Although there is a decrease in spatial density, it is compensated for by an increase in the sizes of the retinal cell dendritic fields, meaning that the area from which the cell directly or indirectly receives information increases.52

In addition, the cumulative number of cells distributed in the peripheral retina is larger than the number of cells found in the fovea.28,52 Therefore, it can be argued that the summation of information from the peripheral retina can easily dominate over that from the fovea.

The results demonstrate a statistically significant difference in peripheral refraction profiles between emmetropes and myopes, in agreement with previous studies.48,55,57 Emmetropes had a relatively myopic peripheral refraction across the horizontal meridian, indicating a more oblate ocular shape. Low myopes were found to have a relatively emmetropic peripheral refraction corresponding to a more spherical ocular shape, whereas most moderate myopes were found to have relative peripheral hyperopia indicating a more prolate ocular shape. Previous literature has shown that relative hyperopia in the periphery becomes more evident in those with myopia greater than −2.50 DS. Although it is not statistically significant, there is an apparent trend in the data suggesting that moderate myopes (greater than −2.50 DS) have a more hyperopic peripheral refraction than low myopes (less than −2.50 DS), as has been reported in previous studies.52,48 A temporal–nasal asymmetry was found in M along the horizontal visual field with greater peripheral refraction shifts in the nasal compared with the temporal visual field. Regional differences in scleral growth have been proposed as a cause of a peripheral refraction profile that is not symmetrical about the visual axis. In contrast to other published studies in the literature, we did not find a difference in temporal–nasal asymmetry in the peripheral M refraction profile between white and East Asian subjects.42 In other studies51,57 increased variability and difficulty have been found in measurements at temporal 15°, which is near the location of the optic disc, and data at this eccentricity have therefore often been disregarded.48,53 We did not find a significant increase in variability in our emmetropic or low myopic subjects. An increase in variability was evident only in white moderately myopic subjects.

There was no statistically significant difference in peripheral refraction profiles along the horizontal meridian between whites and East Asians in the emmetrope and low myope groups, but a statistically significant difference was found in the moderate myope group. In general, moderately myopic East Asians had a greater degree of relative peripheral hyperopia, corresponding to a more prolate ocular shape, when compared with white eyes of similar central refractive error. The results are consistent with those in previous studies42,49 comparing white and Asian myopic subjects in which Asian myopes were found to have greater relative peripheral hyperopia. Mutti et al.49 demonstrated that a significant difference between Asian and white myopes was evident 3 years and 1 year before myopia onset and 1 year after onset.

In agreement with earlier studies, there was a statistically significant increase in J180 with eccentricity. Asymmetry was present, with the nasal visual field displaying greater astigmatism.51,48,54–56 Results in some studies46,48,57 have demonstrated a decrease in temporal–nasal asymmetry with increase in myopia, but this was not evident in our study. In contrast to some previous studies, similar J180 refraction profiles were seen in all three refraction groups, and no difference in J180 profiles was evident between white and East Asian subjects. A possible reason is that there was a greater degree of central myopia in subjects in earlier studies; for example Millodot46 included myopic subjects ranging from −1.00 to −7.87 D spherical equivalent and in Seidemann et al.,31 average myopic refraction was −4.75 ± 1.90 D.

There was a minimal but statistically significant increase in J45 with field angle, in accordance with findings in other studies.48,55,57 The asymmetry in astigmatism (J180 and J45) across the visual field has been attributed to tilted or translated

<table>
<thead>
<tr>
<th>TABLE 2. Corneal Apical Radius and Eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical Radius (mm, mean ± SD)</td>
</tr>
<tr>
<td>Emmetropes</td>
</tr>
<tr>
<td>White</td>
</tr>
<tr>
<td>7.84 ± 0.26</td>
</tr>
<tr>
<td>7.81 ± 0.37</td>
</tr>
</tbody>
</table>

Figure 3. Relative tangential power (D) across the central 5 mm corneal chord for (a) emmetropes, (b) low myopes, and (c) moderate myopes. Error bars, SEM. Negative values, temporal cornea.
crystalline lens, rotated cornea, misalignment from the optic axis and lack of symmetry of the anterior optical surfaces based on modeling schematic eyes. Atchison et al. discovered a significant correlation between angle \( \alpha \) and the turning point of \( J_{\text{iso}} \), which became more temporal (visual field) with larger angle \( \alpha \). These ocular components vary considerably among individuals, which may explain the wide interindividual variations in peripheral astigmatism in most studies. Atchison et al. included subjects from both Caucasian and Asian ethnic backgrounds but differences in angle \( \alpha \) between ethnicities were not ascertained. In our study we assumed that angle \( \alpha \) was similar between our white and East Asian subjects. Furthermore, we did not find any significant differences in \( J_{\text{iso}} \) and \( J_{\text{azi}} \) in the different ethnic groups, and the absence of these differences provides further support for this assumption.

It has also been suggested that the high amounts of variability frequently evident in the peripheral refraction across all refractive groups may be due to individual variations in retinal contour or shape. Anterior optics of the eye and retinal contour together determine peripheral refraction. Although the cornea is the main contributor to the overall power of the eye, it exhibits minimal change beyond infancy and early childhood. In addition, corneal shape and power were found to be comparable between East Asian and white subjects in the three refractive groups over the area measured in this study, as previously reported. Since corneal topography over the corneal chord of interest was similar between East Asian and white moderate myopes, we conclude that it has minimal influence on the difference in peripheral refraction.

A potential limitation of the study was that crystalline lens biometry measurements were not taken, and therefore differences in peripheral refraction in the moderate myope group may not be fully accounted for by differences in ocular shape. However, the averaged pattern of crystalline lens development beyond 10 years of age and the approximate age at which lens development ceases have been found to be similar between East Asian and white children. A recent paper from the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study reported that although there is a statistically significant difference in the Gullstrand lens power between white and Asian children, the difference is not clinically significant (\( \pm 0.75 \) DS). Using the child’s individual refractive index has been found to be a better method of calculating lens power (calculated lens power) than using Gullstrand-Emsley schematic eye values (Gullstrand lens power). In white and Asian children 10 years of age, calculated lens power, crystalline lens thickness, and refractive index have been found to be comparable. Therefore differences between East Asian and white adults in lens biometry are unlikely, and consequently differences in peripheral refraction between the different ethnicities are more likely to be due to differences in retinal shape than to differences in lens biometry.

Another potential limitation of the study was that axial length measurements were not taken. These data could have been used to confirm the differences in ocular shape in white and East Asian moderate myopes. As increases in axial length have been found to be sufficient to account for the myopic refraction, each refractive group was matched for central refractive errors to minimize the effects of differences in axial length on the results found.

Cycloplegia was not used in this study and therefore subjects may have exercised some accommodation when viewing targets. Target vergence varied between 0.23 and 0.46 D in our clinical setting and it has been shown that up to 2 D of accommodation has very little effect on peripheral astigmatism for eccentric fixation angles up to 30°. In addition, cycloplegia can introduce additional peripheral aberrations due to pupil dilation, which may affect autorefraction results.

Peripheral Refraction in Different Ethnicities

An attempt was made to eliminate the influence of progressing myopia on refraction results by excluding subjects who were aware of refraction changes within the past year. Although we cannot assume that all the myopes in our study were nonprogressive, young adults who have an established myopic refractive error are most likely to have developed youth-onset myopia, which has been found to slow or stop progressing during young adulthood.

Individuals of East Asian ethnicity are at greatest risk of myopia, and it appears that location of residence has minimal influence, since the highest prevalence of myopia has been reported in East Asian individuals in Asia and elsewhere. It is possible that differences in ocular shape, as found in this study, play a role in the higher propensity for myopia to develop and progress in East Asian individuals than in other ethnic groups. A more prolate ocular shape, which appears to be common in myopic East Asian individuals, leads to a more hyperopic defocus in the peripheral retina, which then may act as a stronger stimulus for growth in axial length. Mutti et al. have demonstrated that relative peripheral hyperopia was evident 1 year before myopia onset for white children and 5 years before for Asian children. This relative peripheral hyperopia was still evident up to 5 years after the onset of myopia and was greater in Asian children. Therefore, it appears that peripheral relative hyperopic defocus may be a driver in the development of myopia rather than being a result of it. It may be that the longer duration of hyperopic defocus and the more prolate ocular shape, as indicated by greater hyperopic peripheral defocus, explains why Asian eyes seem to be much more susceptible than white eyes to the development and progression of myopia. It is possible that this greater myopic stimulus in Asians remains even after termination of progression, as demonstrated in the nonprogressing myopes in this study.

Acknowledgments

The authors thank all subjects who participated in the study and Edward Lum for technical assistance in design and construction of the peripheral fixation device.

References


