Corneal astigmatism in different ethnic groups in the Western Cape, South Africa.

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Article

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Abstract

Objectives

To determine whether corneal astigmatism magnitude is equivalent amongst individuals of African black, Mixed race and Caucasian descent in the Western Cape Province, South Africa.

Methods

Observational, retrospective study including 117 African black, 156 Mixed race and 100 Caucasian participants. Corneal astigmatism parameters were obtained using a Pentacam corneal topographer. Ethnicity was self-reported. Data were collected during an earlier prospective study. All the participants had clinically normal eyes.

Results

Corneal astigmatism magnitude was equivalent among the three groups. The astigmatism magnitude was −0.7 (0.7) (median (Interquartile range)) in African blacks, -0.8 (0.7) in Mixed race and −0.7 (0.6) D in Caucasians. No difference was found for J0 (p = 0.24) and J45 (p = 0.99). Astigmatism type differed between the three groups (p = 0.008). With the rule astigmatism was most prevalent in Caucasians (80.1%), followed by African blacks (71.3%) and Mixed race (65.3%). Corneas were steeper in Caucasians and mixed race, compared to African blacks (p = 0.001). K1, K2 and Kmax respectively, were 42.4, 43.2 and 43.7 for the African black, 43.2, 44 and 44.8 for the Mixed race and 43.2, 43.8 and 44.5 D for the Caucasian group. Thinnest point of the cornea in African blacks, Mixed race and Caucasians were 500 (39), 510 (40), and 534 (45) µm (p < 0.001).

Conclusion

Astigmatism magnitude is comparable between ethnic groups in South Africa. Hence, we suggest that astigmatism is not influenced by ethnicity. Corneal power and thinnest point differed between the three ethnic groups

Introduction

In 2020, according to estimates, 596 million people worldwide had distance vision impairment from uncorrected refractive errors. After cataract, uncorrected refractive errors rank as the second most common cause of blindness globally (visual acuity < 0.05). In addition, it’s the leading cause of mild to severe visual impairment (visual acuity < 0.05 to 0.3) \(^1\). Astigmatism is a form of a refractive error, in which the refractive error varies between two meridians. This means that the refractive surface is no
longer a perfect sphere and, as a result, light rays are unable to focus on a single spot on the retina. The refractive astigmatism is composed of corneal astigmatism and internal astigmatism. Corneal astigmatism is caused by an irregular shaped cornea. Internal astigmatism is caused by the back curvature of the cornea and a tilted crystalline lens.

Understanding the characteristics of corneal astigmatism in a population is important because they affect how refractive errors and cataract should be treated. For example, when the corneal astigmatism is known, it’s possible to determine whether a patient requires optical correction following cataract surgery with insertion of a spherical intra ocular lens.

In current literature, no data are available outlining differences in corneal astigmatism between different ethnic populations in South-Africa. A literature search using Pubmed only yielded one South African study comparing refractive astigmatism, i.e. the sum of corneal and internal astigmatism as determined during formal refraction, in different ethnic groups. It revealed no significant relationship between ethnicity and refractive astigmatism.

In international literature, several studies examining corneal astigmatism reported no difference between ethnic groups. Only one study reported difference in corneal astigmatism magnitude and prevalence of against the rule astigmatism in a specific age group between Turks and Syrians. On the other hand, for corneal asphericity and specific keratometry values statistically significant differences were found.

We postulate that there is no significant difference in corneal astigmatism between ethnic populations in South Africa. To our knowledge, there has been no study yet comparing corneal astigmatism in different ethnic populations in South Africa. Therefore, this study aims to establish whether corneal astigmatism is equivalent among persons of African black, Mixed race and Caucasian ethnicity in the Western Cape, South Africa. This would add relevant epidemiological data and provide more insight into the corneal morphology of different ethnic groups.

**Methods**

**Study design**

An earlier prospective cross-sectional study aimed to determine whether endothelial cell count could possibly account for the difference in intraocular pressure and central corneal thickness that was previously reported between ethnic groups. For the current observational retrospective study, we analyzed data of participants collected during the original study. Both studies were conducted at Tygerberg Academic Hospital in the Western Cape, South Africa. The tenets of the Declaration of Helsinki were followed. Informed consent was obtained for the original study, however not for the current study, due to its retrospective design and a successful application for a waiver of informed consent. The study was
approved by the Health Research Ethic Committee of Stellenbosch University, South Africa (reference number U22/09/203).

Subjects

All participants from the original study were included in the current study. For the original study, convenience sampling was used. Participants of African black, Mixed race and Caucasian ethnicity were recruited from patients, accompanying persons, students and/or staff member attending Tygerberg Hospital Eye clinic. Participants were excluded if they met the following criteria: non-South African citizen, glaucoma, corneal pathology, previous ocular trauma, previous intraocular surgery, contact lens wearer, younger than 18 years of age.

Research procedure: data collection

For the original study a Pentacam corneal topography (OCULUS Optikgerate GmbH, Wetzlar, Germany) was obtained and a standardised interviewer administered questionnaire was completed. Ethnicity was self-reported by the participant. Data were collected between January 2019 and December 2021. For the current study, data about ethnicity were collected from the questionnaire, and corneal parameters were collected from the Pentacam's internal storage. Both were entered in an Excel file (Microsoft corporation, Redmond, United States).

Definitions

For clinical use, astigmatism magnitude is notated as a negative value with the unit diopter (D). The meridian of astigmatism is shown as the axis, which can range from zero to 180 degrees. Since the axis represents direction of astigmatism, conventional statistical analysis methods can give misleading results. To quantitatively assess the combination of magnitude and meridian of astigmatism, clinical astigmatism notation was converted to power vector notation (J0 and J45)\(^{10}\). Power vector notation makes it possible to compare the combination of astigmatism magnitude and axis between individuals, as well as different groups, when comparing means or medians of the vectors. The following formulas, developed by Thibos\(^{10}\), were used:

- \( J_0 = (-C/2)\cos(2\alpha) \)
- \( J_{45} = (-C/2)\sin(2\alpha) \)

where \( C \) is astigmatism magnitude and \( \alpha \) is the axis of the flat meridian in degrees. With the rule (WTR) and against the rule (ATR) astigmatism magnitude is represented as \( J_0 \). Oblique astigmatism magnitude is represented as \( J_{45} \). A positive and negative value for \( J_0 \) stands for WTR and ATR astigmatism, respectively. A positive and negative value for \( J_{45} \) stands for oblique astigmatism at the 45° and 135°
axis, respectively. Astigmatism is defined as WTR and ATR when the steep meridian is at 90° ± 30 and 180° ± 30, respectively. Oblique astigmatism is defined as an axis that does not meet the criteria for WTR or ATR.

We quantitively assessed irregular astigmatism using Pentacam’s wavefront analysis of total higher order aberrations (HOA) for a pupil diameter of 4 millimeters. Root mean square (RMS) of HOA is found to be higher in irregular astigmatism. RMS values of more than 0.5 micrometer were considered as irregular astigmatism.

**Outcome measures**

As primary objective, the anterior corneal astigmatism magnitude was compared between the three ethnic groups. As secondary objectives, we looked at the lowest corneal power (K1), highest corneal power (K2), maximum corneal power (Kmax), mean corneal power (Kmean), astigmatism axis and thinnest point of the cornea. Furthermore, we determined the prevalence of regular, oblique, and irregular astigmatism.

**Statistical analysis**

For the original study, a required sample size of 400 participants was calculated using One-way Analysis of Variance (ANOVA) with significance set at 0.05 and Power of 80%.

To test the hypothesis of equivalence in the mean corneal astigmatism magnitude between the three ethnic groups, the two-sample T-tests for equivalence was used to calculate the statistical power against the available sample size. A margin of equivalence of 0.30 was used for the pairwise comparisons. The equivalence margin of 0.30 was based on clinical reasoning and previous research that showed a mean difference varying from 0.1 to 0.3 between ethnic groups. A standard deviation of 1 was used for corneal astigmatism magnitude. For comparison of the Mixed race and Africans, and the Mixed race and Caucasians the power will be > 80%. For the comparison of the Africans and Caucasians the power will be < 80%, mainly due to the smaller sample size available for these two subgroups.

The normality of data was evaluated using the Shapiro-Wilk W test, as well as Q-Q plots and histograms. Normally distributed data was presented as mean with standard deviation and non-normally distributed data as median with interquartile range. To evaluate any differences in participant characteristics between the three groups, a chi-square test for categorical data and ANOVA for continuous data was used.

A two-sided quantile regression with main effect model was used to test for equivalence of median astigmatism magnitude among the three groups. The estimation was adjusted to correct for age, sex, and the effect of clustering of eyes within a participant. Age range was restricted to < 70 for all groups. When
looking for equivalences among the three groups, median differences, 90% confidence interval and p values were reported.

When evaluating differences between the three groups, a quantile regression for continuous data and a multinomial logistic regression for categorical data was used. Both models were adjusted to correct for age, sex, and clustering of eyes within a participant. For continuous data, median differences, 95% confidence interval (95% CI) and p values were reported for pairwise comparisons of the three groups. Additionally, we reported the overall p value for the significance of ethnicity when testing for difference between the three groups. Results were considered statistically significant when the p-value was below 0.05. Statistical analyses were performed with STATA (version 17.0, StataCorp., College Station, Texas).

Results

Baseline

Data of 739 eyes from 373 participants were collected. The study groups consisted of 117 African black, 156 Mixed race and 100 Caucasian individuals. The number of eyes for the African black, Mixed race and Caucasian group were 232, 311 and 196, respectively. 72.7% of participants were females. No difference was found for sex between the three groups (p = 0.75; Chi-square test). Mean age differed between the three groups, with the highest age found in the Mixed race group, followed by the Caucasian and African black group (p < 0.001; One-Way ANOVA). The distribution of age differed as well between the three groups, with the highest prevalence of 18–30 year old participants in the African black group, the highest prevalence of 31–65 year old participants in the Mixed race group and the highest prevalence of participants older than 65 years in the Caucasian group (p = 0.03; Chi-square test; table 1).

Table 1

Table 2 shows the results of the comparison of the cornea characteristics between the three groups.

Table 2

Equivalence of astigmatism magnitude

For astigmatism magnitude, the African Black, Mixed Race, and Caucasian group were equivalent when compared pairwise (p < 0.05; Quantile regression; table 3). In other words, the three groups are comparable in terms of astigmatism magnitude. The distribution of astigmatism magnitude in the three groups is shown in Fig. 1.

Figure 1

Table 3

J0 and J45
No overall difference was found for J0 and J45 between the three groups (p = 0.24 and p = 0.99, respectively). J0 and J45 median values for each of the three groups were positive. This indicate that for J0, WTR was more prevalent than ATR. Whereas for J45, oblique astigmatism at the 45° axis was more prevalent than at the 135° axis.

**Astigmatism magnitude distribution**

Regarding astigmatism magnitude distribution, no difference was found between the three groups (p = 0.45; Multinomial logistic regression). An astigmatism magnitude between 0.6–2.0D was most prevalent in all three groups, followed by an astigmatism magnitude < 0.5D and > 2.0D.

**Prevalence of astigmatism type**

Prevalence of astigmatism type (i.e., ATR, WTR and oblique) differed between the three groups (p = 0.008; Multinomial logistic regression). Among all groups, the most prevalent type of astigmatism was WTR. The highest prevalence of WTR was found in the Caucasian group. The Mixed race group showed the highest prevalence of ATR and oblique astigmatism.

**Corneal power**

There was an overall difference for K1, K2, Kmean and Kmax between the three groups (all p < 0.001; Quantile regression). Pairwise comparisons of the three groups showed that corneal power was higher in the Mixed race group compared to the African black group, and in the Caucasian group compared to the African black group for K1 (both p < 0.001, K2 (p < 0.001; p = 0.001, respectively), Kmean (p < 0.001; p = 0.001, respectively) and Kmax (p < 0.001; p = 0.002, respectively). No difference was found for K1, K2, Kmean and Kmax when comparing the Mixed race and Caucasian group (p = 0.63; p = 0.07; p = 0.26; p = 0.11, respectively).

**Irregular astigmatism**

In the African Black, Mixed Race, and Caucasian group, there were 2, 6, and 1 eye(s) with irregular astigmatism, respectively. No difference was found in the prevalence of irregular astigmatism (HOA > 0.5) between the three groups (p = 0.47).

**Thinnest point cornea**

Thinnest point differed between the three groups (p < 0.001). Corneas were thinnest in the African black group, followed by the mixed race and Caucasian group.

Table 4 shows the results for the pairwise comparisons of continuous variables between the three groups.
Table 4
Analysis for differences of continuous variables

Table 4

Discussion

The current study shows that individuals of African Black, Mixed Race, and Caucasian ethnicity have comparable corneal astigmatism magnitude.

Our results are consistent with international studies, comparing corneal astigmatism between different ethnic groups. None of the studies found a statistically significant difference in corneal astigmatism magnitude between ethnic groups \(^4\)–\(^7\). The following ethnic groups were represented in these studies: Caucasians, Asians, Turks, Syrians, Arabs, Bedouins, and Jews. In contrast, a large population-based cohort study in the United Kingdom reported a statistically significant correlation of Caucasian ethnicity and white skin color with increased corneal astigmatism \(^17\).

In the current study, median astigmatism magnitude was \(-0.7\) for both the Caucasian and African black group. Earlier studies reported comparable mean astigmatism magnitude ranging from \(-0.6\) to \(-1.2\) for African blacks \(^18\)–\(^20\) and \(-0.7\) to \(-1.11\) for Caucasians \(^16\), \(^21\)–\(^25\). No data is available about astigmatism magnitude for the mixed race population. The higher astigmatism magnitude in some studies could be explained by an older age in the study population. It has been reported that an older age is associated with a higher corneal astigmatism magnitude \(^25\)–\(^27\), although other studies revealed no such association \(^28\), \(^29\).

It is difficult to compare our findings to those of other South African studies, considering this is the first study to evaluate the magnitude of corneal astigmatism amongst ethnic groups in South Africa. There is, however, one prospective study that looked at the prevalence of refractive astigmatism between different ethnic groups in South Africa \(^3\). This study included a total of 176 participants, counting 76 African blacks, 38 Caucasians and 48 Mixed race individuals from Cape Town. The authors found no statistically significant relationship between ethnicity and astigmatism. Astigmatism was defined as \(-0.5\) diopter cylinder or worse. The prevalence of astigmatism in the different ethnic groups was 62% in African blacks, 53% in Caucasians and 50% in Mixed race. This is in line with the prevalence of corneal astigmatism \(<0.5\) in the current study, which was approximately 65% in all three groups.

The specific involvement of genes in the development of corneal astigmatism is still unclear, according to several review articles on corneal astigmatism. Although there are multiple genes associated with astigmatism, environmental factors appear to play an important role \(^29\), \(^30\). The findings of our study
suggests that environmental factors are more important in the development of astigmatism than genetic factors do, since corneal astigmatism was equivalent among different ethnic groups.

Numerous studies found that WTR is the most prevalent form of astigmatism in persons under the age of 40, whereas after this age, the axis gradually shifts to a predominance of ATR astigmatism. In accordance with the literature, WTR astigmatism was most prevalent in all groups of the current study. This is also reflected in J0, which had a positive value, representing WTR astigmatism. It is interesting to note that, despite the fact that the African Black group had the lowest median age, they didn't have the highest prevalence of WTR. The highest prevalence of WTR was found in the Caucasian group.

Corneal power was higher in the mixed race and Caucasian group compared to the African black group. In other words, in our study, mixed race and Caucasian individuals have steeper corneas than African Black individuals, even though corneal astigmatism was comparable. Differences in corneal power, without differences in corneal astigmatism have previously been described when comparing ethnic groups. However, other studies found differences in corneal power between ethnic groups. Corneal power in Caucasian population studies range from 43.2 to 43.6D (K1) and 44.1 to 44.7D (K2). For African blacks, two studies are available, reporting corneal power ranging from 42.7 to 43.8D (K1) and 43.3 to 44.0D (K2). These results are in line with the results of the current study.

Previous research, conducted in the same hospital, found that central corneal thickness is thinnest in African black's, followed by Mixed race and Caucasians. These findings are supported by the current study, since thinnest point of the cornea was thinnest in the African Black group, followed by the Mixed race and Caucasian group.

This is the first study looking at corneal astigmatism among people of African Black, Mixed Race, and Caucasian descent, which is its main strength. Other strengths include its moderate sample size, the fact that data collection was prospective, and that ethnicity was self-reported.

However, there were also several weaknesses. First, the original study was not randomized, resulting in imbalances of participants age between the three groups. Second, due to the convenience sampling method used in the original study, females were overrepresented in the three groups. Tirth, information about refractive astigmatism and visual acuity was not obtained, consequently it was not possible to look for a correlation between those variables. And last, since the study was conducted in a teaching hospital in the Western Cape Province, it's possible that the findings cannot be extrapolated to other population. Although it must be reiterated that only clinically normal eyes were enrolled.

In conclusion, corneal astigmatism was equivalent among the three ethnic groups in our study. Therefore, we suggest that astigmatism is not influenced by ethnicity. However, corneal power did differ between the groups, with the steepest corneas found in the Mixed race group. This study confirms the results of previous research on this topic. The findings of the current study implicate that no special attention is
needed for corneal astigmatism in a specific population. For example, prior to cataract surgery or while screening for vision impairment.

Declarations

Acknowledgments

We thank dr. C.J. Lombard from the biostatistics unit of Stellenbosch University, Cape Town for his assistance with the statistical analyses of the data.

Conflicts of Interest

The authors declare no conflict of interest.

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Author contribution statement

JM was responsible for the design of the research protocol, extracting the data from a database, analyzing the data in contribution with a statistician, design of tables and figures and writing the article.

DP made contributions to the design of the research protocol and interpretation of the findings. He also offered comments of the final article draft.

R collected the data for the original study. She contributed to the design of the research protocol. Furthermore, she provided feedback on the final article draft.

References

2. Grosvenor T. Primary Care Optometry. 5rd ed. (Philadelphia: Elsevier Health Sciences; 2017).


**Tables**

**Table 1.** Baseline characteristics among the three ethnic groups
Table 2. Corneal characteristics among the three ethnic groups

<table>
<thead>
<tr>
<th></th>
<th>All groups</th>
<th>African blacks</th>
<th>Mixed race</th>
<th>Caucasians</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants: n (%)</strong></td>
<td>373 (100)</td>
<td>117 (31.4)</td>
<td>156 (41.8)</td>
<td>100 (26.8)</td>
<td></td>
</tr>
<tr>
<td><strong>Unilateral: n</strong></td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Bilateral: n</strong></td>
<td>365</td>
<td>230</td>
<td>310</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td><strong>Eyes: n (%)</strong></td>
<td>799 (100)</td>
<td>232 (31.4)</td>
<td>311 (42.1)</td>
<td>196 (26.5)</td>
<td>0.75*</td>
</tr>
<tr>
<td><strong>Females: n (%)</strong></td>
<td>271 (71.7%)</td>
<td>88 (72.7)</td>
<td>111 (71.2)</td>
<td>72 (72)</td>
<td></td>
</tr>
<tr>
<td><strong>Age in years</strong></td>
<td>41.5 ± 15.1</td>
<td>36.3 ± 11.7</td>
<td>44.3 ± 14.9</td>
<td>43 ± 17.4</td>
<td>&lt;0.001b</td>
</tr>
<tr>
<td><strong>Age groups: n (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.03a</td>
</tr>
<tr>
<td>18-30</td>
<td>114 (30.6)</td>
<td>43 (36.8)</td>
<td>37 (23.7)</td>
<td>34 (34)</td>
<td></td>
</tr>
<tr>
<td>31-65</td>
<td>232 (62.2)</td>
<td>72 (61.5)</td>
<td>107 (68.6)</td>
<td>53 (53)</td>
<td></td>
</tr>
<tr>
<td>&gt;65</td>
<td>27 (7.2)</td>
<td>2 (1.7)</td>
<td>12 (7.7)</td>
<td>13 (13)</td>
<td></td>
</tr>
</tbody>
</table>

Continuous values are presented as mean ± standard deviation. Bold values are statistically significant.  
*Chi-square test; b One-Way ANOVA.

Table 3. Analysis for equivalence of astigmatism magnitude

<table>
<thead>
<tr>
<th>Comparison</th>
<th>(Median) difference</th>
<th>90% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astigmatism magnitude (D)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed vs African</td>
<td>-0.08</td>
<td>-0.20 – 0.04</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>-0.01</td>
<td>-0.12 – 0.10</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>-0.07</td>
<td>-0.04 – 0.17</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

90% CI = 90% confidence interval; D = diopter  
Margins of equivalence for astigmatism magnitude: ±0.30.  
Quartile regression with main effect model, adjusted for age, sex and clustering of eyes.  
A p value < 0.05 indicates statistically significant equivalence between groups. Bold values are statistically significant.
Table 4. Analysis for differences of continuous variables

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Median difference</th>
<th>95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power vector notation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J0  Mixed vs African</td>
<td>0.036</td>
<td>-0.047 – 0.119</td>
<td>0.39</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>0.068</td>
<td>-0.011 – 0.147</td>
<td>0.09</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>0.032</td>
<td>-0.044 – 0.108</td>
<td>0.41</td>
</tr>
<tr>
<td>J45 Mixed vs African</td>
<td>-0.002</td>
<td>-0.039 – 0.034</td>
<td>0.90</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>-0.002</td>
<td>-0.039 – 0.035</td>
<td>0.90</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>0.0</td>
<td>-0.03 – 0.03</td>
<td>1.00</td>
</tr>
<tr>
<td>K1 (D) Mixed vs African</td>
<td>0.9</td>
<td>0.5 – 1.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>0.8</td>
<td>0.4 – 1.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>-0.1</td>
<td>-0.5 – 0.3</td>
<td>0.63</td>
</tr>
<tr>
<td>K2 (D) Mixed vs African</td>
<td>1.1</td>
<td>0.6 – 1.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>0.7</td>
<td>0.3 – 1.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>-0.4</td>
<td>-0.8 – 0.0</td>
<td>0.07</td>
</tr>
<tr>
<td>Kmean (D) Mixed vs African</td>
<td>0.9</td>
<td>0.5 – 1.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>0.7</td>
<td>0.3 – 1.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>-0.3</td>
<td>-0.7 – 0.2</td>
<td>0.26</td>
</tr>
<tr>
<td>Kmax (D) Mixed vs African</td>
<td>1.1</td>
<td>0.6 – 1.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>0.7</td>
<td>0.3 – 1.2</td>
<td>0.002</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>-0.4</td>
<td>-0.8 – 0.1</td>
<td>0.11</td>
</tr>
<tr>
<td>Thinnest point cornea (μm)</td>
<td>Mixed vs African</td>
<td>12</td>
<td>3 – 21</td>
</tr>
<tr>
<td>Caucasian vs African</td>
<td>34</td>
<td>23 – 44</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mixed vs Caucasian</td>
<td>22</td>
<td>11 – 33</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

D = diopter; 95% CI = 95% confidence interval; K1 = lowest corneal power; K2 = highest corneal power; Kmean = mean corneal power; Kmax = maximum corneal power; μm = micron.
Quartile regression, adjusted for age, sex and clustering of eyes.
A p value < 0.05 indicates statistically significant difference between groups. Bold values are statistically significant.

Figures
Figure 1

distribution of astigmatism magnitude in the three groups