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Association between anterior corneal astigmatism and posterior corneal astigmatism across age groups: a cross-sectional analysis

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Received: 2017-01-29 Accepted: 2017-09-04

不同年龄段前角膜散光和后角膜散光相关性的横断面研究

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摘要

目的:以不同年龄段分组评估前角膜散光(ACA)和后角膜散光(PCA)。同时分析各年龄段 ACA、PCA 之间散光程度、散光轴的相关性。

方法:横断面研究,包括 381 眼。将临床测得的散光数值转换为向量记法,以分析 ACA 和 PCA。在整体人群和四个不同年龄段(5~19, 20~39, 40~59, 和≥60)中评估 ACA 和 PCA 之间散光程度、散光轴的关系。使用随机效应线性回归模型评估 ACA、PCA 散光程度之间的关系。

结果:在 5~9 岁儿童中,ACA 平均散光度最高为 3.59D, PCA 为 0.50D。总体上来说,ACA 在 1~10.0D,PCA 在 0~3.5D。在较年轻的分组中(5~19 岁),ACA 和 PCA 显著相关(r=0.85, P<0.001)。在 60 岁以上组中,ACA 每增加 1D,PCA 增加 0.04D(95% *CI*: 0.005, 0.07; P=0.03),增加程度相比其余组最少。

结论:在 60 岁以上人群中,相比仅仅依靠经验公式,通过 ACA 数据计算 IOL 度数,更为谨慎的方法是同时测定后角膜散光度和散光轴。

关键词:前角膜散光;后角膜散光;年龄

引用:Shetty V, Haldipurkar SS, Dhamankar R, Haldipurkar T, Pirdankar O, Setia MS. 不同年龄段前角膜散光和后角膜散光相关性的横断面研究. 国际眼科杂志 2017;17(11):1993-1999

Abstract

• AIM: To assess the anterior corneal astigmatism (ACA) and posterior corneal astigmatism (PCA) patterns across various age groups. We also evaluated the association between magnitudes and axes of the ACA and PCA across these age groups.

• METHODS: The present study was a cross-sectional analysis of clinical data of 381 eyes. We converted the clinical astigmatic notation to vector notation for analysis of ACA and PCA. We estimated the correlation between magnitude and axes of the ACA and PCA in the whole population and in four age groups (5-19, 20-39, 40-59, and ≥ 60y). We used random effects linear regression models for estimating the association between the magnitudes of ACA and PCA.

• RESULTS: The mean of the magnitude of the ACA (3.59D) and the PCA (0.50D) was highest in children (5 to 9y). Overall, the magnitude of the ACA ranged from 0D to 10.0 Diopters (D) and the magnitude of the PCA ranged from 0 to 3.5 D. There was a significant correlation between the ACA and the PCA in the younger age group (r = 0.85, P < 0.001). In those 60y or older, the PCA increased by 0.04 units (95% confidence intervals: 0.005, 0.07; P = 0.03) with each unit increase in the ACA, the increase was the smallest in this age group.

• CONCLUSION: It will be prudent to measure the both the magnitude and axis of the PCA, particularly in those above 60y rather than rely on rule-of-thumb calculations based on ACA parameters for IOL power calculation.

• KEYWORDS: anterior corneal astigmatism; posterior corneal astigmatism; age groups

DOI:10.3980/j.issn.1672-5123.2017.11.02

Citation: Shetty V, Haldipurkar SS, Dhamankar R, Haldipurkar T, Pirdankar O, Setia MS. Association between anterior corneal astigmatism and posterior corneal astigmatism across age groups: a cross-sectional analysis. *Guoji Yanke Zazhi (Int Eye Sci)* 2017;17(11):1993-1999

INTRODUCTION

In recent years corneal astigmatism has gained a lot of attention because of its role in clinical and surgical intervention. The prevalence of corneal astigmatism in subjects undergoing cataract surgery is high. Previous studies have reported that more than 35% of cataract surgery candidates show corneal astigmatism of 1.00 Diopters (D) or more in both pediatric as well as geriatric age group[1-2]. An inaccurate preoperative measurement of corneal astigmatism could result in post-operative error[3]. It has been reported that uncorrected astigmatism causes significant decrease in vision and potentially affects patients' independence and activities of daily living such as reading, viewing a mobile screen, or computer screen[4]. Therefore the research on preoperative corneal astigmatism can be of great benefit in forming the guidelines for astigmatism treatment as well as improving surgical outcomes during cataract surgeries.

The effect of aging on refractive and corneal astigmatism has been discussed earlier[5]. It has been observed that with advancing age, the axes of total, refractive and corneal astigmatism shift from with-the-rule towards against-the-rule[5-6]. The total corneal astigmatism comprises of anterior and posterior corneal astigmatism. Though measurement of anterior corneal astigmatism (ACA) has been common in clinical settings, posterior corneal astigmatism (PCA) was usually estimated based on certain assumptions. Previously, Gaussian formula and its paraxial assumption have been used to use to calculate posterior corneal astigmatism, though this may be prone to errors - particularly in patients undergoing refractive surgeries[7-8]. However, with introduction of new technologies and instruments such as slit-scanning devices, Scheimpflug devices, and optical coherence tomography, quantitative measurement of the PCA in a clinical setting is relatively easy.

PCA is important in planning for refractive procedure, such as intraocular lens (IOL) implantation. Furthermore, studies have shown that PCA also has an impact on higher order aberrations[9]; thus, measuring the PCA may be important for toric IOL calculations. Interestingly, there are several toric intraocular lens nomogram has been proposed because of the presence of the PCA and includes Baylor nomograms and Barrett toric IOL calculator[3,10]. These nomograms account for the posterior corneal astigmatism and results in minimal post operative residual astigmatism. Furthermore, neglecting the PCA may lead to errors in the total corneal astigmatism estimation [11-13].

The inclusion of appropriate PCA measurements in IOL calculation may potentially help in reduction of post-surgery residual refractive error. Furthermore, knowledge of the age related trends may also be useful in predicting the refractive and visual outcomes changes post-surgeries. However, there are limited data (particularly in the Indian population) on the relation between ACA and PCA that we designed the present study to assess the ACA and PCA patterns across various age groups and to evaluate the association between ACA and PCA across these age groups.

SUBJECTS AND METHODS

The present study is a cross-sectional analysis of secondary clinical data collected from 381 eyes of 210 patients. The study was conducted at laxmi eye institute (LEI), a private tertiary eye care centre situated in Panvel (about 50km from Mumbai), India. It is a tertiary eye care centre and has a range of specialties (cataract, cornea, glaucoma, paediatric ophthalmology, vitreo-retinal ophthalmology, and neuro-opthalmology).

Data Abstraction We used clinical data of subjects with age ranged from 5-79y who underwent the corneal topography between June 2011 and February 2014 for the current analysis. We abstracted the following data: age, gender, anterior corneal cylinder, anterior corneal axis, posterior corneal cylinder, posterior corneal axis, flat and steep axes, clinical diagnosis, and visual acuity. We excluded all individuals that were diagnosed with corneal pathologies (such as keratoconus, keratitis, granular dystrophy, previous corneal surgery) or systemic diseases that could affect corneal astigmatism (such as graft versus host disease and Stevens Johnson Syndrome). We had data from 499 eyes of 270 patients. However, after excluding the eyes (based on our exclusion criteria), we abstracted complete clinical data from 381 eyes of 210 patients. All the measurements were made using WaveLight Oculyzer II (WaveLight GmbH, Germany). This instrument measured the magnitude and the axis orientation of anterior and posterior corneal astigmatism within the central 3.0mm. We only reviewed WaveLight Oculyzer II (WaveLight GmbH, Germany) scans with good quality (QS okay check mark displayed on the maps).

Statistical Analysis We calculated the means and standard deviations (SDs) for continuous variables, and medians and interquartile range (IQR) for non-parametric continuous variables. We calculated proportions for categorical variables. We converted the clinical astigmatic notation to vector notation for analysis. These were converted for both the ACA and PCA. We calculated the J45 and J180 components using the method described by Miller[14]. We estimated the means for these vector notations and reconverted them to clinical astigmatic notations. These were estimated for each decade (5-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, and 70y and more).

We also categorized the astigmatism into three groups: 1) with-the-rule (WTR); 2) against-the-rule (ATR); 3) Oblique. We used the steep meridian on the corneal surface to categorize these astigmatisms as described by Miyake *et al*[15]. Hence, for anterior corneal surface, steep meridians between 60-120 degrees were considered as WTR whereas steep meridians between 0-30 or 150-180 degrees were considered as ATR. For posterior corneal surface, WTR was considered as steep meridian between 0-30 or between 150-180 were considered WTR, and steep meridians between 60-120 was considered as ATR.

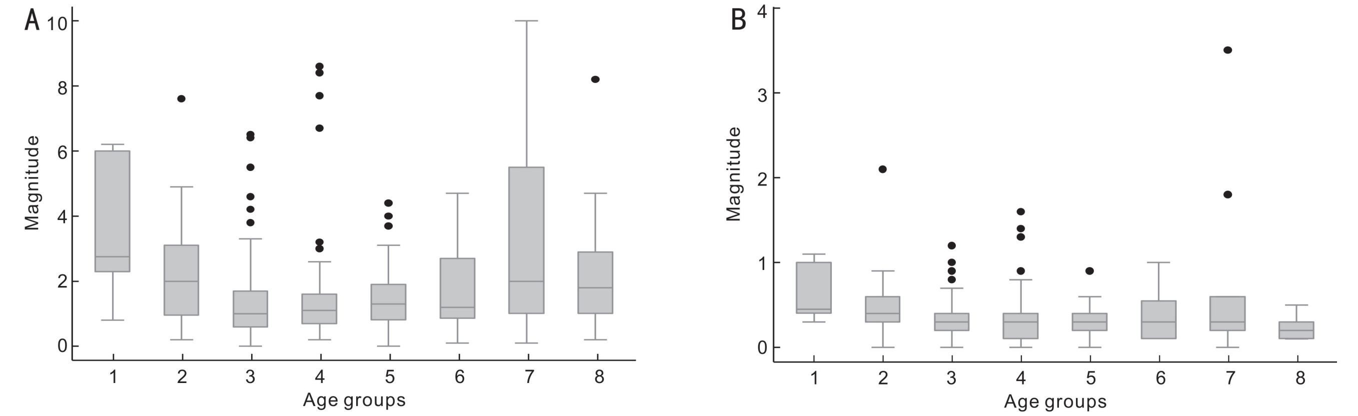

Figure 1　Box plots showing the magnitude of astigmatism on the anterior corneal surface and posterior corneal surface grouped according to the different age in 381 eyes, Mumbai, India　A: Anterior corneal surface; B: Posterior corneal surface; Age groups: 1: 5-9y; 2: 10-19y; 3: 20-29y; 4: 30-39y; 5: 40-49y; 6: 50-59y; 7: 60-69y; 8: 70y and above.

Table 1　Distribution of patients in different decades, mean magnitude of cylinder and centroid mean of axis of anterior and posterior corneal surface in 381 eyes, Mumbai, India

Age groups (a)	Total n (%)	Anterior corneal surface		Posterior corneal surface	
		Anterior cylinder (mean diopters)	Anterior axis (mean degrees)	Posterior cylinder (mean diopters)	Posterior axis (mean degrees)
5-9	12 (3)	3. 25	91. 6	0. 50	90. 0
10-19	72 (19)	1. 50	92. 1	0. 25	89. 0
20-29	140 (37)	1. 00	89. 5	0. 25	92. 6
30-39	63 (17)	0. 50	176. 4	0. 00	95. 1
40-49	33 (9)	0. 50	3. 5	0. 00	94. 8
50-59	16 (4)	0. 25	76. 9	0. 25	89. 6
60-69	31 (8)	1. 25	96. 4	0. 25	80. 4
70 and above	14 (4)	0. 25	123. 6	0. 00	76. 0

The remaining astigmatism was considered as oblique. We estimated the correlation between these categories in the whole population and in four age groups (5-19, 20-39, 40-59, and 60y and above). We also estimated the correlation between the magnitudes of ACA and PCA in these age groups. We used linear regression models for estimating the association between the magnitudes of ACA and PCA. The usual linear regression uses the ordinary least square (OLS) method. Since, we had two eyes from the same patient in our data; we used random-effects (RE) linear regression models. The latter models are useful for correlated data and account for both within-individual and between-individual variance[16]. We initially built unadjusted models - with PCA as the outcome variable and ACA as the explanatory variable. For the adjusted models, we also included age and sex as potential confounders in the model.

The study was approved by the Institutional Ethics Committee, at LEI for secondary data analysis; and was conducted according to the principles in the Declaration of Helsinki.

RESULTS

Of these 210 patients, 102 were males and 108 were females. The age (mean±SD) of the study population was 32. 5±17. 9y; there was no significant difference between the mean ages of males and females (33. 1±19. 2 *vs* 32. 0±16. 7, $P=0.65$).

The mean (according to vector analysis) of the magnitude of the ACA was highest (3. 25) in children (five to nine years). Similarly the mean of the magnitude of the PCA was highest (0. 50) in this age group. We have provided details about the mean of the magnitude and the orientations in age group in Table 1. As seen in Figure 1A, the median ACA (according to the actual values) was highest in the youngest age group (five to nine years); though it reduced in successive age groups, it increased gradually in the later decades of life. The median PCA, however, gradually reduced with age (Figure 1B). The median ACA and PCA was significantly different across these age groups ($P<0.001$). Overall, the magnitude of the ACA ranged from 0 to 10. 0D; a higher proportion of the eyes had an ACA of greater than 1D across all the age groups. The magnitude of the PCA ranged from 0 to 3. 5D. In the younger age groups, the PCA magnitude was between 0. 26 and 0. 50D in a higher proportion of the eyes. However, in the older age group, the magnitude of the PCA was between 0 and 0. 25D in a higher proportion of eyes (Figure 2A and 2B).

There was a significant positive correlation between the ACA and the PCA in the younger age group ($r=0.85$, $P<0.001$). Though this correlation was significantly positive in other groups, the value was lower compared with the youngest age

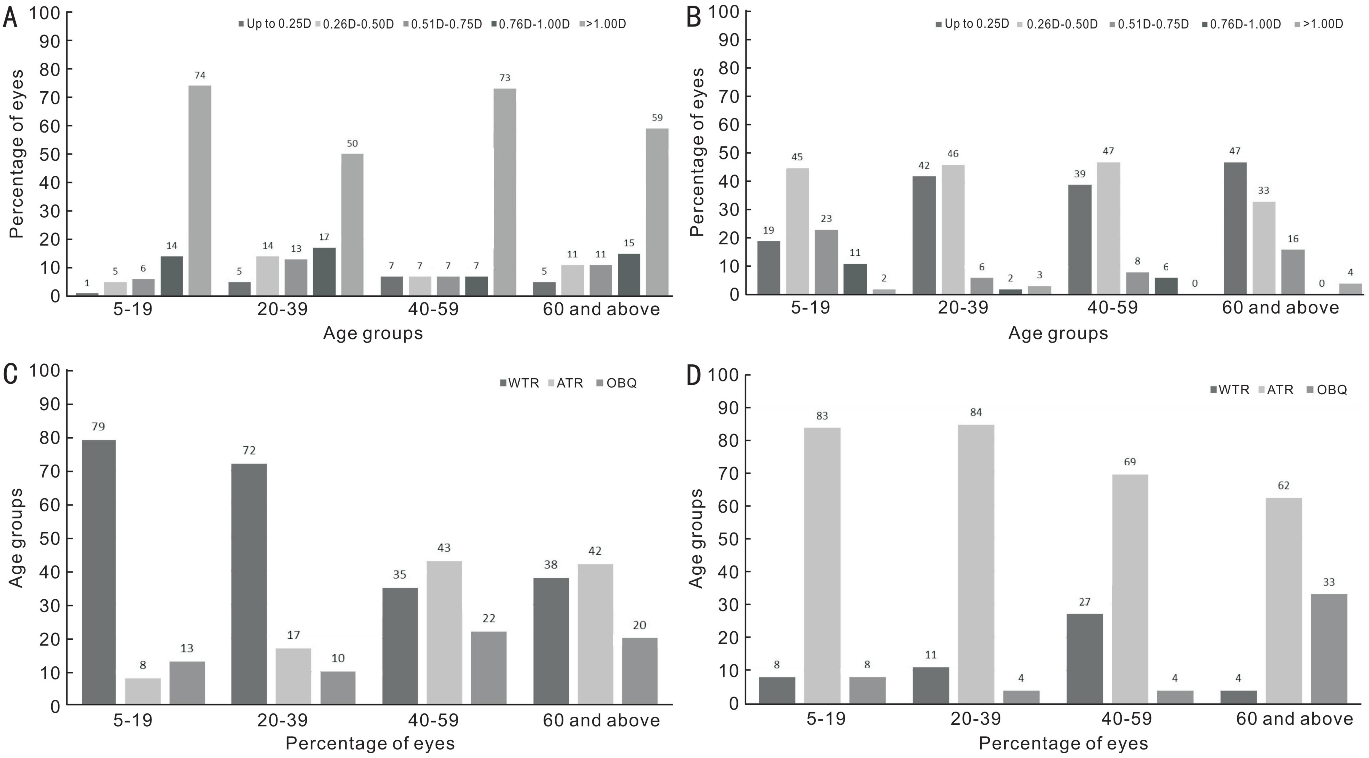

Figure 2 Distribution of magnitude and axis of anterior corneal astigmatism and posterior corneal astigmatism according to age groups in 381 eyes, Mumbai, India A: Distribution of magnitude of the anterior corneal surface; B: Distribution of magnitude of the posterior corneal surface; C: Distribution of axis of the anterior corneal astigmatism; D: Distribution of axis of the posterior corneal astigmatism.

Table 2 Table showing the linear regression (unadjusted and adjusted) for models for association between posterior corneal astigmatism and anterior corneal astigmatism according to age groups in 381 eyes, Mumbai, India

Age groups (a)	Estimation for PCA (95% *CI*) according to ordinary least square regression models		Estimation for PCA (95% *CI*) according to random effects models	
	Unadjusted model	Adjusted model	Unadjusted model	Adjusted model
5-19	0.17 (0.15, 0.19)[c]	0.16 (0.14, 0.19)[c]	0.17 (0.15, 0.19)[c]	0.17 (0.14 0.19)[c]
20-39	0.15 (0.13, 0.16)[c]	0.15 (0.13, 0.17)[c]	0.15 (0.13, 0.16)[c]	0.15 (0.13, 0.17)[c]
40-59	0.09 (0.05, 0.14)[b]	0.08 (0.03, 0.13)[a]	0.10 (0.05, 0.15)[c]	0.09 (0.04, 0.14)[c]
60 and above	0.04 (-0.03, 0.10)	0.04 (-0.03, 0.10)	0.04 (0.004, 0.07)[a]	0.04 (0.004, 0.07)[a]

[a]$P=0.03$, [b]$P=0.001$, [c]$P<0.001$; PCA: posterior corneal astigmatism; CI: Confidence intervals.

group. However, in the older age group (60y and above), the correlation between the ACA and PCA was not statistically significant ($r=0.18$, $P=0.25$). As seen in Figure 2, the slope for the fitted line in the scatter plots flattens with an increase in age.

For the ACA, the orientation of the astigmatism was as follows: WTR (65%); ATR (22%); and Oblique (14%). For the PCA, the orientation of the astigmatism was as follows: ATR (80%); WTR (12%); and Oblique (9%). As seen in Figure 2, the proportion of WTR astigmatism reduced gradually with an increase in age for the ACA, there was a simultaneous increase in ATR astigmatism. However, for the PCA, even though the proportion of ATR reduced with an increase in age, there was a simultaneous increase in "oblique" astigmatism. Furthermore, we also found there was a positive correlation between the magnitudes of anterior and posterior corneal astigmatism in the younger age groups. However, among those aged 60y and above, the correlation was not statistically significant (Figure 3).

In the linear regression models, we found that for each unit increase in the magnitude of ACA, the PCA increased by 0.12 units [95% confidence intervals (*CI*): 0.10, 0.14; $P<0.001$]. In the age group of 5-19y, with a unit increase in the ACA, the PCA increased significantly by 0.17 units (95% *CI*: 0.15, 0.19; $P<0.001$). The magnitude of increase in the PCA was smallest in those who were older than 60y. The relation was not significant in the OLS regression models (Estimate: 0.04, 95% *CI*: -0.03, 0.10; $P=0.25$). In the RE models, we also found that the PCA increased by 0.04 units (95% *CI*: 0.004, 0.07; $P=0.03$) with each unit increase in the ACA. There were no significant changes in the estimates in the adjusted models (adjusted for age and sex). We have described all the estimates and 95% confidence intervals across these four age groups in Table 2.

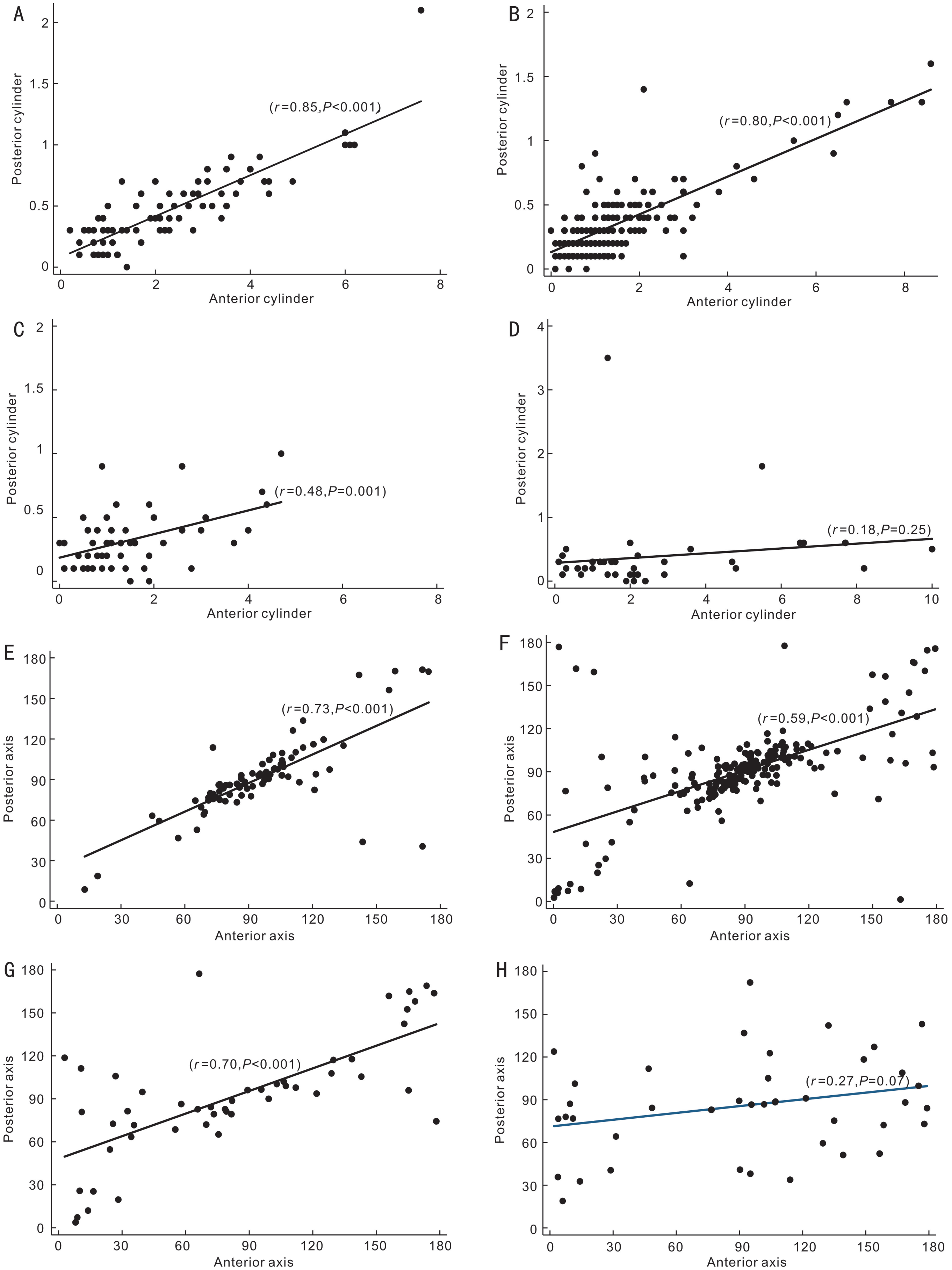

Figure 3 Scatter plots showing the relation between the magnitude or axis of astigmatism of the anterior corneal surface and posterior corneal surface in 381 eyes, Mumbai, India (correlation values along with corresponding *P* values have been also provided) A: Magnitude for 5–19y; B: Magnitude for 20–39y; C: Magnitude for 40–59y; D: Magnitude for 60y and above; E: Axis for 5–19y; F: Axis of 20–39y; G: Axis of 40–59y; H: Axis of 60y and above.

DISCUSSION

In the present study we have presented the relation between ACA and PCA across various age groups. We found that the mean ACA and PCA were highest in younger individuals. Though there was a significant correlation between the magnitude and orientation of the ACA and PCA in the younger age groups, there was no statistical significant correlation in those who were aged 60y or more. Furthermore even though there was a significant change in the PCA with a unit change in the ACA in those up to 60y of age, this change was not significant in those who were older than 60y.

Our study evaluated these aspects of ACA and PCA in Indian eyes: the magnitude of ACA and PCA; the orientation of ACA and PCA; and the relation between these parameters. We also studied these aspects in various age groups. The absolute range of the PCA in our study was similar to that found in some previous studies, though some others differed with our findings[10-11, 17-18]. For instance Koch *et al*[10] found the range of PCA to be between -0.01D and -1.10D; this range was relatively smaller compared with our study. They also found that in 99.9 percent of the cases, the magnitude of the PCA was less than or equal to 1D. In contrast to these, we did find higher magnitude values for the PCA. In addition, Ho *et al*[11] also found an association between the magnitudes of ACA and PCA. Indeed, in a regression model they found that for each unit increase in the magnitude of the ACA, the magnitude of the PCA increased by 0.099 units. Though, this estimate is close our estimate in the overall sample, we did find that the change in the PCA varies according to age group.

The second aspect we assessed was the changes in the orientation of the ACA and the PCA. As seen in our study, other authors also found that the proportion of WTR reduced in the anterior corneal surface and increased in the posterior corneal surface with increasing age[10,19]. Furthermore, it has also been observed that the predominant orientation was ATR in the posterior corneal surface across all age groups[15,20-21]. In general, previous studies have shown that prevalence of ATR astigmatism significantly increased with age and WTR astigmatism significantly reduced with age[6]. Potentially, the age related changes in the ACA and PCA may contribute to these changes in the orientation seen in assessment of total astigmatism. Interestingly, we also found that though there is strong positive correlation between the axes in the younger age groups, there is no such relation in the older eyes. The presence of higher anterior corneal astigmatism in younger age group may potentially be due to upper eyelid tension[22-23]. The lack of relationship between the axes may be attributed to age - related increase in lid laxity, alteration in the biomechanical properties of the cornea, or changes in the intraocular pressure[22-26].

A lot of different methods have been used to evaluate the posterior corneal surface. For instance, Royston *et al*[18] have used Purkinje images to evaluate the posterior corneal surface toricity; however, they also acknowledged that the method is prone to error due the limited number of meridians used in the analysis. We used WaveLight Oculyzer II which is based on the rotating Scheimpflug image for the current study. The Scheimpflug image system has also been used in the measurement of other corneal parameters (such as central corneal thickness) and is considered to be a reliable method for evaluation of the PCA[27-29]. As discussed earlier, total corneal astigmatism is an important parameter for calculation of the IOL power. With the introduction of rotating Scheimpflug imaging technique, which may be easy and feasible to measure the magnitude and axis of the PCA. Incorporating these parameters may potentially reduce the errors in measurement of total corneal astigmatism and further improve uncorrected visual acuity post cataract surgery in pediatric as well as geriatric patients. The cost of the device may, however, be an impediment in large scale use particularly in developing countries.

Though, we did measure the mean of the magnitude and axis in each decade of life, we grouped them for correlation and regression analysis (due to the small number of eyes in certain decades). This is a potential limitation of the study.

Nonetheless, we have provided useful information on the relation between ACA and PCA. We have described the magnitude and the orientations across various age groups and provided a regression estimate between the ACA and the PCA in these age groups. We have used RE models that account for with-individual and between-individual variance and provide robust estimates for correlated data. Interestingly, an association which was not statistically significant by OLS linear regression was found to be statistically significant by the RE linear regression. We found that there was a significant association between the magnitudes of the ACA and PCA in those who were younger than 60y. And after 60y, even though the association was significant, the change in magnitude varied across age groups; the increase was very small compared with other age groups. Since a majority of the cataract surgeries are conducted in those who are above the age of 60y, it will be prudent to measure the both the magnitude and orientation of the PCA rather than rely on rule-of-thumb calculations based on ACA parameters for IOL power calculation. This will help improve the surgical outcomes in these individuals.

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