Corneal and Ocular Residual Astigmatism in School-Age Children

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Abstract

Purpose: To determine the distribution of residual and corneal astigmatism (CA) in children aged 6–18 years and their relationship with age, sex, spherical equivalent, and biometric parameters.

Methods: In this cross-sectional study, multi-stage stratified cluster sampling was done to select students from Dezful, a city in Southwestern Iran. Examinations included the measurement of visual acuity with and without optical correction, refraction with and without cycloplegia, and biometry using the Biograph (Lenstar, Germany). The main outcomes in this report were corneal and residual astigmatism. The CA was measured by Biograph (difference between k1 and k2), and residual astigmatism was calculated using Alpine method. The power vector method was applied to analyze the data of astigmatism.

Results: Of 864 students that were selected, 683 (79.1%) participated in the study. The mean residual and CA were −0.84 diopter (D) and −0.85 D, respectively. According to the results of J0 and J45 vectors, residual astigmatism was −0.33 D and 0.04 D, and CA was 0.38 D and 0.01 D, respectively. With-the-rule (WTR), against-the-rule (ATR), and oblique astigmatism were seen in 3.4%, 66.8%, and 4.5% of the children with residual astigmatism and 67.94%, 1.3%, and 1.5% of the children with CA. Residual astigmatism decreased with an increase in spherical refractive error, whereas CA increased with an increase in spherical refractive error.

Conclusion: The results of the present study showed a high prevalence and amount of residual astigmatism with ATR pattern among the 6–18-year-old population and the compensatory effect of this type of astigmatism on CA that mostly followed a WTR pattern.

Keywords: Biometry, Corneal astigmatism, Power vector analysis, Residual astigmatism

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Introduction

Astigmatism is one of the most common refractive errors worldwide, in which the anterior corneal surface has a major role.[1,2] However, the magnitude and orientation of refractive astigmatism may not match those of corneal astigmatism (CA), and their vectorial difference is known as residual astigmatism.[3-5] Ocular residual astigmatism (ORA) may increase aberrations in the visual system, cause blurred vision, and even amblyopia regardless of its magnitude and orientation.[6] Evaluation of the corneal and internal astigmatism in children may be helpful in several clinical conditions such as contact lens fitting,[7] evaluation of the etiology of astigmatism,[8] research into the emmetropization process,[9,10] and the detection of posterior corneal surface abnormalities, including keratoconus.[11] For instance, it is not necessary to

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determine the origin of astigmatism for refractive correction with spectacles, and the cylinder power of the spectacles is equal to the amount of refractive astigmatism. However, considering the amount of CA and ORA and their relationship is very important if there is a need for contact lens prescription, especially gas permeable and toric lenses.[7]

The distribution of corneal and residual astigmatism in different age groups and populations has been investigated in previous studies.[5,12-15] Some of these studies found a decrease in the compensatory effect of ORA on CA with aging.[16,17] Therefore, considering ORA changes and its relationship with CA and aging, knowledge of the normal distribution of this parameter in children and adolescents and its determinants, including age, sex, refractive errors, and biometric parameters, is very important for predicting ORA in this age group. The aim of the present study was to evaluate the distribution of corneal and ORA and their relationship with age, sex, refractive errors, and biometric parameters in children aged 6–18 years.

Methods

This cross-sectional study was conducted in October 2012.[18] This study was part of another study whose main findings were on ocular biometry, corneal hysteresis, and resistance factor of students in Dezful, a city in southwestern Iran. Details of the methodology of this study have been reported in a previous report, and here we present a brief review. Multi-stage stratified cluster sampling was used to select students from Dezful schools. In this study, from boys' and girls' schools in Dezful, one primary school, one secondary school, and one high school were randomly selected (6 schools in total). Grade and sex were considered the strata, and 6 strata were evaluated in this study. In each stratum, from each grade (cluster), one class was selected randomly, and all of its students were examined. Only students whose parents signed the informed consent form were included in the study. On the examination day, after selecting a site with proper illumination, the students who had their parents' consent entered the study. In schools with more than one class for each grade (cluster), one class was randomly selected, and all of its students were examined. The students were first interviewed, and then, examinations started.

Examinations

The students underwent visual acuity measurement with and without correction, biometry, and refraction with and without cycloplegia. Biometry (mean of three measurements) was done using biograph (LENSTAR/Biograph, WaveLight AG, Erlangen, Germany) by an optometrist, and the data of each eye were checked for errors before recording. If there were errors, artificial tears were instilled, and biometry was repeated after 5 min. After biometry, all students underwent objective refraction without cycloplegia using the Topcon KR 8000 autorefractor (Topcon Corporation, Tokyo, Japan). Three refractive measurements were performed, and the mean of the three measurements was considered in the analysis. Finally, cycloplegic refraction was performed in all students. Autorefractometry was repeated 30 min after instilling three drops of cyclopentolate 1.0% at 5 min apart. CA was calculated based on keratometry values obtained with biograph. Simple calculations of the mathematical difference between refractive and CA cannot be used to calculate residual astigmatism because the orientation of the refractive and CA may not be similar in many cases. Therefore, vector analysis should be used to calculate the difference.[19] The Alpins method was used to calculate residual astigmatism in the present study.[20] The astigmatism axis was categorized as with-the-rule (WTR) (0° ± 30°), against-the-rule (ATR) (90° ± 30°), and oblique (other values).[13]

The power vector method proposed by Thibos and Horner was applied to analyze the data of astigmatism. In this method, all spherocylindrical refractive errors (sphere [S], cylinder [C], axis [α]) are geometrically represented by three dioptric components, including spherical equivalent (SE), J0, and J45. Astigmatism is defined as a Jackson crossed cylinder (JCC) with power j at axis α. This JCC can be further resolved into the sum of 2 other JCC vectors, one with power J0 at axis α = 90° = 180° and the other with power J45 at axis α = 45° = 135°. Positive and negative values of J0 are considered WTR and ATR astigmatism, respectively, and J45 values are considered oblique astigmatism. J0 and J45 are calculated using the following formulas, in which C is negative cylindrical power and α is the cylindrical axis.[21]

$$J0 = -C/2 \times \cos(2\alpha)$$

$$J45 = -C/2 \times \sin(2\alpha)$$

Data analysis

SPSS statistical software package, version 22.0 (IBM Corporation, Armonk, NY, USA) was used for data analysis. Due to the high correlation between the results of the two eyes ($r = 0.741$), we only considered information related to the right eye in our analyses.

We have used cycloplegic SE in our analysis. The mean and standard deviation of different types of astigmatism were determined according to age and sex. Simple and multiple linear regression were used to investigate the effect of each variable on the ORA and CA.

If the relationship was not linear and the data were u-shaped, one group was considered the reference group against which other groups were compared.

Ethical issues

The Ethics Committee of Tehran University of Medical Sciences approved the study protocol, which was conducted in accordance with the tenets of the Declaration of Helsinki. All participants signed a written informed consent. Institutional Review Board approval was obtained (No: 91.s.130.1358).

Results

Of 864 students that were selected, 683 participated in the study (response rate = 79.1%). Two cases were removed due to corneal scarring, one due to congenital cataracts, one due to a history of sharp trauma, and two due to a history of ocular surgery.

Male students comprised 55.1% of the students ($n = 373$). The mean age of the participants was 12 ± 3.4 years (6–18 years).

Table 1 presents the mean value of different types of astigmatism according to age and sex. The mean residual astigmatism was −0.84 D, and the mean CA was −0.85 D in all participants. According to the results of linear regression analysis, residual astigmatism had no significant correlation with sex ($P = 0.173$). The trend of the residual astigmatism changes with age was not significant, either. There was no significant difference in CA between male and female students; however, it decreased with an increase in age.

The results of J0 and J45, according to residual and CA are presented in Table 2.

According to Figure 1, 25.3% and 27.4% of the students had corneal and residual astigmatism of 0.5 D or less, while >40% had corneal and residual astigmatism of 0.5–1 D. Moreover, about 2% and 4% of the participants had residual and CA >2 D, respectively.

The results of the present study showed that 67.94% of the students had WTR, 1.3% had ATR, and 1.5% had oblique CA.

Table 1: Mean and 95% confidence interval of ocular residual astigmatism and corneal astigmatism

	Mean (95% CI)	
	ORA	**CA**
Total	−0.84 (−0.88 to −0.80)	−0.85 (−0.92 to −0.78)
Gender		
Male	−0.87 (−0.92 to −0.81)	−0.88 (−0.95 to −0.81)
Female	−0.82 (−0.88 to −0.76)	−0.82 (−0.94 to −0.71)
Age		
6-8	−0.84 (−0.86 to −0.83)	−0.94 (−1.06 to −0.81)
9-11	−0.91 (−1.05 to −0.78)	−0.83 (−0.94 to −0.72)
12-14	−0.84 (−0.90 to −0.78)	−0.81 (−0.89 to −0.73)
≥15	−0.79 (−0.85 to −0.73)	−0.84 (−1.02 to −0.66)

ORA: Ocular residual astigmatism, CA: Corneal astigmatism, CI: Confidence interval

Moreover, 3.4% had WTR residual, 66.8% had ATR residual, and 4.5% had oblique residual astigmatism.

According to Figures 2 and 3, residual astigmatism decreased with an increase in spherical refractive error. In contrast, the opposite relationship was found for CA (CA increased with an increase in spherical refractive error).

Table 3 shows the association of corneal and residual astigmatism with the studied variables. After analyzing these variables in the multiple models, it was found that both astigmatisms only have a significant relationship with mean keratometry. According to the table, a higher amount of ORA and CA was found in subjects with the steeper cornea. The relationship between corneal and residual astigmatism components with age and sex were also evaluated.

Discussion

This study is one of the few population-based investigations of corneal and residual astigmatism and their associated factors in a 6–18-year-old population. The results showed that the mean corneal and residual astigmatism had the same value but in opposite directions. In other words, residual astigmatism had an ATR pattern with a neutralizing effect on CA that mostly followed a WTR pattern. In general, the results showed no significant correlation between sex and type of astigmatism (corneal or residual). Although there was no significant relationship between age and type of astigmatism, CA decreased non-significantly with aging. Vector analysis also showed a small but significant decrease in J0 in both types of astigmatism with age. In other words, with an increase in age, the prevalence of WTR in CA and ATR in residual astigmatism decreased. No significant relationship was found between SE and type of astigmatism. U-shaped analysis, however, showed that CA increased and residual astigmatism decreased with an increase in refractive errors, especially myopia. Among biometric components, only anterior corneal curvature had a significant correlation with residual and CA, such that an increase in the anterior corneal curvature caused an increase in the corneal and residual astigmatism.

An advantage of the present study was its large sample size and population-based design, compared to other similar

Table 2: Mean and 95% confidence interval of J0 and J45 of ocular residual and corneal astigmatism

	ORA, mean (95%CI)		CA, mean (95%CI)	
	J0	**J45**	**J0**	**J45**
Total	−0.32 (−0.36 to −0.28)	0.04 (0.02 to 0.06)	0.38 (0.34 to 0.41)	0.01 (0.00 to 0.02)
Gender				
Male	−0.31 (−0.36 to −0.26)	0.04 (0.02 to 0.07)	0.39 (0.34 to 0.44)	−0.01 (−0.03 to 0.01)
Female	−0.32 (−0.37 to −0.28)	0.04 (0.02 to 0.06)	0.37 (0.31 to 0.42)	0.03 (0.01 to 0.05)
Age				
6-8	−0.35 (−0.38 to −0.33)	0.02 (−0.04 to 0.07)	0.44 (0.38 to 0.5)	0.03 (0.00 to 0.06)
9-11	−0.39 (−0.46 to −0.32)	0.04 (0.02 to 0.05)	0.38 (0.33 to 0.43)	−0.01 (−0.02 to 0.01)
12-14	−0.31 (−0.37 to −0.24)	0.05 (0.02 to 0.07)	0.35 (0.32 to 0.37)	0.01 (−0.01 to 0.02)
≥15	−0.26 (−0.31 to −0.22)	0.06 (0.03 to 0.10)	0.36 (0.27 to 0.45)	0.01 (0 to 0.02)

ORA: Ocular residual astigmatism, CA: Corneal astigmatism, CI: Confidence interval

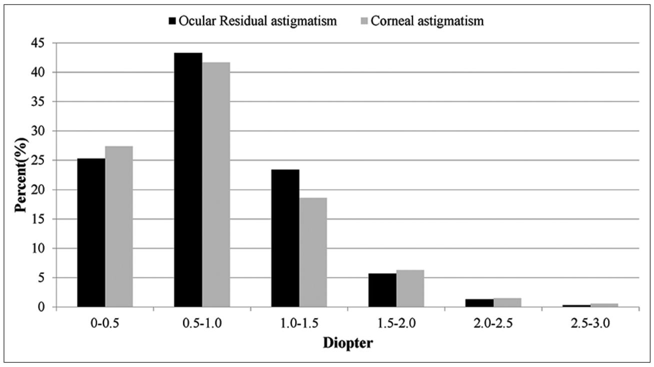

Figure 1: Distribution of corneal and residual astigmatism in children

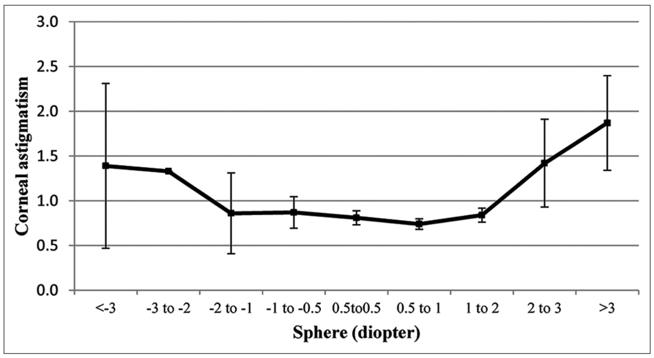

Figure 2: The mean and 95% of corneal astigmatism by spherical error

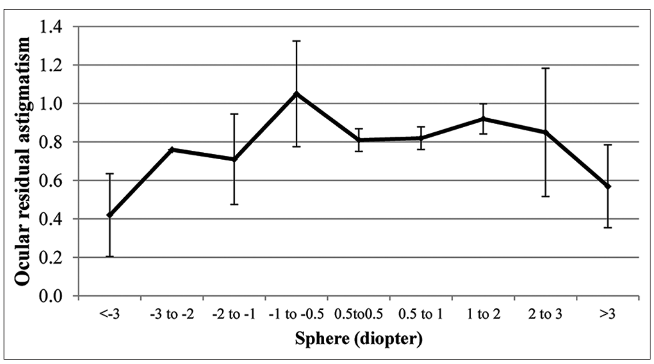

Figure 3: The mean and 95% of ocular residual astigmatism by spherical error

studies, and the evaluation of some probable predictors of ORA and CA. To the best of our knowledge, few studies have investigated residual and CA and their relationship with age, sex, and refractive errors in children and adolescents,[22-25] and no study has evaluated the relationship between corneal and residual astigmatism and biometric components.

The mean corneal and residual astigmatism was −0.84 D and −0.85 D in this study, respectively. Harvey *et al*.[22] conducted a longitudinal study to evaluate the changes of refractive astigmatism components in Native American children (Tohono O'odham) from 3 to 19 years old. In this study, on the baseline visit, the mean CA was 1.79 D WTR, and the mean residual astigmatism was −0.6 D ATR. Liu *et al*.[24] studied astigmatism components in Chinese myopic subjects aged 6–16 years (mean age: 11 years) and reported a mean CA of 1.12 D and a mean ORA of −0.63 D. Huynh *et al*.[23] studied astigmatism components in children aged 5–8 years (mean age: 6 years) and reported different values of CA (−0.82 D) and ORA (−0.76). In other words, the results of the previous studies indicate the effect of ethnicity and age on the prevalence and amount of astigmatism. In addition, this difference can be due to differences in the refraction method (with or without cycloplegia) and the use of different devices for measurement of corneal and residual astigmatism as well as differences in the demographic characteristics and refractive status of the participants.

The relationship between corneal and residual astigmatism is even more prominent in components of power vectors. In this study, the mean J0 was 0.35 in CA and −0.30 in residual astigmatism, and the distribution of J0 values was mostly positive and WTR in CA and mostly negative and ATR in ORA, which was consistent with other studies.[22,26-28] Table 4 summarizes some information provided in previous studies on astigmatism and its components among children.

Moreover, similar to previous studies, the distribution of ORA_J45 was around 0 D.[22,24,27] Several studies have investigated the interrelationship between corneal aberrations and intraocular optical components in different age groups. The results of these studies confirm the findings of the present study and indicate the compensatory effect of intraocular components on corneal aberrations in younger subjects[27] and the augmentation effect of ORA on CA in older subjects.[29]

In the present study, there was no significant difference in the mean ORA and CA between different age groups while vector analysis showed significant differences in the mean J0 of CA and ORA between different age groups ($P < 0.05$). The mean J0 was significantly lower in older age groups. In comparison with CA_J0, ORA_J0 changed less with age, which was similar to the results of a study by Liu on an adult Chinese population.[14] Similarly, the results of a study conducted by Sanfilippo *et al*.[17] showed a decrease of about 0.034 D in CA_J0 with each 10-year increase in age. On the other hand, similar to previous studies, evaluation of the changes of astigmatism orientation with age showed that with aging, the prevalence of WTR in CA[12,14,16] and ATR in ORA decreased.[30] A review of the literature suggests a marked correlation between age and orientation of refractive astigmatism, indicating that refractive astigmatism shifts from WTR to ATR with age. According to different reports, this shift occurs after the age of 50 years, and refractive astigmatism has more stable conditions before this age. A study in Germany showed that the shift from WTR to ATR occurred in the age range 35–74 years.[28] Moreover, this study found that CA shifted from WTR to ATR with aging and that changes of refractive astigmatism with aging mostly originated from changes in the orientation and magnitude of CA. Similarly, in a Korean study of the total astigmatism (TA), CA, and ORA changes with age in a 3–83-year-old population, CA showed a shift from WTR to

Table 3: Simple linear regressions between ocular residual and corneal astigmatism and the studied variables

	Coefficient (95% CI); *P*	
	ORA	CA
Age	0.01 (0.00 to 0.02); 0.052	0.01 (0.00 to 0.03); 0.086
Gender	0.05 (−0.03 to 0.13); 0.173	0.06 (−0.09 to 0.2); 0.426
Axial length (mm)	0.04 (−0.02 to 0.09); 0.181	0.07 (−0.02 to 0.15); 0.120
Anterior chamber depth (mm)	0.08 (0.00 to 0.16); 0.047	0.31 (0.09 to 0.54); 0.011
Lens thickness (mm)	0.03 (−0.13 to 0.20); 0.680	0.11 (−0.12 to 0.35); 0.318
Mean keratometry (diopter)	−0.04 (−0.07 to 0.00); 0.027*	−0.06 (−0.1 to −0.02); 0.004*
Central corneal thickness (mic)	0.00 (0.00 to 0.00); 0.933	0.00 (0.00 to 0.00); 0.402
White to white (mm)	0.05 (−0.01 to 0.10); 0.087	0.11 (−0.01 to 0.23); 0.067
Pupil diameter (mm)	0.06 (0.02 to 0.10); 0.008	0.03 (−0.04 to 0.11); 0.353
SE (diopter)	0.00 (−0.04 to 0.05); 0.920	0.03 (−0.05 to 0.1); 0.473
J0		
Age	0.012 (0.005 to 0.02); 0.003	−0.011 (−0.02 to −0.002); 0.021
Gender	−0.011 (−0.063 to 0.041); 0.656	−0.024 (−0.104 to 0.057); 0.536
J45		
Age	0.006 (−0.001 to 0.012); 0.068	−0.002 (−0.006 to 0.002); 0.274
Gender	−0.005 (−0.027 to 0.017); 0.645	0.041 (0.018 to 0.063); 0.002

*These variables remain in multiple models. ORA: Ocular residual astigmatism, CA: Corneal astigmatism, CI: Confidence interval, SE: Spherical equivalent

Table 4: Summary of some previous studies on corneal and ocular residual astigmatism and their components among children

Author (year)	*n*	Country	Age (Y)	CA (D)			ORA (D)		
				Total	J0	J45	Total	J0	J45
Huynh *et al.*[23]	1765	Australia	6-7	−0.82	-	-	−0.76	-	-
Harvey *et al.*[22]	2176	America	3-18	1.79	0.85	−0.02	−0.60	−0.31	0.05
Liu *et al.*[24]	206	China	6-16	−1.12	0.56	−0.01	−0.63	−0.31	−0.03
Chen *et al.*[25]	25	China	15-18	-	0.58	−0.04	-	−0.29	0.00
Current study	683	Iran	6-18	−0.85	0.38	0.01	−0.84	−0.32	0.04

n: Number of patients, CA: Corneal astigmatism, ORA: Ocular residual astigmatism, D: Diopter

ATR, and residual astigmatism showed a pattern of decreasing ATR with ageing. The authors concluded that the pattern of TA with ageing seemed to be influenced by CA.[31]

In the present study, the mean ORA and CA had no significant correlation with sex. There are contradictory reports of the correlation of sex with refractive astigmatism and its components, and there is no consensus in this regard. Some studies found a marked correlation between sex and different types of astigmatism[24,28] and reported a lower prevalence of ORA in boys versus girls,[22-24] while most studies reported no relationship between sex and astigmatism.[25,27] Some studies in older age groups reported a significant correlation between male gender and decreased odds of CA because the cornea of adult males is flatter compared to their female counterparts.[17,32,33] However, this difference between different age groups was not prominent in the present study because most gender-related corneal changes occur at older ages. More studies are needed in this regard.

In this study, the results of multiple regression analysis showed no correlation between corneal and residual astigmatism and SE. However, U-shaped analysis showed an increase in CA and a decrease in ORA with an increase in refractive errors (myopia and hyperopia). In other words, with an increase in the amount of myopia and hyperopia, the compensatory effect of ORA on CA fades and considering the higher CA and less compensatory effect of ORA, refractive astigmatism will increase. Previous studies found an increase in refractive astigmatism with an increase in myopia or hyperopia. Hashemi *et al.*[13] studied the correlation of astigmatism components with refractive errors. They reported that in high refractive errors, the pattern of refractive and residual astigmatism was WTR and ATR, respectively, which confirms the results of the present study and indicates the more important role of CA in determining the pattern of refractive astigmatism in higher amounts of refractive errors.

As for the relationship between biometric parameters and the amounts of CA and ORA, after modifying the effect of other variables in the multiple regression model, the results showed a marked relationship only between the anterior corneal curvature (mean keratometry) and CA and ORA. In other words, ORA and CA increased with an increase in the anterior corneal curvature. Previous studies also confirmed higher ORA and CA in participants with steeper corneas.[24,28,34]

The limitation of our study was that although refractive errors were studied with and without cycloplegia and the results of cycloplegic refraction were used for analysis, ocular biometry was done before cyclorefraction. However, although some previous studies, considering lack of significant differences in J0 and J45 with and without cycloplegia, were done without cycloplegia,[23,25] there were some studies that evaluate corneal and residual astigmatism in children under cycloplegia.[22,24] This difference in the measurement method should be considered in comparison with the results of different studies.

The results of the present study showed a higher prevalence and amount of ORA among a 6–18-year-old population and the compensatory effect of this type of astigmatism on CA. Therefore, the possibility of the presence of ORA and its relationship with CA should be considered before making any decisions to select appropriate contact lens design for the correction of refractive errors or refractive surgery. In other words, if clinicians only consider CA in the selection of contact lens type or in refractive surgery and ignore internal astigmatism, the desired refractive outcomes will not be achieved.

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Conflicts of interest

There are no conflicts of interest.

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