ARTYKUŁ PRZEGLĄDOWY REVIEW ARTICLE

DOI: 10.24292/01.OT.051225

Uncorrected visual acuity in patients with simple myopic astigmatism based on the power and axis of the astigmatism

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HIGHLIGHTS

In eyes with simple myopic astigmatism, uncorrected visual acuity decreases as the amount of astigmatism increases.
In astigmatism amount of 1 D or less, against-the-rule astigmatism had the worst vision and, with the increase in the power of astigmatism, this pattern changed and with-the--rule astigmatism had the worst vision.

ABSTRACT

Purpose: The aim of the current study is to assess uncorrected visual acuity in eyes with simple myopic astigmatism.
Methods: patients with simple myopic astigmatism who had no history of surgery or pathology with best-corrected visual acuity of logMAR 0.0 (or 6/6) were included in this study. In the present study, eyes were classified into three groups; with-the-rule (WTR) (180 [±30]), against-the-rule (ATR) (90 [±30]) and oblique. The comparison of uncorrected visual acuity among these three groups was made based on the power and type of refractive and corneal astigmatism.
Results: Only right eye per participant was chosen, providing a final sample of 1435 eyes. The number (percentage) of eyes with WTR, ATR and oblique astigmatism were 555 (38.7%), 681 (47.5%) and 199 (13.9%) respectively. The mean uncorrected visual acuity was different among three groups (p <0.001). Mean logMAR visual acuity in eyes with 1 D of astigmatism or less were 0.06 (±0.09), 0.07 (±0.09) and 0.06 (±0.08) in WTR, ATR and oblique astigmatism respectively. Mean logMAR visual acuity in eyes with greater than 3 D of astigmatism were 0.51 (±0.12), 0.17 (±0.06) and 0.43 (±0.19) in WTR, ATR and oblique astigmatism respectively which showed a significant difference among them (p <0.001).
Conclusion: The magnitude and axis of astigmatism both were associated with uncorrected visual acuity in eyes with simple myopic astigmatism so that increasing the power of astigmatism reduces vision.

Key words: astigmatism, visual acuity, uncorrected, axis, power of astigmatism

INTRODUCTION

Astigmatism is identified as one of the most common refractive errors with a prevalence of 13% and 24% across the world and Middle East respectively [1, 2]. Recently, the association between astigmatism and visual acuity has been an object of attention [3, 4]. In general, uncorrected astigmatism, even as low as 1 D, can significantly decrease vision and, if remains uncorrected can significantly affect patients' independence, quality of life, and well-being [5]. An astigmatism consists of two components: power and axis. Increasing the power of astigmatism increases blurred vision and consequently leads to the reduction of uncorrected visual acuity. Axis of astigmatism is categorized into 3 groups according to the orientation of the steepest power: with-the-rule (WTR), against-the-rule (ATR) and oblique [6]. According to many studies, the increase in the power of astigmatism was associated with a decrease in uncorrected visual acuity [7–9]. However, there is an ongoing debate about the effect of astigmatism axis on uncorrected visual acuity [4, 10–12]. This discrepancy in different studies may be due to selection of cases with compound myopic or mixed astigmatism or with low amount of astigmatism, creating astigmatism in healthy people, lack of equal grouping of astigmatism subtypes, not considering corneal astigmatism and the presence of a difference of 25% between the visual acuity of patients with true refractive error and those healthy individuals in whom they created refractive error [4, 10–15]. Despite remarkable advances in the scope of refractive surgeries such as photorefractive keratectomy (PRK) and cataract surgery [16, 17], post-operative residual refractive errors are still one of patients' complaints. For this reason, it has been suggested in some studies that if the type of residual refractive error is astigmatism, it is better to direct it to the power and axis that causes the least reduction in uncorrected visual acuity, and it is preferred that the axis of astigmatism be WTR to create a better vision and less complaints [10, 17]. Despite the low prevalence of oblique astigmatism compared to WTR and ATR, 3.5%, 15% and 17% respectively [18], the visual acuity of patients with oblique astigmatism is much lower than WTR and ATR with the same power of astigmatism. Also, eyes with uncorrected oblique astigmatism show lower reading performance and precision. Finally, astigmatism correction is necessary to obtain excellent visual outcomes, especially in eyes with oblique astigmatism [9, 13–21].

Considering the disagreement in previous studies about the effect of astigmatism axis on uncorrected visual acuity and the lack of sufficient studies on the visual acuity of patients with simple myopic astigmatism, the aim of this study is to compare the uncorrected visual acuity of eyes with simple myopic astigmatism based on axis and power of astigmatism.

METHODS

In this cross-sectional study, all healthy individuals aged from 20 to 30 years referred for routine eye examinations at especially hospital. In this study, eligible participants were patients with simple myopic astigmatism in whom spherical component obtained from dry refraction was between +0.50 D and -0.50 D and the cylindrical component was between -0.50 D and -6.00 D (provided that in subjective refraction, the amount of spherical value acceptable to patient be plano). Those with no history of pathology, refractive surgery, uncompensated phoria or tropia, pupil abnormalities in size or shape, keratoconus and dry eye and with best corrected visual acuity of logMAR 0.0 or better were included in the study. Exclusion criteria were history of ocular surgery, ocular pathology and irregular shape or size of pupil.

The Ethics Committee of Iran University of Medical Sciences approved the study protocol. All participants were informed about inclusion in the study and the protocol of the study was explained to them. All participants signed written informed consent. In order to minimize the error, all examinations were performed by one single clinical expert in the same examination setting. Evaluation of objective refraction status was performed by Topcon autorefractometer 8800 and the findings were confirmed by Heine retinoscope. After participants met the inclusion criteria, their monocular uncorrected visual acuity was assessed under standard room illumination with LED visual chart Smart LC 13 (Medizs Inc., Korea). It should be mentioned that in order to ensure the spherical values, cycloplegia was achieved with two drops of 1% cyclopentolate with a 5 min interval. Half an hour after the last drop, the refractive data was obtained. The astigmatism axis was categorized into three groups: WTR (180 [±30]), ATR (90 [±30]) and oblique [22].

Corneal astigmatism was determined based on keratometry findings of autorefractometer and Pentacam. In general, astigmatism is shown as a Jackson Cross Cylinder with a power in a specific axis in such a way that two astigmatism vectors are combined with the vector analysis and it shows it as only one number (J0 and J45). According to vector principles, astigmatism consists of two orthogonal vectors known as J0 and J45. The J0 and J45 are the horizontal/vertical, and the oblique components of astigmatism, respectively. The following formulas are used to calculate these vectors [23].

$$J0 = -C/2 \times \cos(2\alpha)$$
$$J45 = -C/2 \times \sin(2\alpha)$$

Where C = cylinder power, α = axis of astigmatism in objective refraction

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS software ver. 20.0. Descriptive statistics were presented as frequency percentage for qualitative variables, mean and standard deviation for quantitative variables. The normality of all data samples was first checked by the Kolmogorov–Smirnov test. Considering the normality of the data, an independent t-test and analysis of variance (ANOVA) was used to compare the uncorrected visual acuity among different groups of astigmatism. Correlation between uncorrected visual acuity and other parameters was also investigated in each group with the Pearson correlation test. P values = 0.05 were considered statistically significant.

ETHICAL ISSUES

This project was supported by Iran University of Medical Sciences (IUMS) and followed the tenets of the Declaration of Helsinki. The protocol of the study was approved by the Ethics Committee of Iran University of Medical Sciences. Informed consent was obtained from all participants.

RESULTS

In the present study, right eyes of 1435 subjects (55% females) with a mean age of 28.18 (±4.76) (20–35 years) were evaluated. Mean uncorrected visual acuity was 0.10 (±0.12) logMAR (tab. 1).

The prevalence of refractive astigmatism was 38.7% WTR, 47.5% ATR and 13.9% oblique.

TABLE 1

Baseline data for subjects and refractive characteristics of the right eyes.

Variables	Mean (±SD)	Range
Age (years)	28.18 (±4.76)	20–35
UCVA (logMAR)	0.10 (±0.12)	0.00–0.70
Spherical refractive error (D)	0.12 (±0.33)	-0.50–0.50
Cylindrical refractive power (D)	-1.02 (±0.68)	-0.50 – -6.25
Minimum keratometry (D)	43.65 (±1.70)	27.87–49.00
maximum keratometry (D)	44.65 (±1.67)	31.22–50.7
Corneal astigmatism (D)	1.00 (±0.77)	0.00–7.70
J0 cornea	-0.30 (±0.47)	2.96–1.69
J45 cornea	-0.01 (±0.28)	-2.46–1.68
J0 ref	0.00 (±0.52)	-2.17–2.32
J45 ref	0.01 (±0.33)	-3.13–1.75

D – diopter; SD – standard deviation; UCVA – uncorrected distance visual acuity.

About 73% (1054), 24% (348) and 2% (33) of the eyes had astigmatism less than or equal to 1 D diopter, 1–3 D and more than 3 D, respectively. While the prevalence of corneal astigmatism was 65.5%, WTR 18.1% ATR and 16.1% oblique. About 61.9% (888), 27.7% (398) and 10.4% (149) of the eyes had astigmatism less than or equal to 1 D diopter, 1–3 D and more than 3 D, respectively. In table 2 most of the eyes with astigmatism amount of 1 D or less have ATR astigmatism; as the amount of astigmatism increases, this proportion changes so that about 70% of eyes with higher than 3 D of astigmatism have ATR astigmatism.

TABLE 2

Prevalence of types of refractive astigmatism based on power.

		Astigmatism power (D)			Total
		≤1	2–3	>3	
Astigmatism type	WTR	35.0%	46.8%	69.7%	38.7%
	ATR	49.4%	45.1%	9.1%	47.5%
	oblique	15.6%	8.0%	21.2%	13.9%
Total		100.0%	100.0%	100.0%	100.0%

ATR – against-the-rule; WTR – with-the-rule.

In table 3, the mean and standard deviation of visual acuity (in logMAR) are shown in different groups of astigmatism. As can be seen, subjects with WTR astigmatism had the worst visual acuity. The ANOVA test showed a significant difference between visual acuity in different types of astigmatism (p = 0.006). This relationship did not change after adjusting for age in the ANCOVA model (p <0.001).

TABLE 3

Comparison of characteristics among types of refractive astigmatism axes.

	WTR (n = 555)	ATR (n = 681)	Oblique	P-value
Characteristics	mean (±SD)	mean (±SD)	mean (±SD)	
Age (year)	26.46 (±4.51)	29.26 (±4.64)	29.28 (±4.40)	<0.001
Spherical refractive error (D)	0.08 (±0.36)	0.15 (±0.32)	0.14 (±0.33)	<0.001
Cylindrical refractive power (D)	1.16 (±0.80)	0.94 (±0.50)	0.94 (±0.84)	<0.001
UCVA (logMar)	0.11 (±0.15)	0.09 (±0.11)	0.09 (±0.12)	<0.001

The p-value was calculated by analysis of variance (ANOVA).
ATR – against-the-rule; D – diopter; SD – standard deviation; UCVA – uncorrected visual acuity; WTR – with-the-rule.

Table 4 shows uncorrected visual acuity related to different types of astigmatism and its severity in refractive and corneal astigmatism. Evaluation of uncorrected visual acuity with consideration of refractive astigmatism demonstrates that in astigmatism of less than 1 D, cases with ATR astigmatism have the worst uncorrected visual acuity, with increasing astigmatism magnitude, especially in astigmatism of more than 3 D, people with WTR astigmatism have the worst uncorrected visual acuity. After controlling the confounding factor of age, the ANCOVA test showed that in eyes with refractive astigmatism more than 3 D, the worst uncorrected visual acuity belongs to eyes with WTR astigmatism. While based on corneal astigmatism, the worst uncorrected visual acuity belonged to the eyes that had ATR and oblique astigmatism.

TABLE 4

Comparison of uncorrected visual acuity (logMAR) among types of refractive and corneal astigmatism axes.

		Refraction astigmatism			Corneal astigmatism			P-value
		WTR	ATR	Oblique	WTR	ATR	Oblique	
		mean (±SD)	mean (±SD)	mean (±SD)	mean (±SD)	mean (±SD)	mean (±SD)	
Astigmatism power	≤1	0.06 (±0.09)	0.07 (±0.09)	0.06 (±0.08)	0.06 (±0.09)	0.09 (±0.10)	0.09 (±0.11)	<0.001
	2 –3	0.19 (±0.15)	0.18 (±0.13)	0.18 (±0.11)	0.08 (±0.11)	0.20 (±0.19)	0.14 (±0.13)	<0.001
	≥3	0.51 (±0.12)	0.17 (±0.06)	0.43 (±0.19)	0.26 (±0.19)	0.27 (±0.23(	0.27 (±0.21)	<0.001

The p-value was calculated by analysis of variance (ANOVA).
ATR – against-the-rule; SD – standard deviation; WTR – with-the-rule.

Finally, the changes in uncorrected visual acuity by removing the effect of age were different according to the type of corneal astigmatism (p <0.001), so that subjects with ATR corneal astigmatism have the worst visual acuity (tab. 5).

TABLE 5

Comparison of uncorrected visual acuity among types of corneal astigmatism axes after adjusted age.

Corneal astigmatism		Mean (±SD)	P-value
Power astigmatism (D)	≤1	0.08 (±0.10)	<0.001
	2–3	0.10 (±0.12)	
	>3	0.26 (±0.19)	
Axes groups	WTR	0.10 (±0.13)	
	ATR	0.11 (±0.12)	
	oblique	0.10 (±0.12)	

The p-value was calculated by analysis of variance (ANOVA).
ATR – against-the-rule; D – diopter; WTR – with-the-rule.

The correlation coefficient between uncorrected visual acuity and parameters J45 and J0 calculated for corneal astigmatism was investigated. uncorrected visual acuity had a significant negative correlation with both J45 and J0 parameters calculated for corneal astigmatism, while there was a positive correlation between uncorrected visual acuity and J45 and J0 parameters calculated for refractive astigmatism (fig. 1).

Finally, uncorrected visual acuity was evaluated based on the type of refractive and corneal astigmatism. The results obtained from intergroup analysis showed that eyes with ATR refractive astigmatism and ATR corneal astigmatism had the worst uncorrected visual acuity, and there was a significant difference between them (p <0.001) (tab. 6).

DISCUSSION

The results of the current study showed that in patients with simple myopic astigmatism, uncorrected visual acuity decreases as the amount of astigmatism increases. Also, uncorrected visual acuity changes based on the type of astigmatism axis; in such a way that in eyes with refractive astigmatism amount of 1 D or less, ATR and oblique astigmatism had the worst vision and with the increase in the power of astigmatism, this pattern changed and WTR astigmatism had the worst vision. While eyes with corneal astigmatism amount of 1 D or less showed the same result as refractive astigmatism, that is, ATR astigmatism had the worst vision and, this pattern did not change by increasing the amount of astigmatism. By considering the effect of both refractive and corneal astigmatism, eyes with ATR corneal and ATR refractive astigmatism had the worst uncorrected visual acuity.

TABLE 6

Comparison of uncorrected visual acuity (logMAR) between refractive astigmatism axes based on types of corneal astigmatism axes.

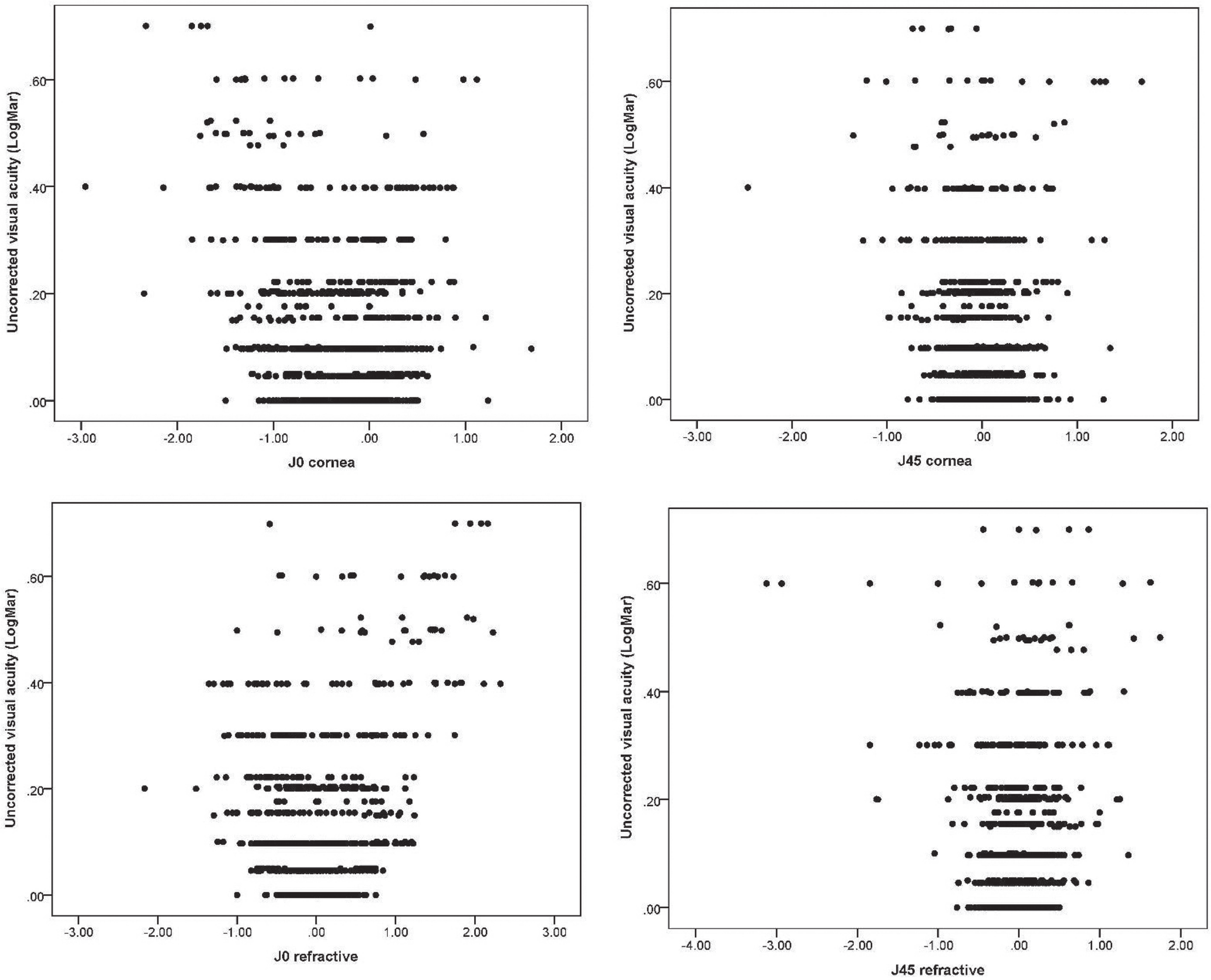
		Types of corneal astigmatism axes			P-value
		WTR	ATR	Oblique	
		Mean (±SD)	Mean (±SD)	Mean (±SD)	
Type of axes refraction astigmatism	WTR	0.12 (±0.15)	0.12 (±0.24)	0.05 (±0.10)	0.497
	ATR	0.70 (±0.10)	0.11 (±0.12)	0.10 (±0.12)	<0.001
	oblique	0.08 (±0.11)	0.09 (±0.21)	0.11 (±0.12)	0.218

The p-value was calculated by analysis of variance (ANOVA).
ATR – against-the-rule; SD – standard deviation; WTR – with-the-rule.

In this study, as in other studies, the power of astigmatism played an important role in uncorrected visual acuity of subjects with simple myopic astigmatism; uncorrected visual acuity decreases as the amount of astigmatism increases [4, 9, 10]. The reason for this may be that in these individuals, one of the focal lines is located on the retina and the other line is in front of the retina, so the greater the power of astigmatism, the greater the distance between the focal line that is in front of the retina from the retina,

FIGURE 1

Scatter plot demonstrating uncorrected visual acuity (UCVA) trends and (J0 and J45) in corneal and refractive astigmatism. J0 and J45 corneal astigmatism and UCVA were not significantly correlated (Pearson's correlation coefficient: r = -0.05; p = 0.06 J45 and r = -0.19; P <0.001 J0). J0 and J45 refractive astigmatism and UCVA were not significantly correlated (Pearson's correlation coefficient: r = 0.22; p <0.001 J0; r = 0.026; P = 0.32 J45).



and subsequently the patient will experience more blurred vision [21].

The results of this study showed that uncorrected visual acuity in an equal amount of astigmatism is different based on the type of astigmatism axis so that, similar to previous studies, in eyes with astigmatism amount of less than 1 D, WTR astigmatism had better vision [10–12, 17]. The reason behind this superiority of WTR-related uncorrected vision may be the squeezing phenomenon (narrowing of palpebral fissure). Considering that the vertical meridian is steeper in WTR astigmatism, it has more refractive aberration, so by narrowing the palpebral fissure, more changes can be made in the vertical meridian of the eye, which leads to better vision in eyes with low astigmatism. However, it is possible that it does not work in higher amount of astigmatism [10]. Also, due to the development of the primary visual cortex and letters being closer horizontally than vertically, vertical blur is more tolerable than horizontal and oblique blur. Thus, cases with WTR astigmatism have better vision than others. This can also be true in eyes with low amount of astigmatism [3, 10, 13]. Another reason that can justify the superiority of WTR astigmatism of less than 1 D in terms of vision, is internal aberrations. Because in these cases, the amount of internal aberrations is such that it compensates for the decrease in optical quality caused by astigmatism. However, when the amount of astigmatism increases, these aberrations worsen uncorrected visual acuity [3]. Nevertheless, one of our findings was that uncorrected visual acuity of subjects with oblique stigmatism of less than 1 D was worse. The worse vision of oblique cases can be due to the fact that most of the objects in our surrounding environment have an orthogonal orientation, so the visual experience for horizontal and vertical lines is more frequent than oblique ones. It has also been proven that the degree of stimulation and response of the visual pathways is dependent on the orientation of the stimulus and is higher for horizontal and vertical stimuli compared to oblique ones [24]. However, the results of this study were consistent with some previous studies that suggested that the type of astigmatism axis has no effect on uncorrected visual acuity [4]. The reason for this disagreement can be due to different methodology, examining small amounts of astigmatism, creating astigmatism in healthy individuals, or even not considering simple myopic astigmatism cases. In eyes with simple myopic astigmatism, not only the pure effect of astigmatism can be assessed, but accommodation also has no role in improving vision [4–13, 15].

When we separately examined the effect of corneal astigmatism on uncorrected visual acuity, we reached a different pattern in refractive astigmatism. ATR astigmatism had the worst uncorrected visual acuity in all amounts. However, when we examined the effect of refractive astigmatism based on the type of corneal astigmatism axis, we concluded that eyes in which both corneal and refractive astigmatism are ATR had the worst uncorrected visual acuity. Lenticular astigmatism can increase or even decrease the effect of corneal astigmatism on uncorrected visual acuity. For instance, in most cases with low amount of WTR astigmatism, internal astigmatism is ATR and they navigate each other to some extent. Therefore, as a result of this compensatory effect, uncorrected visual acuity improves [25]. When corneal astigmatism is ATR, internal astigmatism strengthens its effect. For this reason, the eyes in which both corneal and refractive astigmatism are ATR have the worst uncorrected visual acuity than others.

Finally, one of the most interesting findings of our study was the worse vision of people with high WTR astigmatism. This finding was contrary to our expectations considering the fact that refractive astigmatism is a combination of corneal and lenticular astigmatism and, as it was underscored earlier. Lenticular astigmatism is ATR and has a compensatory effect on corneal astigmatism. Therefore, in higher amounts of ATR astigmatism, it is expected that the amount of corneal astigmatism is significantly higher than lenticular astigmatism (despite the compensatory effect of lenticular astigmatism, there is still a high amount of refractive astigmatism which is indicative of a high corneal astigmatism). When the corneal astigmatism is high, the possibility of corneal irregularity and presence of high order aberrations is also higher. Therefore, this finding can be justified based on the presence of high order aberrations in eyes with WTR astigmatism [26]. The theory of visual receptive fields is one of the most important theories in visual perception. Hyperacuity, visual sensitivity, color vision and brightness can be described by this theory. According to this theory, the spatial resolution of objects (hyperacuity) depends on their structure, dimensions and function [27]. Therefore, acuity in different parts of the visual field, at different distances from the fovea, can have different conditions [28]. This difference may not be evident in spherical refractive errors due to the symmetry of the blurred image with respect to the fixation point. However, in astigmatism, due to the presence of linear images in different meridians and also the expansion of these images and their positions, different conditions may be encountered [15, 28]. To rephrase this, in different types of astigmatism (ATR, WTR and oblique) and myopic and hyperopic (simple and compound) and mixed astigmatism, a single meridian receives a better and clearer image from retina compared to other meridians. The complexity of the issue increases as the amount of astigmatism changes, which is not expected, because it changes the variety and number of receptive fields involved in the visual processing. Moreover, the level of receptive fields' function depends on the type and amount of astigmatism.

CONCLUSION

In this study, we examined a wide range of astigmatism values in a sufficient sample size. In addition to refractive astigmatism, we also examined corneal astigmatism separately and simultaneously. Nevertheless, there were some limitations in this study. One of the limitations is that we did not have access to the amount of high order aberration data. Another limitation is that we only examined the population that had normal pupil size, perhaps if otherwise, it could increase or decrease vision. In conclusion, in eyes with simple myopic astigmatism, uncorrected visual acuity decreases as the amount of astigmatism increases. In astigmatism amount of 1 D or less, ATR astigmatism had the worst vision and, with the increase in the power of astigmatism, this pattern changed and WTR astigmatism had the worst vision. By considering the effect of both refractive and corneal astigmatism, eyes with ATR corneal and ATR refractive astigmatism had the worst uncorrected visual acuity. Therefore, it is recommended to pay heed to the optical correction of patients with astigmatism of 3 D or higher, especially ATR, in order to improve their quality of life.

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Conflict of interest:
None.

Financial support:
This project was supported by Iran University of Medical Sciences.

Ethics:
The Ethics Committee of Iran University of Medical Sciences approved the study protocol, which was conducted in accord with the tenets of the Helsinki Declaration. All participants signed a written informed consent..