

# The Association between Astigmatism and Spherical Refractive Error in A Clinical Population

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## Abstract

**Purpose:** To determine the association between astigmatism and spherical refractive error in a clinical population

**Methods:** In this cross-sectional study, 2,000 patients who presented to our optometry clinic were enrolled. All were tested for objective refraction with a Nidek AR-310A auto refractometer, and non-cycloplegic refraction. For those under 15 years of age, cycloplegic refraction was measured as well. Myopia and hyperopia were defined as a spherical power of -0.5 Diopter (D) or less and +0.5 D or greater, respectively. Astigmatism was defined as a cylinder power of  $\geq -0.5$  D; with-the-rule (WTR) astigmatism if the steep axis was  $0\pm 20^\circ$ , against-the-rule (ATR) astigmatism if the steep  $90\pm 20^\circ$ , and oblique if the axis was in between.

**Results:** The mean age of the participants in this study was  $31.52\pm 18.39$  years, and 910 (45.5%) were male. The Mean cylinder power of the subjects with high myopia and high hyperopia was  $1.92\pm 0.25$  and  $1.48\pm 0.19$  D, respectively. The lowest prevalence of astigmatism was found in subjects with emmetropia ( $P < 0.001$ ). There was an age-related decrease in the prevalence of WTR astigmatism, and an increase in ATR and oblique astigmatism ( $P < 0.001$ ). Mean cylinder error in WTR, ATR, and oblique astigmatism groups was  $1.59\pm 1.24$ ,  $1.10\pm 0.76$ , and  $1.16\pm 0.04$  D, respectively ( $P < 0.001$ ), and absolute mean spherical error was  $1.97\pm 2.03$ ,  $1.49\pm 1.54$ , and  $1.68\pm 1.71$  D, respectively ( $P < 0.001$ ).

**Conclusion:** The results of this study indicated an association between astigmatism and spherical refractive error. Higher amounts of astigmatism were seen in subjects with high spherical ametropia. Astigmatism axis was related to the cylinder and spherical powers which were both higher in subjects with WTR than those with ATR and oblique astigmatisms. In those with ATR astigmatism with the refractive status was close to emmetropia.

**Keywords:** Astigmatism, Axis, Ametropia

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## Introduction

Astigmatism is a refractive error due to differences in the refractive power of the optical system in different axes. This may be caused by irregular curvature of the cornea, especially the anterior surface, and less commonly the crystalline lens.<sup>1-3</sup> Since astigmatism affects the near and distance vision of an individual, its symptoms are more common than other types of refractive errors.<sup>4-6</sup> The most common symptom is headache which is more commonly seen in astigmatism compared to other refractive errors.<sup>7</sup> Astigmatism has been reported to change with age,<sup>2</sup> and both extreme age ranges (infants and the elderly) exhibit higher amounts of astigmatism.<sup>8</sup>

Although astigmatism magnitude plays an important role in the individual's vision, its axis should also be taken into consideration.<sup>6,9,10</sup> Astigmatism axis is related to age and based on most previous studies, the more common type is with-the-rule (WTR) at younger ages and against-the-rule (ATR) at older ages.<sup>8,10</sup> The association between vision and astigmatism axis has been demonstrated in some studies such as the report by Abrahamsson and Sjostrand who noted that amblyopia was mostly seen in patients with oblique astigmatism.<sup>9</sup> There are also other reports showing that myopia is more common in WTR astigmatism.<sup>4-6</sup>

Astigmatism affects a considerable proportion of people at different ages, and thus, deserves attention. Previous studies suggest a possible relationship between sphere and astigmatism components of the refractive error.<sup>6</sup> Taking into account, the relatively few number of studies on the relationship between cylinder and spherical components,<sup>6</sup> we designed this study to examine such relationship in detail. Should our findings support the hypothesis, a natural progression would be to case-control studies to test the issue more specifically, and on to cohort studies that can give stronger evidence.

## Methods

In this cross-sectional study, we studied the refractive errors of 2,000 patients who presented to a private optometry clinic in Mashhad during 2009-2010.

Exclusion criteria were a history of, or the presence of any disease affecting refractive errors, such as cataract, corneal opacity, ptosis, glaucoma, age-related macular degeneration (ARMD) or other retinal disorders, aphakia, and amblyopia. All participants signed a written informed consent form. Objective refraction was measured with a Nidek AR-310A auto refractometer which is annually calibrated, and the average of 5 measurements was recorded. The auto refractometer results were then checked with a Heine EN 100 retinoscope.

Spherical and cylindrical refractive errors were compared. Myopia and hyperopia were defined as a sphere power of -0.5 Diopter (D) or worse and +0.5 D or greater, respectively. A negative cylinder notation was chosen and astigmatism was defined as a cylinder error  $\geq 0.5$  D; WTR astigmatism if the steep axis was  $0 \pm 20^\circ$ , ATR astigmatism if the steep axis was  $90 \pm 20^\circ$ , and oblique if the axis was in between. The participants with myopia and hyperopia were classified into three subgroups according to the amount of refractive errors as low (-0.5 to -3.0 D), moderate (-3.0 to -6.0 D), and high myopia ( $< -6.0$  D), and low (0.5 to 2.0 D), moderate (2.0 to 4.0 D) and high hyperopia ( $> 4.0$  D).

The collected data from patients were then analyzed using the SPSS (V 11.5). To study the refractive errors of the population, data were summarized as mean and standard deviation (SD). The relationship between spherical and cylinder error was studied with linear regression analysis; the agreement between them was determined with Pearson's correlation test, and their difference in different types was tested using analysis of variance.

## Results

Of the 2,000 participants in this study, 910 (45.5%) were males. The mean age of the subjects was  $31.52 \pm 18.39$  (range, 5 to 82) years. Mean sphere and cylinder errors were  $-0.56 \pm 2.40$  D and  $-1.09 \pm 1.09$  D, respectively, and mean spherical equivalent was  $-1.11 \pm 2.49$  D. The distribution of different types of refractive error based on spherical equivalent is shown in Table 1.

Table 2 presents the mean and SD of sphere and cylinder errors in different age

groups. The spherical equivalent showed a trend towards myopia up to the age of 30, and then progressed into hyperopia; the overall trend was U shaped and changes were statistically significant ( $P < 0.001$ ). The highest mean cylinder error value ( $-1.57$  D) was seen in the under 10 year and the over 70 year old age groups.

Figure 1 illustrates the relationship between astigmatism and spherical refractive error; the degree of astigmatism was highest in individuals with spherical error less than  $-6.0$  D (high myopia) and greater than  $4.0$  D (high hyperopia) (ANOVA:  $P < 0.001$ ). Mean astigmatism was  $1.92 \pm 0.25$  in high myopics and  $1.48 \pm 0.19$  D in high hyperopics.

WTR, ATR, and oblique astigmatism of  $0.5$  D or greater were found in  $51.5\%$  ( $n=788$ ),  $26.5\%$  ( $n=405$ ), and  $22.1\%$  ( $n=338$ ) of patients, respectively; there was no significant inter-gender difference in this distribution ( $P=0.663$ ). The correlation between astigmatism type and age is shown in figure 2. The proportion of WTR astigmatism

decreased with age from  $90\%$  in those under 10 years old to  $16.7\%$  in the over 70 year age group ( $P < 0.001$ ). The reverse was true about ATR astigmatism; the proportion among the astigmatic sample increased from  $2.5\%$  to  $56\%$  in the youngest and oldest age groups ( $P < 0.001$ ). The mean cylinder error in WTR, ATR, and oblique astigmatic groups were  $1.59 \pm 1.24$ ,  $1.10 \pm 0.76$ , and  $1.16 \pm 0.04$  D, respectively (ANOVA:  $P < 0.001$ ). The prevalence rate of WTR astigmatism increased at higher degrees of cylinder error (Figure 3).

Our findings showed that patients with WTR and ATR astigmatism had the highest and lowest spherical error, respectively (Figure 4). The absolute values of the mean spherical error in WTR, ATR and oblique astigmatism were  $1.97 \pm 2.03$ ,  $1.49 \pm 1.54$ , and  $1.68 \pm 1.71$  D, respectively. The post hoc analysis showed that the difference was due to spherical error values in WTR and ATR types of astigmatism ( $P < 0.001$ ).

**Table 1.** The distribution of refractive errors by the severity

	Frequency	Percent
High myopia	68	3.4
Moderate myopia	275	13.8
Low myopia	836	41.8
Emmetropia	448	22.4
Low Hyperopia	261	13.1
Moderate hyperopia	79	4.0
High hyperopia	33	1.7
Total	2,000	100.0

**Table 2.** The distribution of sphere, cylinder and spherical equivalent by age

	Sphere Mean $\pm$ SD	Cylinder Mean $\pm$ SD	SE Mean $\pm$ SD
0-10	$0.42 \pm 2.72$	$-1.57 \pm 1.2$	$-0.37 \pm 2.8$
11-20	$-1.41 \pm 2.26$	$-1.03 \pm 1.07$	$-1.92 \pm 2.34$
21-30	$-1.44 \pm 2.29$	$-1.14 \pm 1.24$	$-2.01 \pm 2.35$
31-40	$-0.78 \pm 2.24$	$-1.11 \pm 1.14$	$-1.33 \pm 2.33$
41-50	$0.1 \pm 1.72$	$-0.88 \pm 0.8$	$-0.34 \pm 1.79$
51-60	$0.62 \pm 1.76$	$-0.9 \pm 0.97$	$0.17 \pm 1.9$
61-70	$0.46 \pm 2.76$	$-1.14 \pm 1.08$	$-0.11 \pm 2.97$
>70	$0.5 \pm 3.42$	$-1.57 \pm 1.04$	$-0.29 \pm 3.62$

SD: Standard deviation

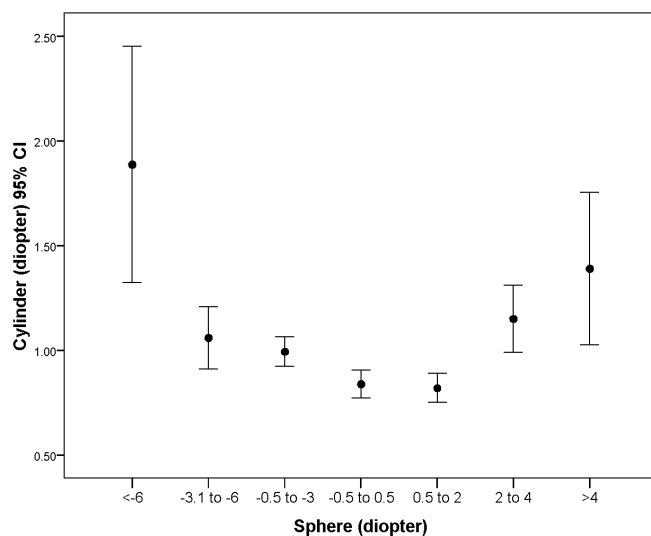


Figure 1. The association between spherical and cylindrical ametropia

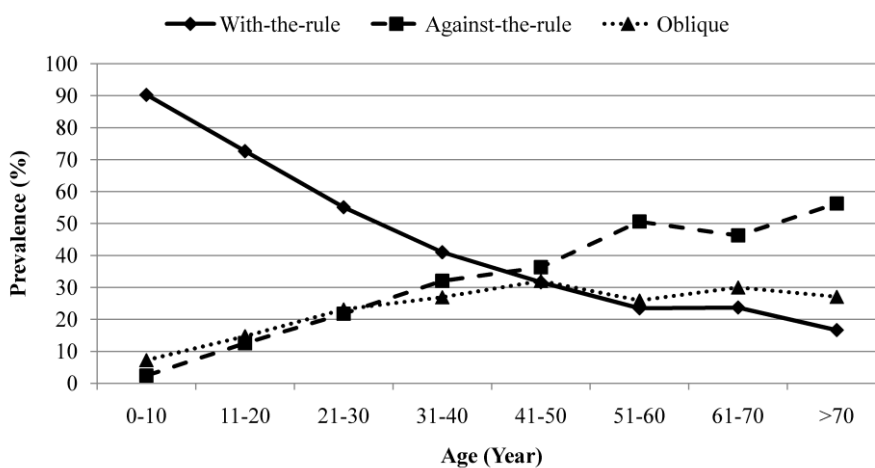


Figure 2. The distribution of astigmatism type by age groups

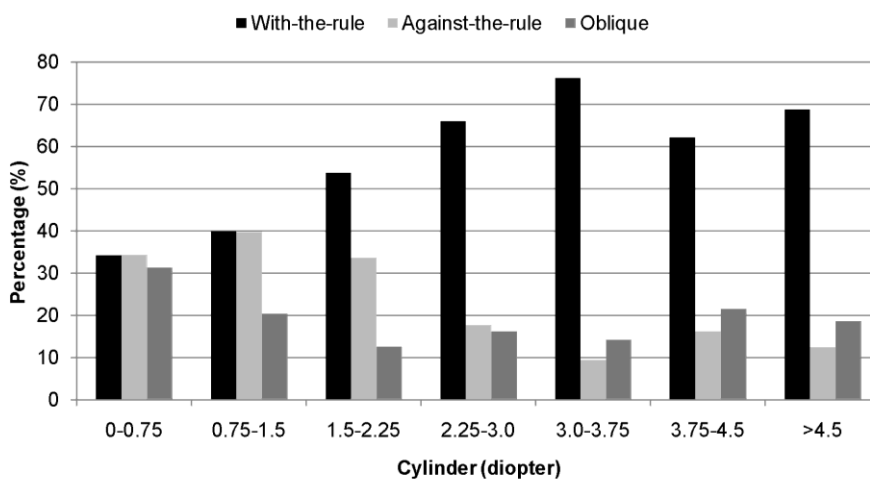
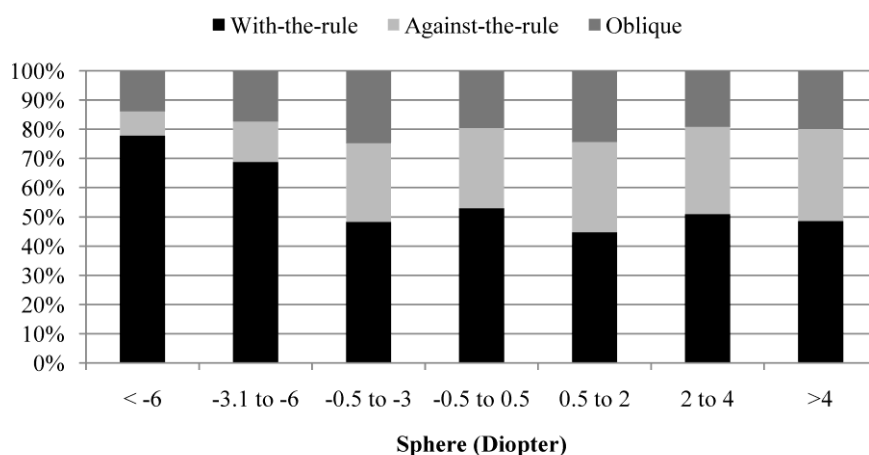


Figure 3. The distribution of cylinder power by astigmatic type/orientation



**Figure 4.** The association between astigmatism type and spherical ametropia

## Discussion

The present study aimed to assess the relationship between astigmatism and the spherical component of refractive errors, and we observed a direct correlation between them; the higher the cylinder error, the higher the spherical error. In a study on high myopic subjects, Heydari et al reported that astigmatism increased with an increase in spherical equivalent.<sup>11</sup> In a comprehensive report by Gwiazda et al, this relationship was demonstrated in high myopic subjects and they suggested two possible mechanisms for it: first, infantile astigmatism disrupts focusing mechanisms, hence infants who experience astigmatism early in life are more likely to develop myopia due to a defocus image; and second, ocular growth induces astigmatism and myopia.<sup>5</sup>

Through this study, not only did we confirm previous findings, we also observed high spherical hyperopia in subjects with high astigmatism. Most previous studies reported such a correlation between astigmatism and myopia.<sup>4,5,11,12</sup> One possible explanation would be their use of spherical equivalent, which contains the cylinder component, rather than the spherical component alone. Even so, Gwiazda et al's<sup>5</sup> second theory on the effects of ocular growth on the induction of astigmatism and myopia could be the most possible reason for their correlation.

In our study, WTR astigmatism was the most prevalent type. Comparisons with previous findings can be relatively difficult for several reasons; different definitions have

been used to categorize astigmatism, and the age range of our sample was quite wide. For example, while some studies base their classification on axes ranges of  $180 \pm 30$  for WTR and  $90 \pm 30$  for ATR astigmatism, some others allow only  $\pm 15$  degrees deviation from the horizontal and vertical axes, and we like many other investigators, chose  $\pm 20$  degrees.<sup>2,5,10,11</sup> However, results of our study were in agreement with those reported by most previous ones showing that WTR astigmatism was the most common type.<sup>6,10,13</sup> Also, in terms of age, we observed a decreasing share of WTR astigmatism from 90% to 16.7% in the youngest and oldest age groups, respectively, while the share of ATR astigmatism increased from 2.5% to 56% in these two age groups, respectively. These trends were in accordance with many other studies. In a review article, Read et al<sup>8</sup> reported that the most prevalent types of astigmatism was ATR between birth and the age of 4 years, WTR between 4 to 40 years, and again ATR after 40 years of age. Generally, ATR astigmatism increases with the decrease of eyelid pressure with age.<sup>8</sup>

In our study, high cylindrical powers in subjects with WTR astigmatism were comparatively less than those with ATR astigmatism. Like us, Mandel et al also reported that high astigmatism was mostly of the WTR type.<sup>10</sup> A similar relationship was found between spherical, myopia and the type of astigmatism; there was a higher prevalence of WTR astigmatism in those with high

spherical myopia. Like our study, Mandel et al<sup>10</sup> also showed that WTR astigmatism had a larger share among subjects with high myopia, and near emmetropic people mostly had oblique and ATR astigmatism. Similar findings were reported by Farbrother et al<sup>6</sup> and Heidary et al<sup>11</sup>. Overall, it seems that the higher prevalence of squinting among myopes, causes the eyelids to squeeze the corneal surface and lead to WTR astigmatism.

As a limitation of this study, we did not test the cycloplegic refraction which would be of special importance in the under 30 year age group. Thus, we feel that our findings regarding hyperopia should be interpreted and

quoted with caution.

### Conclusion

The results of this study showed the association between astigmatism and spherical refractive errors. High astigmatism prevalence was found in subjects with high spherical ametropia. Astigmatism axis was related to the cylindrical and spherical components. Subjects with WTR astigmatism had higher spherical and cylinder refractive errors in comparison to those with oblique and ATR astigmatism. ATR astigmatism had a higher prevalence in subjects with emmetropia.

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