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Magnitude of astigmatism – A comparison between eyes

Doerte Luensmann [a,b,*], Jack L. Schaeffer [c], Nicholas J. Rumney [d], Andre Stanberry [b], Desmond Fonn [a,b]

[a] Centre for Ocular Research & Education, Waterloo, Canada
[b] School of Optometry & Vision Science, University of Waterloo, Waterloo, Canada
[c] Schaeffer Eye Center, Birmingham, Alabama, United States
[d] BBR Optometry, Hereford, United Kingdom

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ABSTRACT

Purpose: Astigmatism is a highly prevalent refractive error and while studies typically focus to describe the axis symmetry between eyes, little is known about the refractive symmetry. Therefore, this study determined the astigmatic power symmetry between eyes in a large clinic population.

Methods: A clinical chart review was conducted at three optometric practices in the United States, the United Kingdom and Canada and subjective refraction data from 88,891 patients 14–70 years of age who presented with at least −0.25DC refractive astigmatism in at least one eye were included in the analysis. Data were obtained at these practices between January 2014 and March 2017. The overall distribution (%) and magnitude (DC) of astigmatism was determined and refractive differences between eyes were identified.

Results: The mean age of the patients was 42.1 ± 15.9 years and included 51,685 (58%) female and 37,206 (42%) male patients. In this data pool of 177,782 eyes, 10.9% required zero astigmatic correction, while 56.2% had astigmatism of −0.25 to −0.75DC. In total 23.9% of patients presented with astigmatism of at least −0.75DC in only one eye, while the other eye had 0 to −0.50DC. Overall, the difference in astigmatism between eyes was less than −0.75DC for 82.1% of astigmatic patients. For patients who presented with astigmatism of −1.00DC in the right eye, 80.8% of them had an astigmatic prescription of −1.00 ± 0.50DC in the left eye. For an astigmatic prescription of −4.00DC in the right eye, only 40.6% of patients exhibited astigmatism of −4.00DC ± 0.50DC in the left eye.

Conclusions: The majority of patients exhibited a difference in astigmatism between eyes of less than −0.75DC, however the refractive cylinder power symmetry was significantly lower in patients with higher refractive astigmatism.

1. Introduction

Astigmatism is reported to be the most common refractive error but is rivaled by myopia in certain ethnicities [1]. Astigmatism prevalence is dependent on age, ethnicity, race, and has been associated with spherical ametropia [1–6]. The prevalence has been studied extensively [1–6] and none more comprehensively than Hashemi et al. whose meta-analysis included 135 articles on astigmatism [1]. Hashemi et al. concluded that the prevalence of astigmatism in children was 14.9% and 40.4% in adults.

There is evidence that inter-ocular symmetry exists for astigmatism [6–8] and other ocular parameters. However, studies comparing the symmetry of astigmatism, focus primarily on the axis distribution and less on the refractive cylinder power [9–11]. In a pool of 5,505 patients who exhibited astigmatism of a least 0.75DC in at least one eye, Young et al. found that 49% of these patients had astigmatism of at least 0.75DC in one eye only [3] and Satterfield also found a surprisingly high percentage (26%) of subjects with unilateral astigmatism amongst the astigmatic patient cohort [12]. This seemed like an inordinately high prevalence and has clinical implications when prescribing toric soft lenses where the choice of lens design could incorporate prism ballast in the toric lens, thus creating potential binocular imbalance. A previous report by Luensmann et al. [2] described the spectacle prescription data of 101,973 patients which included ametropic and emmetropic conditions and the prevalence of astigmatism but did not report on the symmetry between eyes. This presented an opportunity to determine the

* Corresponding author at: Centre for Ocular Research & Education, School of Optometry & Vision Science, University of Waterloo, Waterloo, Canada.
E-mail address: doerte.luensmann@uwaterloo.ca (D. Luensmann).

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level of symmetry of refractive astigmatism between the right and left eyes in this patient cohort and to calculate the proportion of the patients who have astigmatism in one eye (unilateral astigmatism) only as a secondary objective.

2. Methods

In a retrospective chart review, de-identified spectacle prescription data were collected from three clinical eye care institutions including, the Eye Care Center with multiple locations in Alabama (United States), a large Optometry office in Hereford (United Kingdom), and the School of Optometry & Vision Science in Waterloo (Canada). Details on the method of subjective refraction to determine the spectacle prescription were not recorded and may have varied between practitioners. Ethics clearance was obtained from the research ethics committee at the University of Waterloo, Canada for the conduct of the analysis.

The patient population was between 14 and 70 years of age and the data included in the analysis were obtained at these practices between January 2014 and March 2017. In cases when patients had multiple records during this period, only the most current spectacle prescription information was used.

The majority of patient data were obtained from the US (93%), followed by the UK (6%) and Canada (1%). The US data set was sourced from offices in Alabama and represents primarily White (69%) and Black/African American (27%) people [13]. As shown previously, the percentage of astigmatic patients with a spectacle cylinder in both eyes of up to −2.50DC was similar between sites [2] and the analysis has therefore been conducted for the combined data pool. All subsequent data analysis was conducted including all patients with astigmatism of at least −0.25DC in at least one eye.

The data are presented in patient count, percentage, and confidence intervals (CI). Box & Whisker Plots further highlight the distribution of astigmatic power for each eye. Paired *t*-test and Pearson correlation were calculated to determine the relationship between eyes. Chi-square analysis and independent t-tests were conducted to compare the power symmetry with different magnitudes of astigmatism. All other comparisons are intended to allow for easier interpretation of the data and are not based on inferential statistical analysis.

3. Results

3.1. Patient cohort

The astigmatic group consisted of 88,891 patients (87.2% of the entire sample) who presented with astigmatism of at least −0.25DC in at least one eye and included 51,685 (58%) female and 37,206 (42%) male patients. The average age of the patients was 42.1 ± 15.9 years. Based on the eye with the larger absolute value of the spherical equivalent refraction this study included 63,837 (71.8%; CI: 71.5–72.1) myopes, 23,752 (26.7%; CI: 26.4–27.0) hyperopes and 1,302 (1.5%; CI: 1.4–1.5) emmetropes.

3.2. Magnitude of refractive astigmatism per eye

The mean astigmatism was −0.83 ± 0.81DC for the right eye and −0.83 ± 0.82DC for the left eye. The Box & Whisker Plots (Fig. 1) show the distribution of astigmatic prescriptions for the right and the left eyes; the median was −0.50DC in each eye and the interquartile range was from −0.25 to −1.00DC respectively. Overall, the magnitude of the astigmatism was similar between eyes (Paired *t*-test p = 0.11).

A strong linear correlation for the astigmatism as determined by Pearson correlation (r = 0.72, p < 0.00) highlights the refractive symmetry between right and left eyes.

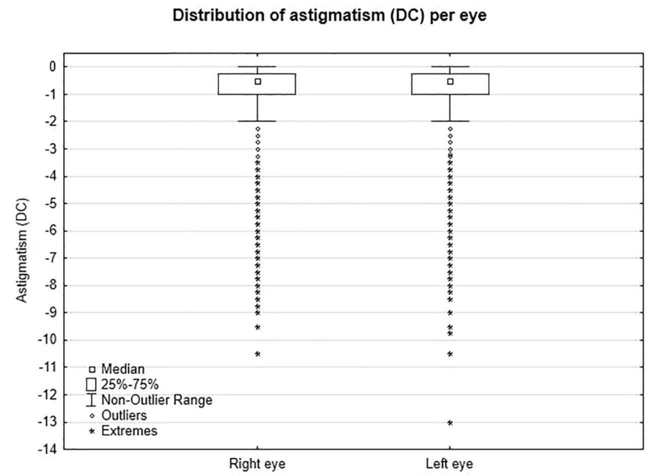

Fig. 1. The Box & Whisker Plots show the distribution of astigmatism (DC) for the right and left eyes of 88,891 astigmatic patients (n = 177,782 eyes).

3.3. Refractive cylinder power symmetry between eyes

In total, 39.8% of astigmatic patients had no more than −0.50DC in both eyes, 36.3% had −0.75DC or more in both eyes and the remaining 23.9% of patients exhibited at least −0.75DC in one eye while the other eye exhibited no more than −0.50DC. This also means that 60.2% of all astigmatic patients exhibited astigmatism of at least −0.75DC in at least one eye.

Fig. 2a shows that 56.2% of all eyes (including right and left eyes) exhibited astigmatism of −0.25 to −0.75DC. Of the entire astigmatic patient pool, 21.8% (19,340 patients) had astigmatism in one eye only. The first bar in Fig. 2a shows the total proportion of these eyes with zero astigmatism (10.9%) while Fig. 2b highlights the astigmatism prescription in their contralateral eyes in detail. Patients with no astigmatism in one eye and significant astigmatism of at least −0.75DC in the contralateral eye accounted to 5.3% (n = 4,742) of all astigmatic patients (Fig. 2b).

In 36.9% of patients, the astigmatism in the right eye was at least −0.25DC higher, while in 37.4% of patients the left eye had a higher astigmatism, and 25.7% of patients had the same prescription in both eyes. Fig. 3 shows that 82.1% of the patients had a difference in astigmatism of no more than −0.50DC between eyes.

Fig. 4a–d illustrate the variability of astigmatism between eyes for different magnitudes of astigmatism. All right eyes with astigmatism of −1.00DC, −2.00DC, −3.00DC and −4.00DC were selected respectively and the amount of astigmatism found in the left eye is plotted. Fig. 4a illustrates that 80.8% of patients exhibit ±0.50DC spread in the left eye for the −1.00DC in the right eye. As the astigmatism in the right eye progressively increased, the corresponding left eye showed a decrease in astigmatic power symmetry as illustrated in Fig. 4a-d. Chi-square analysis comparing the left eye within and outside of ±0.50DC of the right eye power confirmed different distribution profiles in all four graphs (p < 0.05 for all). Furthermore, independent t-tests comparing the absolute power difference between right and left eyes also determined statistically significant differences between all graphs (p < 0.05 for all), except for the comparison between −3.00DC (Fig. 4c) and −4.00DC (Fig. 4d) (p = 0.75).

4. Discussion

The threshold is critical when comparing data on ametropia from different publications. In a *meta*-analysis by Hashemi they found that the most commonly reported threshold for astigmatism was −0.50DC or −0.75DC [1]. Even though a low prevalence of 0.3% [14] and 0.7% [15] was found for children in Vietnam and Thailand, other countries such as

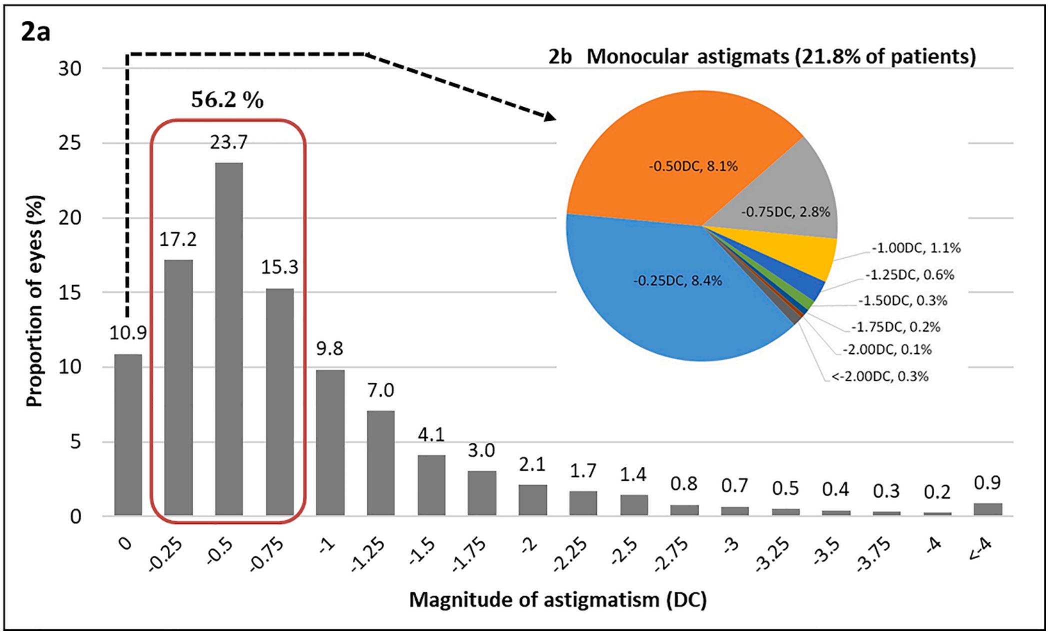

Fig. 2. a + b: Distribution (%) of astigmatism (DC) by eye including 88,891 astigmatic patients (n = 177,782 eyes) (a); Distribution of the astigmatic prescription (DC) in the eyes of patients with zero astigmatism in the other eye (n = 19,340 patients) (b).

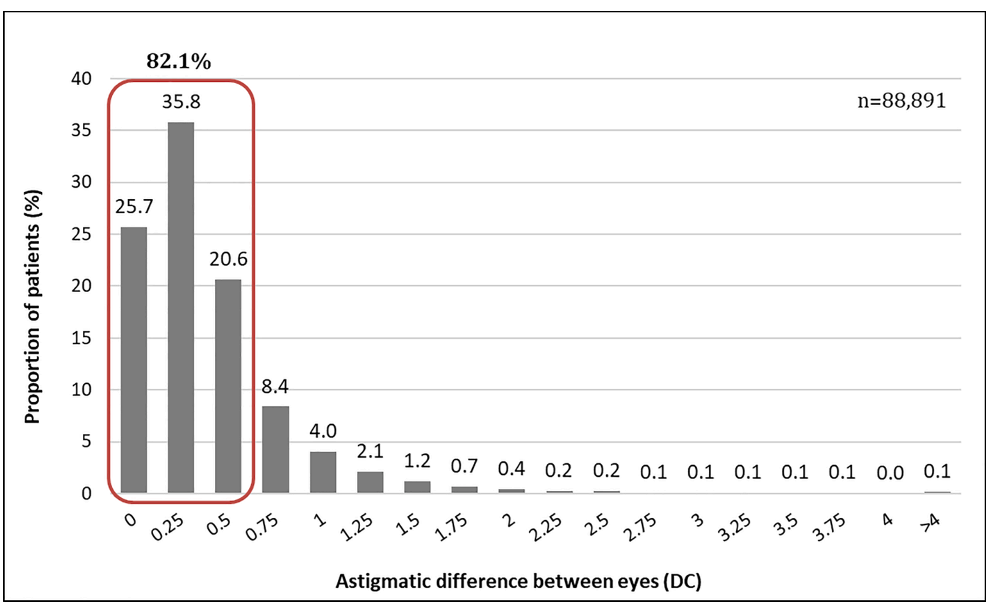

Fig. 3. Difference in astigmatism (DC) between eyes of astigmatic patients (n = 88,891).

China reported between 25% [16] and 41% [17] for similar age groups for astigmatism of at least −0.75DC. Data from the US showed that 23% of young adults age 20–39 years have astigmatism of at least −1.00DC in at least one eye [18]. This can be compared to the previous publication on a clinic population including patients 14–70 years of age [2]. In this study 37% of patients were found to have a cylinder of at least −1.00DC in at least one eye, which was not surprising considering the different population samples [2]. The percentage of eyes with astigmatism of more than −1.00DC (26%) was however only slightly lower compared to the study conducted by Satterfield, who found 30% of eyes exhibiting this level of astigmatism in a military population conducted approximately 30 years ago [12].

Results from the current analysis show that amongst the astigmatic patient group the percentage of unilateral astigmatism was slightly lower with 21.8% compared to 26% as reported by Satterfield [12]. Another comparison to a previous publication from Young et al. [3] can also be made if the entire database of patients is considered which includes those without astigmatism (n = 101,973 patients); Young et al. [3] reported that 47.4% of their patients showed astigmatism of at least 0.75DC in at least one eye, which is also in close agreement to the current results which found this level of astigmatism in 52.5% of all patients.

Within the astigmatic population, 23.9% required a correction of at least −0.75DC in one eye only, while the other eye had no more than −0.50DC. While low astigmatism of −0.25DC or −0.50DC are correctable with spectacle lenses, this is often not the case for soft contact lenses which typically start at a cylinder correction of at least −0.75DC, likely due to manufacturing reasons. This may be of clinical relevance when a

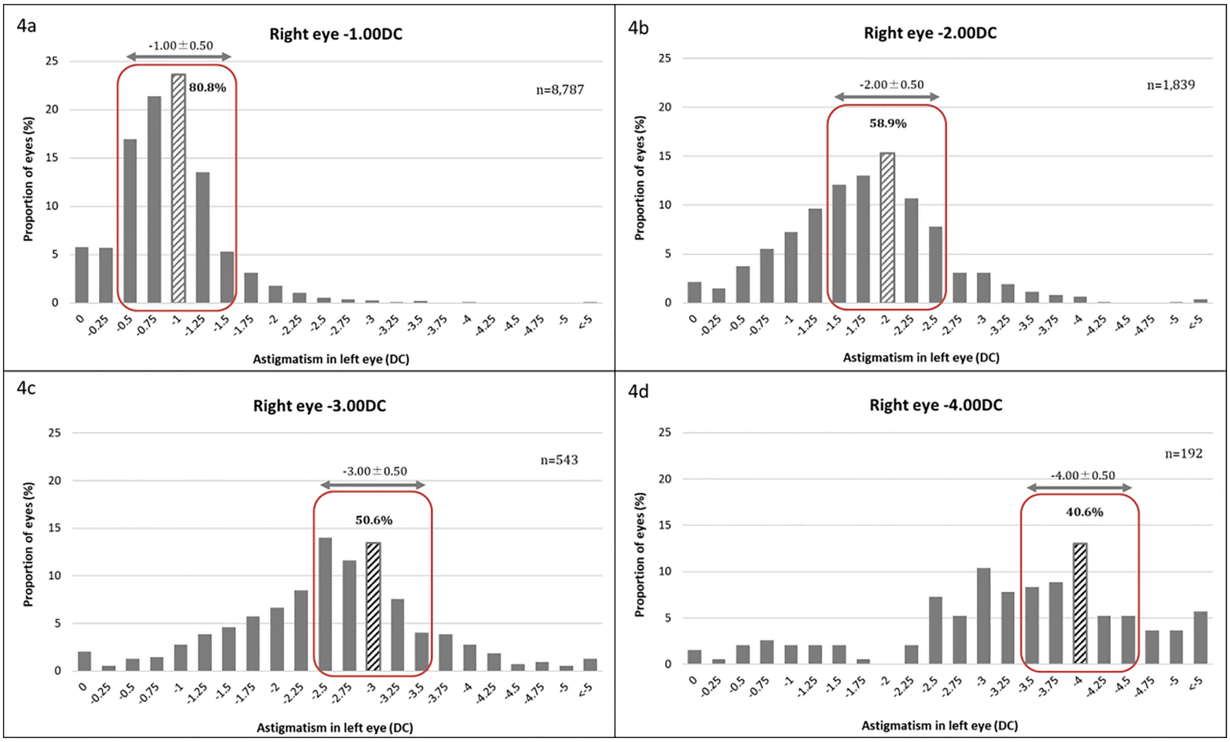

Fig. 4. a-d: Level of astigmatism (DC) in the left eye when the right eye presented with a cylinder of −1.00DC (a), −2.00DC (b), −3.00DC (c) and −4.00DC (d).

toric contact lens with prism ballast is worn monocularly, while the other eye is corrected with a spherical lens. Whether to overcorrect astigmatism of −0.50DC in the contralateral eye with a −0.75DC stock toric lens or whether to leave the astigmatism of −0.50DC uncorrected is a clinical decision.

A study by Sulley et al. [19] determined that toric soft contact lenses that use a prism ballast to stabilize the lens on eye, create a vertical prism ranging from 0.52 to 1.15 Δ prism diopters within the central 6 mm zone of the lens. This could impact binocular vision, stereopsis and may cause visual discomfort as well as symptoms of asthenopia, nausea and motion sickness [20–22]. However, in contradiction, a unilateral prism ballast toric lens could be used to correct a vertical phoria where appropriate. In a short-term study, Nilsson reported that unilateral wear of a prism-ballasted toric soft contact lens seldom led to patient symptoms of visual discomfort or diplopia [23], which is supported by Morgan's work who determined a vertical fusional reserve of 3–3.5 prism diopters [24,25]. Based on these values, one would expect that the fusional reserve should compensate for the 0.5–1.5Δ induced prism of the toric lens, but as the authors have suggested the clinical assessment and significance of these relatively small amounts of vertical induced prism induced by toric soft lenses have to be studied. With a variety of lens designs available, eye care practitioners have the option to choose a lens with a different stabilization technique if they believe their patient may not be able to compensate the vertical prism.

A shift in symmetry between eyes was noted with higher astigmatism, indicating that only 40.6% of patients who presented with an astigmatism of −4.00DC in the right eye had a similar prescription (±0.50DC) in the left eye compared to the symmetry of 80.8% for the −1.00DC. It is possible that reasons due to eye injuries, surgery or ocular disease may have contributed to a more variable astigmatism between eyes for those who presented with higher astigmatism.

A limitation of the analysis relates to the fact that the data are representative of an optometric population because they were collected from clinical practice sites and not from the general population. However, the data are representative of a typical office environment which acknowledges that practitioners have different techniques to successfully determine their patients' subjective refraction. The analysis purposely included patients 14–70 years of age who are potential contact lens wearers, however, it should be noted that astigmatism changes with age and slightly higher magnitudes of astigmatism are present in the presbyopic age group [2].

5. Conclusion

The analysis of this large population of astigmatic clinic patients has revealed that there is high symmetry of astigmatic power between right and left eyes indicating that more than 4 in 5 patients exhibit a difference in astigmatism between eyes of no more than −0.50DC. Astigmatic power symmetry was high in lower astigmatic powers; however, it gradually decreased with increasing levels of astigmatism. Approximately 1 in 4 patients exhibited astigmatism of at least −0.75DC in one eye only, while the other eye required a lower correction. This could have implications if a toric soft lens with a prism ballast is fit on one eye only. In general, unilateral astigmatism was found in 1 of 5 astigmatic patients which was slightly less then reported previously.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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