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ORIGINAL PAPER

Corneal astigmatism in cataract surgery patients from Bosnia and Herzegovina

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Abstract
Purpose To determine corneal astigmatism prevalence, its correlations with age and symmetry pattern in fellow eyes of patients undergoing cataract surgery.
Methods This is a clinical-based retrospective cross-sectional study. Keratometry measurements of patients undergoing cataract surgery assigned to University Clinical Center Tuzla, Bosnia and Herzegovina, between January 2011 and June 2012 were recorded and analyzed retrospectively.
Results The study consisted of 4080 eyes of 2205 consecutive cataract surgery patients with a mean age of 68.24 years ± 9.25 (SD) (range 32–84 years), and 54.0% of the patients were women. Mean corneal astigmatism was 0.72 ± 0.61 D (range 0–6.5 D). The prevalence of corneal astigmatism 1.0 D or more was in 1291 eyes (31.64%), 1.5 D or more in 736 eyes (18.03%), 2.0 D or more in 396 eyes (9.71%) and 3.0 D or more in 108 eyes (2.65%). There was no significant difference in the magnitude of astigmatism between age groups ($p = 0.10$), male and female ($p = 0.29$) or right and left ($p = 0.75$) eyes. The prevalence and amount of astigmatism increased with age ($p < 0.05$). Gradual shift from with-the-rule astigmatism toward against-the-rule astigmatism was observed ($p = 0.03$). Patients with higher amount of astigmatism in one eye are more likely to have significant astigmatism in fellow eye ($p < 0.01$). Symmetry in pairs of eyes is present in eyes with astigmatism greater than 2.5 D ($p < 0.01$).
Conclusion This study provides useful reference data for cataract surgeons and patients from Bosnia and Herzegovina.

Keywords Prevalence · Keratometry · Symmetry · Fellow eye · Toric IOL

Introduction

Cataract presents the leading cause of preventable blindness in the world [1]. Increased life expectancy, with higher number of aging population, resulted with increased cataract prevalence in the world [2]. Newer cataract surgery technology has emerged in an era wherein patients are demanding excellent visual results [3]. In order to meet heightened patient expectations, it is crucial to pay utmost attention to patient selection, accurate keratometry and biometry readings, and the application of correct intraocular lens (IOL) power formula with optimized lens constants [4]. Furthermore, at the time of the cataract surgery it is necessary to address both spherical refractive error and the astigmatism [5].

Preoperative astigmatism can be reduced or eliminated by several surgical techniques [5]. Corneal

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astigmatism (CA) represents the major factor affecting the total ocular astigmatism and can be significantly altered during the cataract surgery [3, 5]. Phacoemulsification (PE) with smaller incisions is not consistently associated with less surgically induced astigmatism (SIA) [6]; therefore, preoperative assessment of corneal astigmatism is essential for achieving spectacle independence [7]. Several studies have described CA and its associations with age or other ocular parameters [8–28]. It is considered that there is a high correlation in the bilateral ocular astigmatism magnitude and direction, especially at higher levels [29]. Thus, there are only a few studies considering the symmetry of astigmatism in eye pairs [15, 29–31]. Therefore, it is useful to assess the relationship of CA and other parameters in order to predict the necessity of offering astigmatism correction during the same procedure [15, 22, 26].

The purpose of this study is to report the prevalence of CA and evaluate the profile of bilateral astigmatism and its relationships in a population of patients presenting for cataract surgery at university hospital.

Materials and methods

This was a retrospective cross-sectional study of the eyes of 2205 consecutive patients who attended the cataract surgery in Ophthalmology Department of University Clinical Center Tuzla between January 2010 and June 2011. The current study was approved by hospital's ethics committee. Informed consent was obtained from all patients after receiving an explanation of the investigative nature and intent of the study, and tenets of the Helsinki Declaration were followed.

The CA analysis was performed using the Tomey RT-7000 Auto Refractor-Keratometer (Tomey Corporation, Nagoya, Japan), which performs automatic measurement of the central eye keratometry. Experienced technicians measured keratometry data, with at least three automatic measurements performed in each eye. Integrated software automatically selected the most reliable measurement, which was later used for IOL calculation and for this research. Data were initially compiled on Microsoft excel spreadsheet, and all entries were double-checked before further statistical analysis. After keratometry, patients underwent a complete ophthalmic examination, including visual acuity testing with Snellen charts, tonometry, detailed slit lamp biomicroscopy examination, pupillary reaction and fundoscopy. Inclusion criteria included presence of cataract and age more than 30 years. The exclusion criteria were irregular astigmatism, previous corneal or intraocular surgery, and history of intraocular inflammation and penetrating eye trauma.

Changes in keratometry data, amount of astigmatism and axial orientation with age, gender and side were analyzed. Corneal astigmatism was designated as with-the-rule (WTR) when the axis of correcting minus cylinder was within 30° of the vertical 90° meridian, against-the-rule (ATR) when the correcting minus cylinder axis was within 30° of the horizontal 180°, and oblique (OBQ) if it was neither WTR nor ATR orientation. Data for right and left eyes were analyzed separately, and only data from patients who had both eyes measured were included in analysis to identify possible correlation between right and left eyes. Axis symmetry was categorized in two patterns: direct (parallel) and mirror symmetry. We used a method similar to the method described by Asharlous et al. [30] to analyze symmetry patterns, but categorized the deviation in each model into two categories as 0° (exact symmetry) and 0°–15°.

Data were analyzed using Stata Statistical Software, version 13.0 (StataCorp LP, College Station, Texas, USA). For statistical analysis, age was categorized into six categories: < 40, 41–50, 51–60, 61–70, 71–80 and > 80 years of age. The Kolmogorov–Smirnov test was used to check normal distribution of variables. Bivariate correlations were evaluated using the Spearman rank correlation coefficient for non-normally distributed variables. Differences between age groups were analyzed using an analysis of variance for normally distributed variables and the Kruskal–Wallis (K–W) test for non-normally distributed variables. Linear regression models were used to assess the associations between age and astigmatism. The *t* test was used with parametric variables and Wilcoxon signed-rank test with nonparametric variables to compare corneal cylinder. The intereye relationship between right and left eyes was analyzed by calculating Pearson correlation coefficient. All statistical analyses were two-sided, and p values less than 0.05 were considered statistically significant.

Results

This study was composed of 4080 eyes from 2205 patients. A total of 1190 patients (54.0%) were female, and there were 2050 right eyes (50.2%) in the analysis. The mean age of included patients was 68.24 years ± 9.25 (SD) (range 32–84 years). The inclusion criteria were not met by 213 patients, and 3 of them were later diagnosed with bilateral keratoconus, resulting with keratoconus prevalence of 0.14%. Table 1 shows the age and sex distribution of the cohort and the laterality of the eyes. Patient's age group younger than 40 years contained only 7 patients and was excluded from statistical analysis to identify changes with age.

Average keratometry values for steep and flat corneal meridian were 44.18 ± 1.58 D (range 40.25–49.25 D) and 43.46 ± 1.56 D (range 37.50–47.50 D), respectively. Keratometry values for both steep and flat corneal meridians although increased with age did not present significant differences (K–W $p = 0.08$; $p = 0.09$) (Fig. 1). Furthermore, no significant differences in average keratometry values of steep and flat corneal meridians were found between male and female ($p = 0.92$; $p = 0.84$) or right and left eyes ($p = 0.10$; $p = 0.09$).

Mean total astigmatism was 0.72 ± 0.61 D (range 0–6.5 D). There was no significant difference in the magnitude of astigmatism between age groups ($p = 0.10$), male and female ($p = 0.29$) or right and left eyes ($p = 0.75$). The prevalence of astigmatism increased with age ($p < 0.05$) (Table 2). The CA of 1.0 D or more was in 1291 eyes (31.64%), 1.5 D or more in 736 eyes (18.03%), 2.0 D or more in 396 eyes (9.71%) and 3.0 D or more in 108 eyes (2.65%) (Fig. 2). In patients with CA greater than 2.5 D in one eye, 83.3% patients had more than 1.5 D astigmatism in the fellow eye, and 52.5% more than 2.5 D. However, in patients with astigmatism between 1.0 and 1.5 D only 18.7% patients had similar finding in fellow eye ($p < 0.01$).

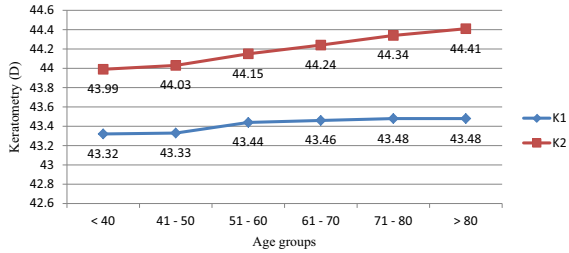

Fig. 1 Keratometry changes with age

A total of 1652 of eyes (40.5%) presented with WTR astigmatism, 836 (20.5%) with OBQ and 1592 (39.0%) with ATR astigmatism. There was no difference in the axis orientation regarding the amount of CA, between male and female ($p = 0.74$) or right and left eyes ($p = 0.92$). There was increase in the prevalence of ATR astigmatism with age ($p = 0.03$) (Fig. 3). However, there was no significant change in prevalence of OBQ and WTR astigmatism ($p = 0.11$). Analysis of symmetry patterns in 1875 included eye pairs showed exact or 0°–15° symmetry in 79 (4.2%) and 638 (34.0%) pairs, respectively. Axial symmetry with respect to the type of the astigmatism was as follows: direct symmetry 515 (27.5%), 534 (28.5%) indirect symmetry and 826 (44.1%) pairs of eyes presented no axial symmetry ($p = 0.51$). In patients with CA greater than 2.5 D in one eye, exact or 0°–15° symmetry was present in 29 (24.6%) and 75 (63.6%) eye pairs, respectively ($p < 0.01$).

Discussion

Improvement in surgical technique, biometry and IOL calculation provides improved visual outcomes, while

Table 1 Age and sex distribution of patients

Age group (years)	Patients	Total eyes	Right eyes (%)	Left eyes (%)	Male (%)	Female (%)
< 40	7	14	7 (50)	7 (50)	3 (42.9)	4 (57.1)
41–50	156	291	148 (50.9)	143 (49.1)	77 (49.4)	79 (50.6)
51–60	769	1437	716 (49.8)	721 (50.2)	352 (45.8)	417 (54.2)
61–70	865	1583	798 (50.4)	785 (49.6)	391 (45.2)	474 (54.8)
71–80	287	531	270 (50.8)	261 (49.2)	131 (45.6)	156 (54.4)
> 80	121	224	111 (49.6)	113 (50.4)	61 (50.4)	60 (49.6)

Table 2 Total amount and prevalence of corneal astigmatism

Age group (years)	Steep meridian (D)	Flat meridian (D)	Corneal astigmatism (D)	Prevalence of astigmatism > 1 D% (*n*)
< 40	43.996 ± 1.40	43.316 ± 1.30	0.680 ± 0.610	42.85 (6)
41–50	44.034 ± 1.61	43.328 ± 1.58	0.706 ± 0.614	19.24 (56)
51–60	44.150 ± 1.54	43.439 ± 1.54	0.711 ± 0.603	20.08 (288)
61–70	44.240 ± 1.58	43.464 ± 1.50	0.776 ± 0.599	21.66 (343)
71–80	44.337 ± 1.60	43.476 ± 1.67	0.861 ± 0.402	31.63 (168)
> 80	44.410 ± 1.34	43.820 ± 1.59	0.930 ± 0.601	42.41 (95)

D diopter

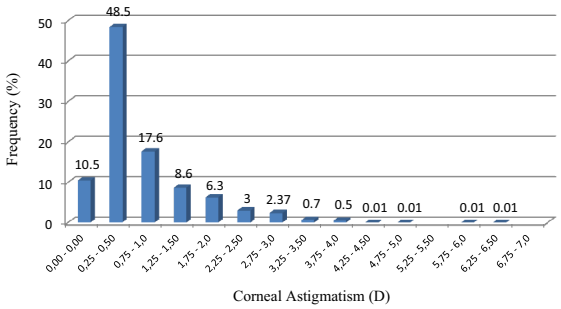

Fig. 2 Distribution of corneal astigmatism

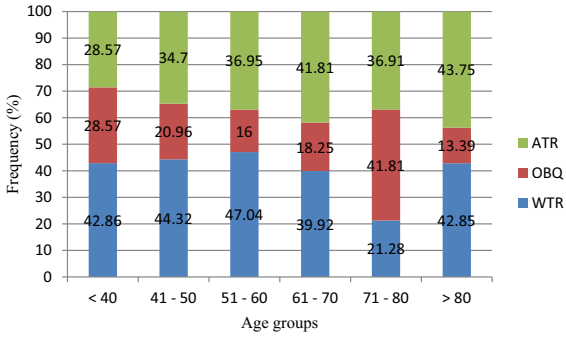

Fig. 3 Axial distribution of astigmatism in age groups

cataract surgery generally provides a high rate of patient satisfaction. With these advancements, cataract surgery has become a refractive procedure aimed at achieving postoperative emmetropia and spectacle independence for distance in most cases [27]. However, the presence of residual CA can be one of the major determinants that affect the quality of postoperative vision [15]. Cataract surgery provides unique opportunity to address CA at the time of the surgery. Corneal astigmatism can be successfully treated with different modalities including placing the corneal incision on the step meridian, opposite clear corneal incisions, peripheral corneal relaxing incisions and with the use of toric IOL (up to 9 D) [5, 7]. Toric IOLs offer patient the opportunity to correct moderate and high CA and achieve spectacle independence for distance vision [7]. Furthermore, toric IOLs reduce lifetime economic costs by reducing the need for glasses or contact lenses following cataract removal [32]. However, initial costs of toric IOLs surgery in a developing country might present a significant barrier; therefore, determining the number of potential toric IOL candidates can be of great importance in planning the spending of the health insurance resources.

Keratometry values, of both steep and flat corneal meridian, in our study gradually increased with age, which is consistent with the results of previous studies [8, 9, 11, 14, 17, 19–21, 23–27]. Some studies found that women have steeper corneas than man [9, 14, 17, 19, 21, 23, 27], but this was not revealed in our results. Mean CA in our study is lower than that in all previously published studies, and keratometry readings of patients from European populations generally present slightly lower keratometry values, which might have resulted in a lower magnitude and prevalence of CA (Table 3). The magnitude of CA is positively correlated with age [8, 13, 14, 17, 19, 21, 22, 26, 27], which is consistent with observed keratometry changes. It is already known that the overall prevalence of CA increases relative to age [8, 10, 15, 16, 19, 22]. However, the prevalence of astigmatism < 1 D decreases with age, while CA between 1–3 D and > 3 D increases with increasing age [11, 13, 22], which matches our results (Table 2).

In the present study 31.6% eyes were found with CA ≥ 1.0 D, which is similar and lower than

Table 3 Patient demographics and main outcomes of recently published studies

Author	Country	Eyes/patients	Age (years) mean ± SD	Female (%)	K1 (D) mean ± SD	K2 (D) mean ± SD	Corneal astigmatism			
							Mean ± SD	≥ 1.0 D	≥ 2.0 D	≥ 3.0 D
Ferrer-Blasco et al. [8]	Spain	4540/2415	60.59 ± 9.87	68.2	43.48 ± 1.61	44.08 ± 1.59	0.90 ± 0.93	34.8	9.26[a]	3.31[b]
Hoffmann and Hutz [9]	Germany	23,239/15,448	74	NR	NR	NR	0.98 ± 0.78	36.04	8.09	2.65
Lekhanont et al. [10]	Thailand	2010/1005	68.21 ± 9.19	61.4	44.03 ± 1.56	44.91 ± 1.54	1.05 ± 0.62	37.8	7.88	1.58
Khan and Muhtaseb [11]	UK	1230/746	75.54 ± 10.71	54.0	43.43 ± 1.49	44.46 ± 1.56	1.03 ± 0.73	40.41	9.69	1.93
Ercegović et al. [12]	Croatia	392/202	77 median	55	42.8 ± 1.53	43.7 ± 1.51	0.75 median	31.6[c]	6.6[a]	3.3[b]
Guan et al. [13]	Eastern China	1430/827	72.27 ± 11.59	56.6	43.57 ± 1.56	44.64 ± 1.65	1.07 ± 0.73	45.45	10.42	2.31
Chen et al. [14]	Southern China	4831/2849	70.56 ± 9.55	61.7	43.76 ± 1.53	44.76 ± 1.56	1.01 ± 0.69	41.3	8.22	3.52
Lyall et al. [15]	Scotland	3498/1814	74.52 ± 10.23	60.1	NR	NR	1.04 ± 0.78	41.0	9.85	2.75
De Bernardo et al. [16]	Italy	657/380	71.89 ± 10.19	53.9	43.54 ± 1.43	44.56 ± 1.52	1.02 ± 0.69	41.74	8.32	2.64
Cui et al. [17]	Southern China	6750/4561	70.4 ± 10.5	55.6	43.57 ± 1.69	44.69 ± 1.69	0.9 median	43.9	11.6	3.4
Isyaku et al. [18]	Nigeria	3286/3169	60.8 ± 12.7	42.4	43.80	43.99	1.16	66.92	21.0	6.12
Yuan et al. [19]	Northern China	12,449/6908	69.80 ± 11.15	53.7	43.93 ± 1.67	45.08 ± 1.73	1.15 ± 0.84	47.27	13.16	3.75
Oh et al. [20]	South Korea	2847/2847	66.64 ± 12.06	64.2	43.77 ± 1.53	44.56 ± 1.57	0.79 ± 0.64	34.5	7.2	1.1
Prakairungthong et al. [21]	Thailand	2688/2671	66.23 ± 10.79	56.7	43.81 ± 1.57	44.89 ± 1.62	1.09 ± 0.87	36.6	11.2	3.9
Collier Wakefield et al. [22]	UK	2247/2247	72.28 ± 13.84	NR	43.18 ± 1.64	44.29 ± 1.70	1.11 ± 0.88	44.2	11.6	3.7
Mohammadi et al. [23]	Iran	2156/1317	64.92 ± 11.48	53.8	43.70 ± 1.70	44.83 ± 1.79	1.12 ± 1.10	48.3	14.9	7.4
Curragh and Hassett [24]	North Ireland	2080/1788	NR	59.0	43.09 ± 1.61	44.16 ± 1.62	1.09 ± 0.83	41.3	11.6	3.27
Michelitsch et al. [25]	Austria	6900/3450	72.5 ± 12.2	NR	42.83 ± 1.63	43.88 ± 1.75	1.05 ± 0.90	38.3	9.3	3.4
Yu et al. [26]	Central China	3209/2821	70.51 ± 9.81	62.0	43.75 ± 1.59	44.84 ± 1.65	1.09 ± 0.77	43.85	10.56	2.80
Prasher and Sandhu [27]	India	2502/2312	59.54 ± 10.96	50.2	43.87 ± 1.92	44.91 ± 1.88	1.04 ± 1.04	40.65	12.03	4.56
Moulick et al. [28]	India	223/223	60.70 ± 10.46	45.7	44.12 ± 1.61	44.95 ± 1.62	0.87 ± 0.61	18.8[d]	NR	NR
Present study	Bosnia and Herzegovina	4080/2205	68.24 ± 9.25	54.0	43.46 ± 1.56	44.18 ± 1.58	0.72 ± 0.61	31.64	9.71	2.65

NR Not reported, *D* diopter, *SD* standard deviation, *K1* flat keratometry, *K2* steep keratometry

[a]Not including 2.0 D

[b]Not including 3.0 D

[c]Not including 1.0 D

[d]More than 1.25 D

previously reported 31.6–44.2% in European populations [8, 9, 11, 12, 15, 16, 22, 24, 25]. However, it is still lower than 34.5–61.9% in cataract patients from other regions [10, 13, 14, 17–21, 23, 26, 27]. Overall, our results correspond mostly to the results from neighboring state Croatia [12]. The lower figures in our study are likely to be concurrent to the lower mean age of 68.24 years, but also to ethnic and racial differences in included participants, as well as differences in the instruments used to take measurements [27]. The most cost-effective methods to reduce CA are to make smaller corneal incisions in order to reduce SIA and choose the most appropriate location for the corneal incision [26]. In patients with CA up to 1.0 D, and up to 2.0 D, on-axis incision and paired on-axis incisions can be appreciably efficient in astigmatism correction [33]. This means that in our study 90.29% of patients could be associated with favorable results in CA correction without the use of toric IOLs.

In this study we presented the analysis of keratometry readings, namely anterior CA [20]. However, astigmatism correction based on anterior curvature readings alone might be insufficient [7]. Refractive power of the posterior corneal surface does not always correlate with the anterior surface, and posterior corneal curvature also changes with the age, although magnitude of these changes is significantly smaller [34]. Our results reported keratoconus prevalence of 0.14%, which is lower than 1.96% reported in Iranian population aged 40–64 years [35]. This relatively low prevalence might be a result of selection bias, where keratoconus patients seek for help years before the cataract surgery, and many of them are earlier directed to other treatment modalities [36]. The mean posterior corneal power and astigmatism are highly reliable characteristics that can distinguish keratoconus from normal corneas [37]. Thus, in order to achieve maximum results before correcting CA, it is necessary to determine total CA by measuring anterior as well as posterior CA [38]. Therefore, data on prevalence of CA should be carefully analyzed in estimation of number of patients that might require toric IOL and associated projected costs [15, 22, 27].

We have found that there is a continuous increase in the prevalence of the ATR astigmatism with the age, which is in line with results of most previous reports [8–10, 12, 13, 15–17, 19, 20, 22, 23, 25–28]. Some authors found decrease in WTR astigmatism with increasing age [12–15, 17, 19–23, 25–28], which was not the case in our study because of variable prevalence of WTR and OBQ astigmatism in different age groups. The ATR astigmatism can be increasingly prevalent with increasing magnitude of astigmatism [17, 22]. Furthermore, CA continues to change toward ATR astigmatism over 20 years after cataract surgery, and this change was similar in eyes that did not have surgery [39]. The reason for age-dependent changes in the astigmatism axis and magnitude is still unclear, but it is hypothesized that it is due to changes in upper eyelid morphology and power [40, 41], intraocular pressure [42] and possibly changes in the corneal structure [39, 42]. Nevertheless, these changes highlight the need for special considerations in long-term astigmatism management. One should consider treating ATR astigmatism more aggressively with the aim to fully correct it as its magnitude is likely to increase with age [13, 15, 20, 22]. However, in younger patients full correction of WTR astigmatism at the time of the cataract surgery might be misleading, since ITS (or HIS) probable progression to the ATR astigmatism in years to come.

Some authors found differences in astigmatism magnitude between right and left eyes [9]. Our results showed that there is a strong correlation between the right and left eye of the same individual. In patients with CA greater than 2.5 D in one eye, there is a greater chance that the same patient will have astigmatism of a similar magnitude in the fellow eye too [15]. Furthermore, in patients with higher magnitude of astigmatism there is a higher chance for axial symmetry in eye pairs [30]. There is also a higher tendency toward direct or mirror symmetry with increasing age [29, 30]. This is important since toric IOL surgery requires bilateral surgery if it is to achieve maximum patient satisfaction [7, 15]. Additionally, strong correlation between right and left eyes supports current practice that both eyes should have biometry performed even if only unilateral surgery is planned. This allows for any erroneous measurement to be identified if there is any large discrepancy between the eyes [15].

To the best of our knowledge, this is the first study from Bosnia and Herzegovina that focused on preoperative assessment of CA in cataract surgery patients. This study has some limitations, while it was retrospective and clinically based study which may lead to some selection bias. Nonetheless, this study is based on population of consecutive patients in period of time

longer than 1 year in region where all surgical procedures are performed in single tertiary healthcare institution. Therefore, our data have a wide range providing a real profile of astigmatism in cataract surgery patients. Another limitation of current study was the use of conventional automatic keratometer for the analysis of CA [8, 10, 12, 27]. The CA measurements from manual keratometry, automated keratometry, partial coherence interferometry, corneal topography, scanning-slit topography and Scheimpflug imaging are comparable [43]. However, in eyes with high irregular astigmatism, measurements obtained by automated keratometry and ray tracing keratometry (Pentacam) were not comparable [44]. Therefore, a conventional autorefractor can be effective as a first-level screening method to detect irregular CA in places where corneal topography facilities are not available [45]. In eyes with greater amount or irregular CA further diagnostic workup should be planned.

In conclusion we present the first study reporting the prevalence and characteristics of CA in patients undergoing cataract surgery in Bosnia and Herzegovina. This study supports the trend of age-related increase in keratometry readings, astigmatism prevalence, astigmatism magnitude and the prevalence of ATR astigmatism. Significant correlation was found in amount of astigmatism between the right and left eyes of the same individual. Symmetry in axial astigmatism distribution was only present in eye pairs with amount of astigmatism greater than 2.5 D. The patients demand excellent postoperative visual results, and data on astigmatism and especially on the profile of bilateral astigmatism are important in planning toric IOL implantation in order to achieve maximum results. Smaller and temporal corneal incisions could address preexisting corneal astigmatism in the vast majority of cataract surgery patients from Bosnia and Herzegovina.

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Compliance with ethical standards

Conflict of interest The author declares that there is no conflict of interest.

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