Automated Comprehensive Analysis of Preoperative Biometric Parameters in Cataract Patients: A Retrospective Study of over 6000 Eyes

Automatisierte Analyse der präoperativen biometrischen Parameter bei Kataraktpatienten: eine retrospektive Studie mit über 6000 Augen

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ABSTRACT

Cataract surgery is one of the most successful surgical procedures, improving vision and quality of life for millions globally. An accurate preoperative measurement is crucial for predicting outcomes, particularly in minimizing postoperative refractive errors through precise intraocular lens (IOL) selection. This study aimed to analyze preoperative biometric data in cataract patients to identify key parameters relevant for clinical decision-making. The study also sought to understand patient demographics and biometrics in a representative population. An automated retrospective analysis was conducted on the preoperative biometric data of 6163 eyes from 3118 patients who underwent cataract or clear lens extraction (CLE) surgery in a German clinic over the past 2 years. All measurements were taken using the IOL Master 700 (Carl Zeiss Meditec, Jena, Germany), and data were automatically transferred for analysis using a dedicated software tool. Biometric parameters assessed included axial length (AL), keratometry values (K, TK), anterior chamber depth (ACD), lens thickness (LT), and vitreous length (VL). The age and gender distribution of the cohort was also considered. The biometric data from this large patient cohort largely aligns with published norms for cataract patients. The majority of eyes exhibited ALs and corneal curvatures within expected ranges, supporting accurate IOL power calculations. The study also confirmed a high prevalence of mild astigmatism, suggesting that toric IOLs could address residual astigmatism for better visual outcomes. This study's large sample size adds valuable insights into preoperative cataract patient data and shows the value of an automated analysis.

ZUSAMMENFASSUNG

Die Kataraktoperation ist einer der erfolgreichsten chirurgischen Eingriffe, der das Sehvermögen und die Lebensqualität von Millionen Menschen auf der ganzen Welt verbessert. Eine genaue präoperative Messung ist entscheidend für die Vorhersage der Ergebnisse, insbesondere für die Minimierung postoperativer Brechungsfehler durch eine präzise Auswahl der Intraokularlinse (IOL). Ziel dieser Studie ist es, präoperative biometrische Daten von Kataraktpatienten zu analysieren, um Schlüsselparameter für die klinische Entscheidungsfindung zu ermitteln. Außerdem soll die Studie ein Verständnis der demografischen und biometrischen Daten der Patienten in einer repräsentativen Population ermöglichen. Es wurde eine automatisierte retrospektive Analyse der präoperativen biometrischen Daten von 6163 Augen von 3118 Patienten durchgeführt, die sich in den letzten 2 Jahren in einer deutschen Klinik einer Katarakt- oder Clear-Lens-Extraction-Operation (CLE) unterzogen. Alle Messungen wurden mit dem IOL Master 700 (Carl Zeiss Meditec) durchgeführt, und die Daten wurden automatisch zur Analyse mit einem speziellen Softwaretool übertragen. Zu den untersuchten biometrischen Parametern gehörten Achsenlänge (AL), Keratometriewerte (K, TK), Vorderkammertiefe (ACD), Linsendicke (LT) und Glaskörperlänge (VL). Auch die Alters- und Geschlechtsverteilung der Kohorte wurde berücksichtigt. Die biometrischen Daten dieser großen Patientenkohorte stimmen weitgehend mit den veröffentlichten Daten für Kataraktpatienten überein. Die Mehrheit der Augen wies Achsenlängen und Keratometriewerte innerhalb der erwarteten Bereiche auf. Die Studie bestätigte auch eine hohe Prävalenz eines leichten Astigmatismus, was durch torische IOLs ausgeglichen werden sollte, um bessere Sehergebnisse zu erzielen. Die Größe dieser Studie gibt wertvolle Einblicke in die präoperativen Daten von Kataraktpatienten und zeigt, wie nützlich eine automatische Analyse von Patientendaten sein kann.

Background

Cataract surgery is one of the most common and successful surgical procedures performed worldwide, offering many patients the opportunity to significantly improve their vision and, consequently, their quality of life [1]. A critical factor for postoperative success is preoperative planning. Accurate measurement and analysis of preoperative data enable a precise calculation of the intraocular lens (IOL) to be implanted, which plays a significant role in minimizing postoperative refractive errors [2].

Cataracts are the leading cause of preventable blindness worldwide, particularly in older adults. The prevalence of cataracts increases significantly with age. Approximately 50 % of individuals aged 65 to 74, and about 70 % of those over 75, develop cataracts. Globally, an estimated 65 million people still suffer from visual impairments due to cataracts [3].

The global incidence rate of new cataract cases is approximately 10 million per year. In many countries, however, cataract surgery is routinely performed, significantly reducing the impact of the condition [4].

The preoperative measurement of the eye before cataract surgery has evolved significantly over decades. This progress has been crucial in improving postoperative outcomes, especially through more accurate IOL calculations. In the early days of cataract surgery, preoperative eye measurements were rudimentary. IOLs were either not implanted at all or were estimated based on general empirical data. With the introduction of A-scan ultrasound in the 1960 s, it was possible to measure the axial length (AL) of the eye. This method uses sound waves to measure the AL, though the process was manual, and contact with the cornea led to inaccuracies, causing systematic errors due to misalignment or pressure on the eye. Consequently, accuracy was limited. The AL measurement improved using an immersion A-scan ultrasound [5] but the corneal radii and the position of the lens inside the eye were often only estimated [6].

In the 1980 s, optical biometry was introduced, representing a significant improvement over ultrasound. This method used light rays instead of sound waves to measure the AL of the eye. This technique allowed for a contact-free, more accurate, and reproducible measurement of the AL, leading to a significant reduction in errors caused by corneal contact [7].

Alongside the development of measurement methods, increasingly complex IOL calculation formulas were developed. More advanced calculation models incorporated not only AL and corneal curvature but also additional variables such as anterior chamber depth (ACD), corneal curvature (K-values), and the calculated postoperative position of the IOL to determine the exact refractive power of the lens to be implanted [8].

The introduction of the IOL Master by Zeiss (Jena, Germany) in 1999 was a major step in preoperative eye measurements. This device utilized interferometry to measure AL, enabling even greater accuracy compared to previous optical methods. Furthermore, it also measured corneal curvature (keratometry) and ACD. The contact-free and rapid measurement, as well as the avoidance of direct eye contact, led to better results and reduced the risk of measurement errors [9].

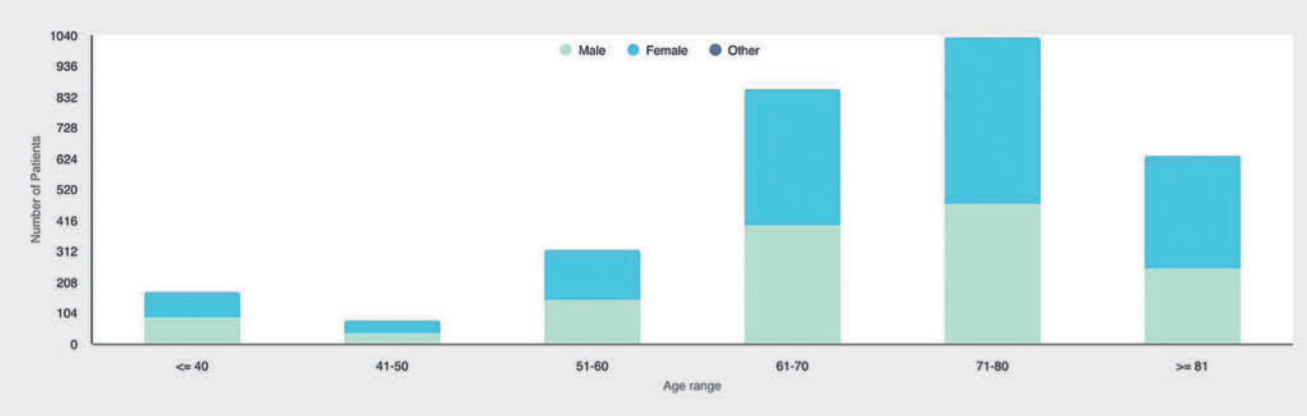
One of the latest generations of preoperative eye measurement is represented by swept-source optical coherence tomography (SS-OCT), first used in the IOL Master 700 by Zeiss (Jena, Germany) in 2015. By using OCT waves, not only the AL but also the ACD and the position of the posterior capsule could be accurately measured.

SS-OCT technology allows for precise measurements, even in cases of dense cataracts or irregular corneas. Additionally, lens thickness (LT) can now be measured, further improving IOL calculation accuracy [10]

In summary, preoperative eye measurements before cataract surgery have evolved significantly, from basic estimations to modern optical biometry. This evolution has led to significant improvements, particularly in reducing refractive errors and improving the accuracy of IOL calculations.

Biometric data collection without automated data export was challenging, as it required manual entry of data, increasing the likelihood of transcription errors. This was time-consuming and prone to mistakes, as human operators had to handle large volumes of data. These errors could compromise the accuracy and reliability of the biometric records, leading to problems in identification and security. Additionally, manual processes lacked the speed and efficiency of modern automated systems, making data handling slow and resource intensive.

The aim of this study was to systematically evaluate and analyze the preoperative measurement data of our cataract patients to identify typical parameters and relate them to the current literature. Therefore, we used the automated data export provided by the “data analyzer,” which is a software tool linked to the IOL Master 700 (Carl Zeiss Meditec, Jena, Germany). The focus was on AL,



▶ **Fig. 1** Age and gender distribution of 3 118 patients at the time of biometric measurement.

corneal refractive power, ACD, and the lens. Ultimately, the results should help improve the preoperative planning process and provide insights into a typical population in a standard care center in North Rhine-Westphalia.

Methods

We retrospectively evaluated the preoperative biometric data of cataract patients over the past 2 years in an ophthalmologic day clinic in Germany. The total population includes 6 163 eyes from 3 118 patients. We considered the gender and age distribution at the time of biometry.

Additionally, we analyzed the biometric data regarding AL, keratometry values (K and TK), ACD, LT, vitreous length (VL), and corneal astigmatism. The evaluated data includes patients who underwent both cataract surgery and clear lens extraction (CLE).

All biometry measurements were done using the IOL Master 700 (Carl Zeiss Meditec, Jena, Germany). The data was automatically transferred to a cloud-based data platform called the "data analyzer" by Carl-Zeiss Meditec.

Results

▶ **Fig. 1** shows the age and gender distribution of patients who underwent cataract surgery. It reflects the higher prevalence of cataracts with increasing age. A total of 2537 patients (81.4%) were over the age of 60. Within the overall population, 1 697 patients (54.4%) were female and 1 421 patients (45.6%) were male. This can be explained by the higher life expectancy of the female gender. Among the age group under 60, the gender distribution was more balanced (285/581 male – 49.1%; 296/581 female – 50.9%). Among the population over 60, cataracts were more prevalent in females (1 136/2 537 – 44.8% male, 1401/2 537 – 55.2% female).

The average data analysis of our patient cohort falls within previously published data (▶ **Table 1**). Astigmatism (Ast. K), the mean astigmatism in diopters (D) based on keratometry values, was − 0.95 D, with a standard deviation (SD) of 0.8 D.

▶ **Table 1** Table presenting the mean biometric measurements of 6 163 eyes.

	Mean	SD
Ast. K.	− 0.95	0.8
Ast. TK	− 0.97	0.79
TK	43.07	1.56
Vit. distance	15.62	2.83
LT	4.48	0.87
ACD	3.19	0.53
AL	23.7	1.32

Ast. K: astigmatic keratometry; Ast. TK: astigmatic total keratometry; TK: total keratometry; Vit. distance: vitreous distance; LT: lens thickness; ACD: anterior chamber depth; AL: axial length

Ast. TK: the mean astigmatism derived from total keratometry (TK) was − 0.97 D, with a similar SD of 0.79 D.

TK: the mean total keratometry (the average corneal curvature) was 43.07 D, with an SD of 1.56 D.

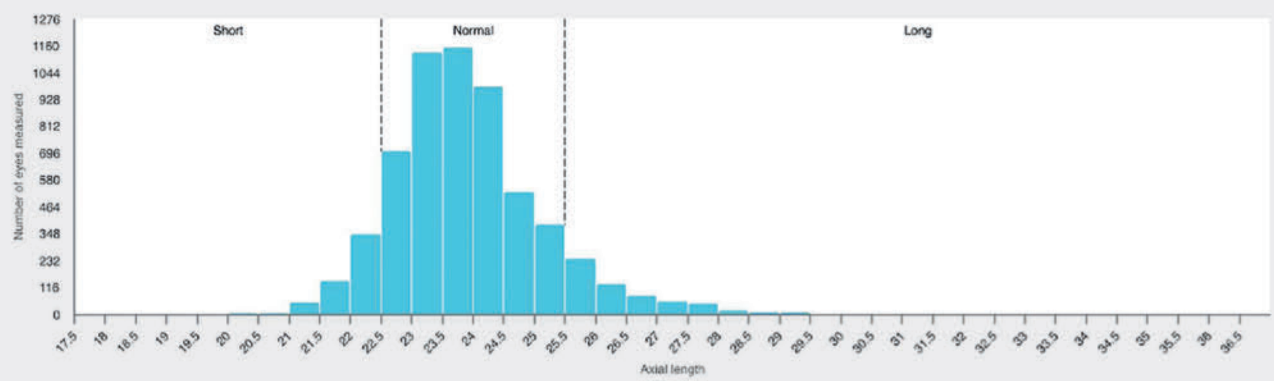
Vit. distance: The mean VL (the distance from the posterior lens capsule to the retina) was 15.62 mm, with an SD of 2.83 mm.

LT: the average LT was 4.48 mm, with an SD of 0.87 mm.

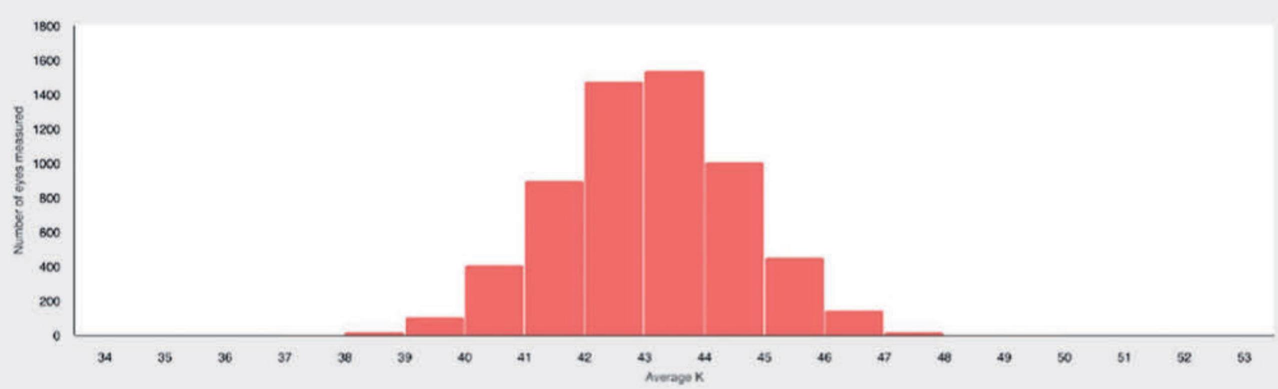
ACD: the mean ACD (distance from the corneal endothelium to the anterior surface of the lens) was 3.19 mm, with an SD of 0.53 mm.

AL: the mean AL (overall eye length) was 23.7 mm, with an SD of 1.32 mm.

The histogram presents the distribution of ALs measured in 6 134 eyes (▶ **Fig. 2**). The X-axis represents the AL in millimeters, while the Y-axis indicates the number of eyes measured within specific AL ranges. The data show a unimodal distribution, with most eyes falling into the "normal" AL category, typically between 22.5 and 25.5 mm. In total, 4 921 eyes out of 6 134 (80.2%) fell within this category. A smaller number of eyes are categorized as either "short" (< 22.5 mm) or "long" (> 25.5 mm), indicating ALs



▶ **Fig. 2** Histogram presenting the axial length distribution of 6 134 eyes. Eyes shorter than 22.5 mm were considered short while eyes longer than 25.5 mm were considered long.



▶ **Fig. 3** Average keratometry values of 6 136 cases.

shorter or longer than the standard range. In total, 590 of 6 134 eyes (9.6 %) can be considered short while 623 of 6 134 eyes (10.2 %) fall within the long category. The highest frequency of ALs was observed around 23.5 to 24.5 mm, with a gradual decline towards both extremes.

The histogram presents the distribution of corneal curvature (keratometry) measured in 6 136 eyes from patients who underwent cataract surgery (▶ **Fig. 3**). The X-axis represents the average corneal curvature (K) in diopters, while the Y-axis represents the number of eyes measured in each curvature range. The data exhibit a unimodal distribution, with the majority of eyes showing an average corneal curvature between 41 and 44 D, with a relatively symmetrical decline toward both steeper (> 44 D) and flatter (< 40 D) corneas.

▶ **Fig. 4** shows the distribution of astigmatism (measured in diopters) in a cohort of 6102 eyes. There were 3 955 of 6 102 eyes (64.8 %) that showed an astigmatism of < 1 D. Astigmatism between 1 and 2D was seen in 1 651 of the 6 102 cases (27.1 %), while an astigmatism in the 2 to 3D range was present in 346 of the 6 102 cases (5.7 %).

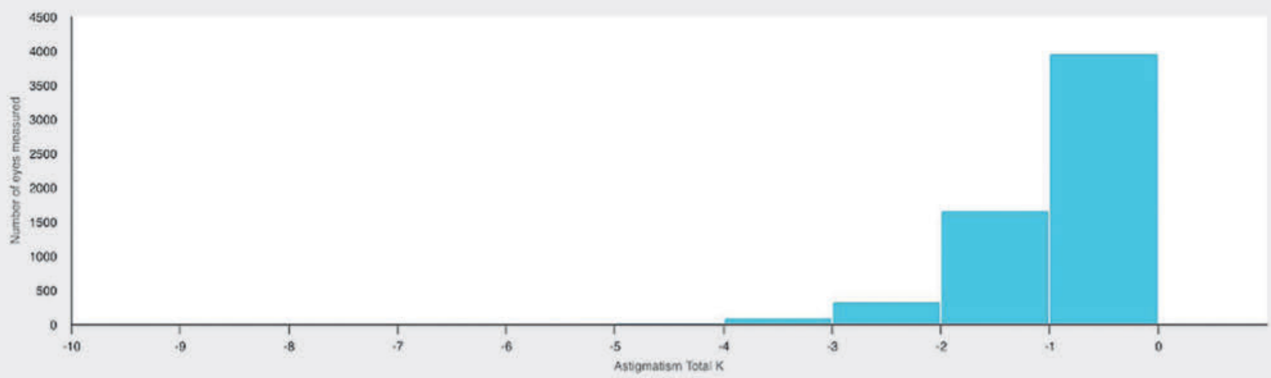
A high astigmatism (3D or more) was present in 124 of the 6 102 cases (2.0 %).

Conclusion

Looking at our cohort, both astigmatism measures (Ast. K and Ast. TK) had mean values close to − 1.0 D, indicating mild astigmatism on average.

The average corneal curvature of 43.07 D is within the expected range for the general population undergoing cataract surgery. This value is critical for IOL calculations and is consistent with other studies reporting similar ranges in keratometry [11].

The vitreous distance showed a wide variability (SD = 2.83 mm), reflecting the diversity in posterior segment anatomy, which is influenced by varying ALs in different eyes



▶ **Fig. 4** Distribution of astigmatism for total keratometry measurements in 6 136 cases.

The average LT (4.48 mm) falls within the expected range for cataract patients [12].

The mean ACD of 3.19 mm is an essential factor in IOL power calculation. The relatively low SD (0.53 mm) suggests consistent results across the patient population.

The mean AL of 23.7 mm is typical for an emmetropic eye, and the SD of 1.32 mm indicates some variation. The range observed here is comparable to data in the literature, where the mean AL in cataract patients is often around 23–24 mm, with variability due to refractive errors.

It is well established that the prevalence of cataracts increases significantly with age, especially after the age of 60. This is confirmed by the current data, which shows that most surgeries were performed on patients in the age group of 61–80 years [13]. This aligns with findings from the Beaver Dam Eye Study and other epidemiological research, which have demonstrated that the majority of cataract surgeries are conducted on individuals over 60 years old [14].

Younger patients (< 50 years) represent only a small fraction of the overall patient population, indicating that early cataract surgeries are often triggered by specific risk factors such as trauma, genetic predispositions, or secondary cataracts. Here, it must be noted that our data also include clear lens exchanges for refractive reasons.

The higher proportion of female patients is also well documented in the literature. Women have a greater risk of developing age-related cataracts, which is partly attributed to their longer life expectancy and potentially greater exposure to risk factors (e.g., UV radiation). A study by McCarty demonstrated that women are more frequently affected by cataracts and are more likely to undergo surgery compared to men, particularly in older age groups [15].

The distribution of ALs is consistent with findings in the current literature [16]. The majority of adult eyes undergoing cataract surgery typically present with ALs between 22.0 and 25.5 mm, which is considered normal. The peak at around 23.5 mm is in line with previous studies that have identified this range as the most common AL in cataract surgery populations.

Recent studies have suggested a growing prevalence of myopia worldwide, which could shift the typical AL distribution in cataract surgery populations over time.

The distribution of corneal curvature observed in this patient cohort is consistent with the expected range of keratometry values in cataract surgery patients. A typical corneal curvature ranges from 41 to 45 D, with the most frequent values being in the mid-42 D range, as reflected in this graph (▶ **Fig. 3**). This is consistent with data from other studies of cataract patients, where the average keratometry values typically lie between 42 and 44 D [17].

One of the most critical aspects of cataract surgery is achieving accurate postoperative refractive outcomes, and corneal curvature is a major factor in determining the IOL power. The benefit of a clear distribution of keratometry values, as shown in this figure (▶ **Fig. 3**), is the ability to recognize that the majority of eyes fall within a predictable range of curvature, allowing for more reliable use of standard IOL formulas. However, for eyes with more extreme curvatures, either flatter or steeper, adjustments to IOL calculations need to be made using advanced biometric formulas (e.g., Barrett) to ensure optimal refractive accuracy.

In Germany, it is estimated that around 6–7% of all IOLs implanted are toric IOLs, designed to correct astigmatism during cataract surgery. The adoption of toric IOLs has grown steadily, driven by increasing awareness of the benefits of astigmatism correction during cataract surgery and improvements in lens design that offer better rotational stability and visual outcomes.

The distribution of astigmatism reflects the general population, in which the majority of patients have only mild or no astigmatism. This is consistent with common clinical studies showing that the majority of cataract patients have only mild astigmatism and therefore often do not require a toric IOL.

Other epidemiologic studies have shown that approximately 25% of cataract patients have astigmatism ≥ 1.00 D preoperatively. This underestimates the rate of astigmatism with the results of our study in which a proportion of 34.8% of patients had an astigmatism ≥ 1 D [18]. Other studies showed a higher rate of astigmatism, which corresponds with our results [19].

In ▶ **Fig. 4**, the histogram shown provides a useful overview of astigmatism distribution in a large patient population and supports the finding that the rate of implanted toric IOLs remains very low relative to the prevalence of astigmatism [20]. A substantial proportion of patients benefit from astigmatic correction. Postoperative residual astigmatism is linked to reduced patient satisfaction regarding vision, a lower quality of life, and an increased reliance on glasses and should be addressed in every cataract patient with a visually relevant astigmatism [21].

The large number of patients is the strongest argument for the scientific significance of the study results. However, the retrospective study design must be considered a limitation. The data are purely descriptive preoperative measurements without any correlation to final refractive outcomes.

Longitudinal studies showing the context between preoperative measurements and long-term refractive results need to be further evaluated.

The possibility of an automated data transfer from biometry measurements to perform statistic evaluation presents great opportunities for further data analysis.

In the present study, we examined the preoperative measurement data of cataract patients from a city in North Rhine-Westphalia with a population of approximately 80 000. This urban population represents an interesting cohort, as it includes an aging population as well as rural and urban influences. Since care in such a medium-sized city requires a balance between specialized and general medical care, the preoperative data of this patient population is particularly valuable. They offer the opportunity to optimize local care structures and derive specific conclusions for similar regions.

CONCLUSION BOX

Already known:

- The measurements observed in this study align with previously recorded data, further validating established methodologies and findings.
- Previous research has demonstrated the potential for digital tools to support data collection and analysis in clinical settings.
- The potential of fully automated data extraction from clinic software to streamline the analysis of large datasets has not been fully explored until now.

Newly described:

- This study highlights how automated extraction from clinic software can significantly aid in the efficient handling and analysis of big data.
- The approach presented here simplifies the process of data aggregation, reducing manual effort while improving accuracy.
- Despite these advancements, the rate of toric IOL implantation remains far too low compared to the high prevalence of astigmatism, underscoring an ongoing gap in surgical decision-making and patient care.

Conflict of Interest

F. Kretz is a consultant and receives travel grants by Carl Zeiss Meditech. The other authors declare no conflict of interest.

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