Effect of 1.8-mm steep-axis clear corneal incision on the posterior corneal astigmatism in candidates for toric IOL implantation

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Abstract

PURPOSE In the present study, we aimed to analyze the effects of cataract surgery using a 1.8-mm steep-axis clear corneal incision (CCI) on the posterior corneal surfaces based on the keratometry from the rotating Scheimpflug imaging device (Pentacam HR) in candidates for toric intraocular lens (IOL) implantation. **METHODS** Preoperative and at least 1-month postoperative data measured by Pentacam HR were collected in patients for toric IOL implantation. Surgically induced astigmatism on the posterior cornea (P-SIA) was calculated based on the preoperative and postoperative keratometric data, and the related factors of P-SIA were analyzed. **RESULTS** A total of 60 eyes from 56 patients were enrolled. The preoperative anterior and posterior corneal astigmatism was 1.58 ± 0.61 D and 0.28 ± 0.22 D, respectively. The postoperative anterior and posterior corneal astigmatism was 1.26 ± 0.68 D and 0.41 ± 0.26 D, respectively. The astigmatism was significantly decreased on anterior surface ($P < 0.001$, paired t-test) and increased on posterior surface ($P < 0.001$, paired t-test). The mean of P-SIA calculated by Holladay–Cravy–Koch method was 0.34 ± 0.20 D, with 0.5 D or greater accounting for 26.7%. P-SIA showed no significant difference among with-the-rule (WTR) astigmatism, against-the-rule (ATR) astigmatism and oblique astigmatism ($F = 1.85$, $P = 0.167$). A statistically significant correlation was observed between the P-SIA and preoperative anterior corneal astigmatism ($r = 0.29$, $P = 0.024$), as well as preoperative posterior corneal astigmatism ($r = 0.27$, $P = 0.038$). **CONCLUSIONS** In candidates for toric IOL implantation with a 1.8-mm steep-axis CCI, the incision caused a significant reduction of the anterior corneal astigmatism but an increase of the corneal posterior astigmatism. P-SIA could not be ignored, and it played a significant role in SIA, especially in cases with higher preoperative anterior or posterior corneal astigmatism.

Background

The corneal astigmatism greater than 1.0 D, 1.5 D and 2.0 D approximately accounts for 30%, 22% and 8% of cataract patients before surgery, respectively ^[1–3]. Corneal astigmatism may lead to a series of visual discomfort, which will decrease patients' satisfaction after cataract surgery. No adding on the preexisting astigmatism thereby correcting corneal astigmatism is an important principle in cataract surgery. Nowadays, corneal relaxing incision (CRI), limbal relaxing incision (LRI) and toric intraocular lens (IOL) are used to correct corneal astigmatism, and remarkable results have been achieved ^[4–7].

The accurate measurements of corneal astigmatism are overwhelmingly important for the correction of corneal astigmatism. In recent years, with the development of the Scheimpflug anterior segment analysis system, the measurement of astigmatism on the posterior cornea has been achieved. Some characteristics about posterior cornea have been revealed ^[8–11], and it has been widely accepted that the posterior corneal astigmatism is non-ignorable, especially in patients for toric IOL implantation ^[11–13].

Although the importance of posterior corneal astigmatism has drawn great attention, surgically induced astigmatism (SIA) is calculated based on the keratometric data without taking the real effect of the incision on the posterior corneal surface in previous studies, which may lead to mis-estimation of SIA. For toric IOL implantation especially, accurate SIA estimation is crucial for better postoperative outcomes.

However, it still remains controversial whether the cataract incision has a significant influence on the posterior corneal astigmatism^[14–16].

In the present study, we aimed to analyze the surgically induced astigmatism on the posterior cornea (P-SIA) in the cataract surgery using a 1.8-mm steep-axis clear corneal incision (CCI) based on the Pentacam HR (Oculus Optikgerate GmbH, Wetzlar, Germany) in candidates for toric IOL implantation and explore the correlation between P-SIA and preoperative parameters (such as preoperative keratometry and astigmatism).

Patients And Methods

This retrospective study adhered to the tenets of the Declaration of Helsinki and had obtained human research ethics approval from the ethics committee of the Second Affiliated Hospital of Zhejiang University. Patients, who underwent cataract surgery with a 1.8-mm steep-axis CCI at the Eye Center, the Second Affiliated Hospital of Zhejiang University during March 2017 to December 2018, were enrolled in this study. Patients were included if they met the criteria as follows: (1) patients aged at least 45 years old who were scheduled for cataract surgery; (2) regular corneal astigmatism ≥ 1.0 D; (3) the imaging quality parameter (QS) of Pentacam HR was “OK”; and (4) follow-up time ≥ 1.0 month. The exclusion criteria were set as follows: (1) irregular corneal astigmatism; (2) corneal scar, corneal degeneration, pterygium invading the optic zone; (3) corneal endothelium count $< 1,000/\text{mm}^2$, corneal endothelial dystrophy, iritis, glaucoma and retinal disease; (4) history of eye surgery, such as corneal refractive surgery, corneal transplantation and retinal surgery; (5) the main incision was expanded or sutures were used during surgery; and (6) some postoperative complications, such as persistent corneal edema, Descemet’s membrane detachment and poor wound healing, and any others that might affect the measurement results of the Pentacam HR during the follow-up period.

Pentacam HR was set to auto mode, scanning was completed within 2 s, and 50 images were taken. The examination was completed in the dark room. The patients were asked to keep their eyeballs still, and the images were automatically captured by the device. Only the measurement with an “OK” reading displayed in the QS window was enrolled; otherwise, this measurement was retried. Eyes that still failed to reach the standard after repetition were excluded.

All surgeries were performed by the same skillful and experienced surgeon Dr. Xu. Standard toric IOL implantation process was performed. The following data were collected: the patient’s identification number, age, gender, OD/OS, date of surgery, date of follow-up; and the following parameters of the corneal central 3 mm measured by Pentacam HR, both preoperative and postoperative: anterior corneal K_1 and K_2 , astigmatism and its axis, posterior corneal K_1 and K_2 , astigmatism and its axis. The corneal astigmatism, both anterior and posterior, was classified as with-the-rule astigmatism (WTR, $60^\circ \sim 120^\circ$), against-the-rule astigmatism (ATR, $0 \sim 30^\circ$ or $150 \sim 180^\circ$) and oblique astigmatism ($30 \sim 60^\circ$ or $120 \sim 150^\circ$) according to the astigmatism axis.

P-SIA was calculated according to the preoperative and postoperative corneal curvature parameters (K_1 , K_2 and astigmatism axis) using the Holladay-Cravy-Koch method [17, 18].

Double-angle plots [19] were performed to show the distribution of astigmatism in the anterior and posterior corneal surfaces, as well as the P-SIA. The distance between each spot to the original point represented the size of astigmatism, and the angle of each spot was the doubled astigmatism axis.

Statistical analysis

All statistical analyses were performed using SPSS software version 20.0 (SPSS, Inc., Chicago, IL). Paired t-tests were used to compare the differences between preoperative and postoperative mean astigmatism. One-way analysis of variance (ANOVA) was performed for comparisons of multiple groups. The correlation between P-SIA and parameters was assessed by using Pearson's correlation analysis. A P value less than 0.05 was considered as statistically significant.

Results

Demographics

In the present study, 60 eyes of 56 patients with 1.8-mm steep-axis CCI were enrolled, including 29 left eyes and 31 right eyes. The age of patients ranged from 43 to 82 years with an average of 58.8 ± 10.7 years. The follow-up period ranged from 4 to 13 weeks with an average of 8.7 ± 3.4 weeks (Table 1).

Preoperative astigmatism conditions

The number of eyes with the anterior corneal astigmatism less than 1.5 D accounted for 48.3 %, that of ≥ 1.5 D and < 2.5 D accounted for 43.3%, and that of more than 2.5 D accounted for 8.3% (Table 2). The anterior corneal astigmatism ranged from 0.70 D to 3.70 D with an average of 1.58 ± 0.61 D. The mean preoperative anterior corneal K_1 was 43.36 ± 1.67 D, and K_2 was 44.96 ± 1.64 D (Table 4).

There were 49 eyes with a posterior corneal astigmatism less than 0.5 D, accounting for 81.7% (including seven eyes with an astigmatism of 0 D), and there were 11 eyes with an astigmatism of more than 0.5 D and less than 1.0 D, accounting for 18.3% (Table 2). The mean preoperative posterior corneal K_1 was -6.28 ± 0.25 D, and K_2 was -6.55 ± 0.27 D. The posterior corneal astigmatism ranged from 0.00 D to 0.80 D with an average of 0.28 ± 0.22 D.

The numbers of eyes with WTR astigmatism, ATR astigmatism and oblique astigmatism of the anterior corneal were 34, 24 and 2, respectively. In contrast, the numbers of eyes with WTR astigmatism, ATR

astigmatism and oblique astigmatism of the posterior corneal were 34, 10 and 9, respectively, of which WTR astigmatism accounted for 56.7%. Table 3 shows the types of preoperative astigmatism.

Postoperative astigmatism conditions

The postoperative anterior corneal astigmatism ranged from 0.30 D to 3.30 D, with an average of 1.26 ± 0.68 D. The postoperative K_1 was 43.32 ± 1.74 D, and K_2 was 44.61 ± 1.68 D (Table 4). Paired t-test showed a significant reduction in postoperative anterior corneal astigmatism compared with the preoperative one ($P < 0.001$). Fig. 1 shows the preoperative and postoperative astigmatism distribution of anterior cornea. A concentration trend could be found between Fig. 1A and Fig. 1B.

The postoperative posterior corneal astigmatism ranged from 0.00 D to 1.10 D with an average of 0.41 ± 0.26 D. The postoperative K_1 was -6.33 ± 0.28 D, and K_2 was -6.75 ± 0.37 D (Table 4). Paired t-test showed a significant increase in postoperative posterior corneal astigmatism compared with the preoperative one ($P < 0.001$). Fig. 2 shows the preoperative and postoperative astigmatism distribution of posterior cornea. A significant decentration pattern was noted between Fig. 2A and Fig. 2B.

P-SIA and its correlation analysis

P-SIA ranged from 0.00 D to 0.70 D with an average of 0.34 ± 0.20 D. There were 44 eyes with a P-SIA of less than 0.5D, accounting for 73.3%, while the P-SIA of 26.7% eyes was not less than 0.5 D (Table 4). Fig. 3 reveals that P-SIA had no concentration trend in a certain direction on the polar plot.

According to the astigmatic axis of the posterior cornea, the corneal astigmatism was divided into three groups: WTR group ($n = 34$), ATR group ($n = 10$) and the oblique astigmatism group ($n = 9$). The P-SIA of the WTR group, ATR group and oblique astigmatism group was 0.36 ± 0.21 D, 0.38 ± 0.17 D and 0.31 ± 0.18 D, respectively. There was no significant difference among the groups by using one-way ANOVA ($F = 0.335$, $P = 0.717$).

Pearson correlation analysis was performed between P-SIA and anterior/posterior corneal astigmatism, K_1 and K_2 , and the following results were obtained. (1) P-SIA was significantly and positively correlated with anterior corneal astigmatism ($r = 0.29$, $P = 0.024$) (Fig. 4). (2) There was no significant correlation between P-SIA and anterior corneal K_1 ($r = 0.07$, $P = 0.576$) (Fig. 5). (3) There was no significant correlation between P-SIA and anterior corneal K_2 ($r = 0.07$, $P = 0.608$) (Fig. 6). (4) P-SIA was significantly and positively correlated with the posterior corneal astigmatism ($r = 0.27$, $P = 0.038$) (Fig. 7). (5) There was no significant correlation between P-SIA and posterior corneal K_1 ($r = 0.04$, $P = 0.789$) (Fig. 8). (6) P-SIA was not significantly correlated with posterior corneal K_2 ($r = 0.18$, $P = 0.163$) (Fig. 9).

In this study, the incision was placed on the steepest meridian of the total corneal astigmatism. In order to investigate whether the P-SIA was smaller in patients with closer axis of anterior and posterior corneal

astigmatism, we performed the correlation analysis between the P-SIA and absolute axis differences of the corneal anterior and posterior astigmatism. There was no significant correlation between P-SIA and the absolute difference ($r = 0.03$, $P = 0.808$) (Fig. 10).

Discussion

In recent years, the influence of posterior corneal astigmatism has caused great concern in the clinical practice with the access to the measurement of posterior corneal astigmatism. Optical coherence tomography (OCT) and Scheimpflug anterior segment analysis systems can directly measure the posterior cornea surface, which is more accurate than corneal topography systems^[20,21]. The reliability and repeatability of Pentacam have been clinically proven for corneal astigmatism measurements^[22,23].

It has been reported that the posterior cornea is a minus lens, which is WTR astigmatism^[24]. With the growth of age, the meridian of posterior corneal astigmatism remains stable, while the anterior corneal astigmatism changes from WTR to ATR. If the fixed ratio is used based on the anterior corneal astigmatism, an overcorrection of 0.5~0.6 D is caused in patients with WTR astigmatism, while an undercorrection of 0.2~0.3 D is caused in patients with ATR astigmatism^[10, 13].

However, it still remains controversial whether we should treat the posterior corneal astigmatism as a fixed, minus value or dynamic parameter that changes after cataract surgery. There is a debate about whether a cataract surgical incision can cause significant P-SIA. According to the results of Nemeth et al.^[15], P-SIA is non-negligible with an average of 0.31 D, and about 25% of patients have a P-SIA of 0.5 D or more. In addition, it is more likely to cause larger P-SIA among patients with toric IOL implantation. Cheng et al.^[14] have also found that ignoring the P-SIA may cause calculation errors of SIA. However, some studies have concluded that the effect of the incision on the corneal posterior surface is negligible. For example, Klijn et al.^[16] have found that the average P-SIA is 0.1 D. Kim et al.^[25] have found that P-SIA is not uniform with an average of 0.20 ± 0.17 D.

Previous studies on P-SIA^[15] have predicted that P-SIA may have an important impact on the patients who are suitable for toric IOL implantation. The biomechanical effect of the incision on patients with larger corneal astigmatism may be different from those with smaller corneal astigmatism, and the accurate estimation of SIA is especially important for toric IOL implantation. Therefore, patients who are suitable for toric IOL implantation were set as the research objects in the current study. In this study, the preoperative anterior corneal astigmatism was 1.59 ± 0.69 D. Similar to previous studies^[10], the posterior corneal astigmatism was 0.28 ± 0.20 D, which was dominated by WTR (62.7%).

The method described by Holladay-Cravy-Koch, which is different from simple vector calculation and has been recognized as a more accurate calculation method, was used to calculate P-SIA in this study. We found that 26.7% of patients had a P-SIA greater than 0.5 D with an average of 0.34 ± 0.20 D, suggesting that the effect of the incision on the posterior corneal astigmatism was significant and might affect the postoperative total corneal astigmatism. Besides, P-SIA has a large individual difference, possibly due to

the difference in corneal rigidity, thickness, biomechanical condition and healing ability^[26,27]. The P-SIA obtained in this study was not significantly different from the P-SIA obtained by Nemeth et al.^[15] ($P = 0.64$), which is larger than the P-SIA obtained by Kim et al.^[25] ($P = 0.00$). This discrepancy might be attributed to the different locations of incision. This study, as well as Nemeth's study^[15], used the steepest meridian incision, while the temporal side incision is used in Kim's study^[25], suggesting that the location of the incision might have an effect on the results.

In order to explore the influencing factors of P-SIA, P-SIA was divided into different groups based on the astigmatism axis on the posterior corneal astigmatism. The results showed that there was no significant difference among the three groups, indicating that P-SIA was not associated with the astigmatism axis of the posterior cornea. The Pearson's correlation analysis showed that P-SIA had a significant positive correlation with anterior and posterior corneal astigmatism, suggesting that patients with large preoperative astigmatism on the corneal anterior or posterior surface might cause larger P-SIA.

This study indicated that cataract incisions caused a significantly reduced anterior corneal astigmatism but an increase of the corneal posterior astigmatism, and the P-SIA did not show reduction trend in patients with closer axis of anterior and posterior corneal astigmatism. This finding could probably be attributed that the posterior corneal astigmatism was smaller than anterior corneal astigmatism, and the biomechanical characteristics of posterior cornea were different from the anterior cornea, leading to the difficulty in releasing the posterior corneal astigmatism. We speculated that the shape of the incision, corneal thickness, rigidity, especially the distance from the end of the incision to the center of the cornea, might be related to the P-SIA^[28-29]. For example, we inferred that with the shorter distance between the end of the incision and the center of the cornea, the P-SIA might be greater.

There are some advantages and significances in this study. (1) In this retrospective study, the inclusion and exclusion criteria were severely restricted to control the information bias. (2) This study considered relatively comprehensive factors that might be related to P-SIA, and we concluded that patients with larger corneal anterior or posterior astigmatism might have larger P-SIA. (3) As the accurate prediction of P-SIA of toric IOL is demanding, this study focused on patients who were suitable for toric IOL implantation and limited the corneal astigmatism of patients.

However, there are still some limitations in this study as follows. (1) The follow-up period of this study was relatively short. Although previous study has indicated that there is no significant difference of SIA between 1 month and 6 months after surgery^[29], extending the follow-up time can avoid the influence of the difference in individual healing ability on the experimental results to a certain extent. (2) Although we only included the measurements with the QS reading "OK," there might still be differences between measurement and re-measurement of the Pentacam result. (3) Some important factors, such as the distance from the end of the incision to the center of the cornea, corneal thickness and so on, were not investigated in this study due to the incomplete data. These limitations suggest that it is necessary to design a prospective, long-term study with a control group to verify the conclusion of this study.

Declarations

Ethics approval and consent to participate

This research article was approved by the ethics committee of the second Affiliated Hospital, Zhejiang University School of Medicine, and the research followed the tenets of the Declaration of Helsinki. Written consent was obtained from all patients.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors conceived of and designed the study. All authors were involved in the data analysis. LX did the patients follow-up, collected data and drafted the article. CX and HSH reviewed the literature. XW did the surgery and drafted the article. All authors reviewed the manuscript and approved the final manuscript.

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Figures

Figure 1

Double-angle plot of the distribution of astigmatism on the anterior corneal surface. Fig. 1A is the preoperative anterior corneal astigmatism. Fig. 1B is the postoperative anterior corneal astigmatism.

Figure 2

Double-angle plot of the distribution of astigmatism on the posterior corneal surface. Fig. 2A is the preoperative posterior corneal astigmatism. Fig. 2B is the postoperative posterior corneal astigmatism.

Figure 3

Double-angle plot of the distribution of P-SIA.

Figure 4

P-SIA was significantly and positively correlated with preoperative anterior corneal astigmatism (Pearson's $r=0.29$, $P=0.024$). P-SIA= surgically induced astigmatism on the posterior cornea. D=diopeters.

Figure 5

P-SIA was not significantly correlated with preoperative anterior corneal K_1 (Pearson's $r=0.07$, $P=0.576$). P-SIA= surgically induced astigmatism on the posterior cornea. K_1 = keratometric value at the flattest corneal meridian. D=diopeters.

Figure 6

P-SIA was not significantly correlated with preoperative anterior corneal K_2 (Pearson's $r=0.07$, $P=0.608$). P-SIA= surgically induced astigmatism on the posterior cornea. K_2 = keratometric value at the steepest corneal meridian. D=diopeters.

Figure 7

P-SIA was significantly and positively correlated with the preoperative posterior corneal astigmatism (Pearson's $r=0.27$, $P=0.038$). P-SIA= surgically induced astigmatism on the posterior cornea. D=diopeters.

Figure 8

P-SIA was not significantly correlated with preoperative posterior corneal K_1 (Pearson's $r=0.04$, $P=0.789$). P-SIA= surgically induced astigmatism on the posterior cornea. K_1 = keratometric value at the flattest corneal meridian. D=diopeters.

Figure 9

P-SIA was not significantly correlated with preoperative posterior corneal K_2 (Pearson's $r = 0.18$, $P = 0.163$). P-SIA= surgically induced astigmatism on the posterior cornea. K_2 = keratometric value at the steepest corneal meridian. D=diopeters.

Figure 10

P-SIA was not significantly correlated with the absolute axis difference of the preoperative corneal anterior and posterior astigmatism. P-SIA= surgically induced astigmatism on the posterior cornea. D=diopeters.

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