• Clinical Research •

Relationship between early structural changes at cornea incision sites and surgical outcomes after phacoemulsification

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Abstract
● AIM: To assess the early structural changes at clear corneal cataract incision sites and surgical outcomes using anterior segment optical coherence tomography (AS-OCT).

● METHODS: We evaluated 80 eyes of 59 patients who underwent phacoemulsification with a clear corneal incision. All incisions were evaluated 1wk, 1, and 3mo postoperatively using AS-OCT and analyzed regarding angle, length of the incision, maximal corneal thickness at the incision, and if present, corneal endothelial gap length and incision gap area. The patients were divided into two groups according to whether or not an endothelial gap was present at 1wk postoperatively (endothelial gap, group 1; no endothelial gap, group 2). We analyzed the difference in patient and surgical factors between the two groups, and compared the surgical outcome and the refractive outcome.

● RESULTS: An endothelial gap was observed in 56 (70.0%) of 80 eyes at 1wk postoperatively but not at 3mo postoperatively. The mean patient age was significantly higher in group 1 than in group 2. The longer the length of the corneal incision and the steeper the incision angle, the greater the length and area of the endothelial gap. In group 1, the mean change in mean keratometry of the anterior cornea was significantly greater than in group 2, and the spherical equivalent (SE) and mean numerical error indicated significant myopic changes at 1wk postoperatively.

● CONCLUSION: The risk of an endothelial gap increases with patient age and a long corneal incision and steep incision angle. The presence of an endothelial gap after surgery may affect the early postoperative corneal curvature and SE.

● **KEYWORDS:** corneal incision structure; phacoemulsification; corneal curvature; corneal endothelial gap; anterior segment optical coherence tomography

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INTRODUCTION

Modern techniques in cataract surgery aim to achieve better uncorrected visual acuity (UCVA) and rapid postsurgical recovery. The clear corneal incision (CCI) technique, first introduced by Fine[1] in 1992, is commonly used in phacoemulsification cataract surgery. Its advantages include shorter procedural times, more rapid postoperative wound recovery, minimizing induction of astigmatism, and less bleeding[2]. However, there have been several reports suggesting that CCIs are associated with an increased risk of postoperative infection because of postoperative wound leak and dehiscence[3-9]. Recently, anterior segment optical coherence tomography (AS-OCT), which allows visualization of the ultrastructure of the cornea in real time, has enabled qualitative analysis of structural changes in the cornea. It is important to identify the morphologic changes associated with CCIs and preoperative factors conducive to rapid visual recovery and to decrease the risk of intraocular infection caused by wound leak. Several studies have used AS-OCT to assess the short-term and long-term architectural changes at CCI sites after cataract surgery[10-12]. However, to our knowledge, there have been no studies comparing the structural changes after CCI with the surgical outcomes after cataract surgery.

The purpose of this study was to investigate the early structural changes associated with CCI using AS-OCT, to identify surgical factors that might contribute to architectural changes at the wound site, and to assess whether these postoperative changes affect the early visual outcome and refractive change after cataract surgery.

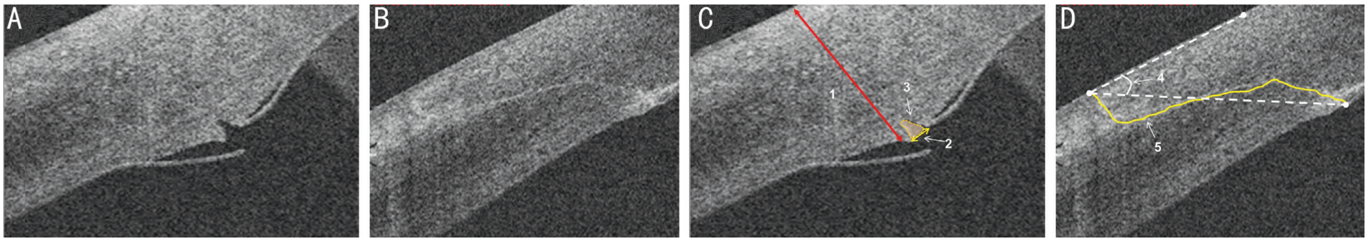

Figure 1 Representative AS-OCT image of corneal incision site A, B: AS-OCT images show a clear corneal incision site postoperatively. C, D: The incision site parameters are defined as follows: 1) maximal corneal thickness at the incision site (red line); 2, 3) endothelial gap length and area; 4) incision angle; and 5) incision length (yellow line). The incision angle was measured as the angle between the tangent of the corneal surface at the incision and the line connecting the internal and external wound openings.

SUBJECTS AND METHODS

Ethical Approval All procedures were compliant and consistent with the tenets of the Declaration of Helsinki. Informed consent was obtained from all individual participants included in this retrospective study.

The study included 80 eyes of 59 patients who underwent cataract surgery by phacoemulsification through a 2.75 mm temporal sutureless CCI. The inclusion criterion was grade III or IV cataract and best corrected visual acuity (BCVA) worse than 20/32. Preoperative exclusion criteria included previous ocular surgery, dry eye syndrome, and the presence of any ocular pathology.

Surgical Technique All eyes underwent phacoemulsification and implantation of an intraocular lens through a sutureless CCI. All procedures were performed under topical anesthesia by the same surgeon (Jin KH) and comprised creation of a self-sealing 2.75 mm temporal CCI followed by creation of a 1.0 mm side port incision 90 degrees away from the main temporal incision. The Constellation Vision System with Ozil IP software (Alcon Laboratories, Fort Worth, TX, USA) was used for the cataract surgery.

Patient Examinations Examinations were performed preoperatively and at 1wk and 1mo postoperatively. Before and after surgery, all patients underwent the following examinations: uncorrected and corrected visual acuity testing, automated refraction using the Nidek ARK-1s (Nidek Technologies, Gamagori, Japan), measurement of intraocular pressure, slit-lamp examination, and fundus evaluation. Corneal curvature and astigmatism were analyzed using a Scheimpflug rotating camera (Pentacam, Oculus, Wetzlar, Germany). AS-OCT (Cirrus OCT, Carl Zeiss Meditec, Jena, Germany) was used to visualize the structure of the wound. The mean numerical error (MNE) was defined as the difference between actual postoperative spherical equivalent (SE) and predicted postoperative SE. MNE is widely used to compare how much refraction measured after refractive surgery, including cataract surgery, is matched to the target refraction. A negative predictive error indicates more myopic results *i.e.* tendency towards over correction, and vice-versa.

AS-OCT Assessment The CCIs were visualized on radial AS-OCT scans at 1wk, 1 and 3mo postoperatively to evaluate the length and area of the endothelial gap, incision angle and the maximal corneal thickness at the incision site. The incision angle was measured between the corneal surface tangent at the external wound opening and the line connecting the internal and external wound openings. The length and area of the endothelial gap were calculated using ImageJ software (National Institutes of Health, Bethesda, MD, USA; Figure 1). The patients were divided into two groups according to whether or not an endothelial gap was present at 1wk postoperatively. Patients with an endothelial gap were classified as group 1 and those without an endothelial gap were classified as group 2.

Statistical Analysis The statistical analysis was performed using the independent samples *t*-test in SPSS version 18.0 software (SPSS Inc., Chicago, USA). The Pearson correlation was used to analyze the relationship between preoperative factors and the length and area of the endothelial gap. A *P*-value less than 0.05 was considered to be statistically significant.

RESULTS

The study included 80 eyes in 59 patients of mean age 68.8±12.9 (range 52-82)y. No intraoperative complications were encountered and there were no reports of hypotony, shallow chamber, or endophthalmitis during the 3mo of follow-up.

Structural Analysis of Clear Corneal Incision Site Using AS-OCT An endothelial gap was observed in 56 (70.0%) of 80 eyes at 1wk, 3 eyes (3.8%) at 1mo, and 0 eyes at 3mo postoperatively (Table 1). The average length and area of the endothelial gap at 1wk were 148.54±73.55 μm and 9684.86±11 932.89 μm^2, respectively. These values decreased to 6.58±33.52 μm and 238.12±1228.37 μm^2, respectively, at 1mo after surgery. No endothelial gap was observed at 3mo after surgery. The mean patient age was significantly higher in group 1 than in group 2, but there was no significant difference in sex ratio, endothelial cell count, axial length, mean incision length or angle, or preoperative cataract grade between the two groups (Table 2).

Table 1 Frequency of endothelial gaps and their length and area after surgery

Variables	Postop. 1wk	Postop. 1mo	Postop. 3mo
Incidence of endothelial gap, eyes (%)	56 (70.0)	3 (3.8)	0
Endothelial gap length (μm)	148.54±73.55	6.58±33.52	0
Endothelial gap area (μm^2)	9684.86±11932.89	238.12±1228.37	0

Table 2 Demographic and preoperative data for the two groups

Variables	All patients	Group 1	Group 2	*P*
No. of eyes (%)	80 (100)	56 (70.0)	24 (30.0)	
Sex (M:F)	34:46	23:33	11:13	0.794
Age (y)	68.8±12.9	71.8±11.7	61.9±13.4	0.002
IOP (mm Hg)	13.71±2.41	13.72±2.48	13.68±2.28	0.951
Endothelial cell count (cells/mm^2)	2678.82±429.87	2719.30±276.09	2586.80±658.9	0.231
Axial length (mm)	23.75±1.45	23.85±1.56	23.52±1.16	0.388
Mean incision length (μm)	1678.61±320.29	1770.78±324.27	1587.52±298.28	0.400
Mean incision angle (°)	34.00±6.65	33.74±6.84	34.62±6.32	0.852
Cataract grade	3.34	3.36	3.28	0.615

Values are presented as mean±SD unless otherwise indicated; *P* value by independent *t*-test.

The maximum corneal thickness was significantly greater in group 1 (1024.19±105.63 μm) than in group 2 (924.50±105.32 μm) at 1wk postoperatively (P=0.001; Figure 2). However, there was no difference in maximum corneal thickness between the two groups at 1 and 3mo postoperatively.

Correlation of Length and Area of the Endothelial Gap with Incision Length and Angle The length and area of the endothelial gap correlated significantly with corneal incision length and angle at 1wk postoperatively (Figure 3). The longer the corneal incision length and the steeper the incision angle, the greater the length and area of the endothelial gap. This finding was statistically significant.

Changes in Corneal Curvature At 1wk postoperatively, there was a statistically significant increase in the mean keratometric value (K_{mean}) of the anterior cornea with respect to preoperative corneal astigmatism in group 1 (Figure 4A). The K_{mean} of the posterior cornea increased at 1wk postoperatively, however, there was no statistically significant change (Figure 4C). In group 2, the K_{mean} of the anterior cornea decreased and that of the posterior cornea increased at 1wk postoperatively; however, there was no statistically significant change in the anterior or posterior K_{mean} at any of the follow-up assessments (Figure 4A, 4C).

There was a significant difference in the mean change in anterior corneal K_{mean} between groups 1 and 2 at 1wk postoperatively (Figure 4B) but not at 1 and 3mo postoperatively. The mean K_{mean} changes in the posterior cornea were not significantly different between the two groups at any time during follow-up (Figure 4D).

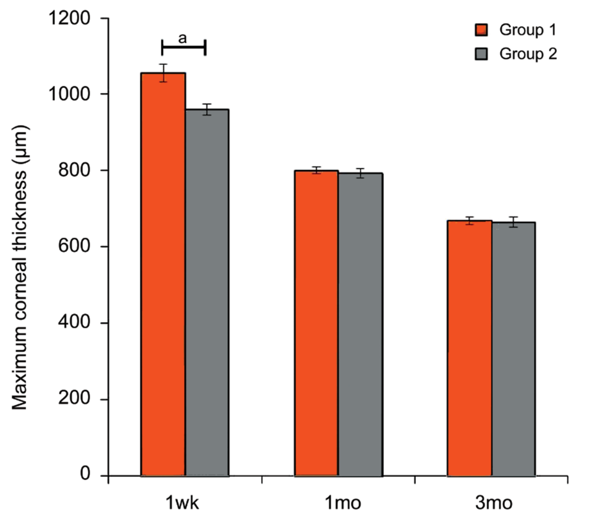

Figure 2 Change in maximum corneal thickness after phacoemulsification The bar graph shows a significant increase in maximum corneal thickness in group 1 at 1wk after surgery when compared with group 2. [a]P<0.05, independent *t*-test.

Changes in Corneal Astigmatism In group 1, there was a statistically significant increase in anterior corneal astigmatism with respect to preoperative corneal astigmatism at 1wk and 1mo but not at 3mo postoperatively (Figure 5A); there was also a statistically significant increase in posterior corneal astigmatism at 1wk but not at 1 or 3mo postoperatively (Figure 5C). In group 2, there was no significant change in anterior or posterior corneal astigmatism (Figure 5A, 5C).

The mean changes in anterior corneal astigmatism increased in groups 1 and 2 at 1wk and 1mo postoperatively, with no statistically significant difference between the groups (Figure 5B).

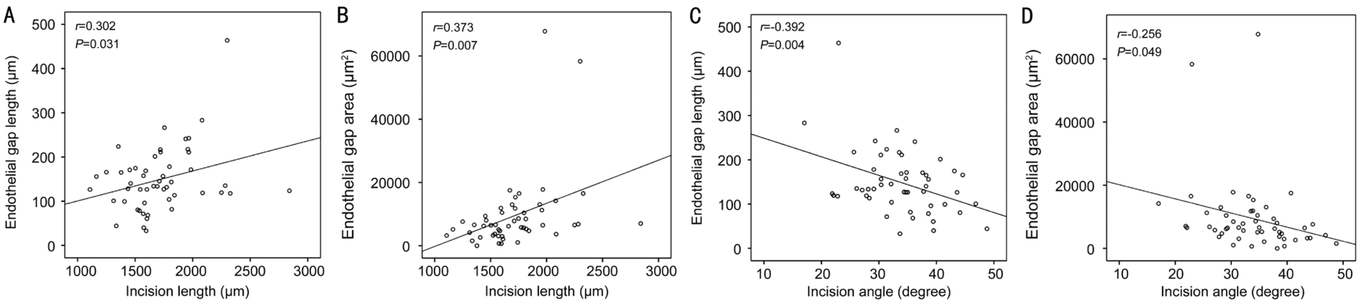

Figure 3 A correlation plot between the incision length and endothelial gap length (A), incision length and endothelial gap area (B), incision angle and endothelial gap length (C), and incision angle and endothelial gap area (D) *r*: Pearson correlation coefficient; *P*-value by Pearson correlation test.

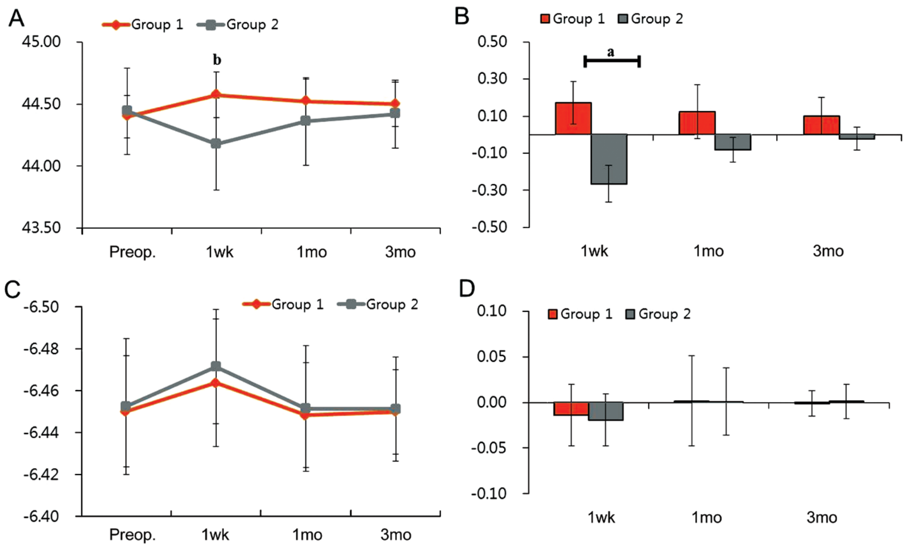

Figure 4 Mean corneal curvature (K_{mean}) and mean changes in K_{mean} in groups 1 and 2 A: Postoperatively in group 1, the K_{mean} of the anterior cornea has increased significantly; B: The mean change in K_{mean} of the anterior cornea is greater in group 2 than in group 1 at 1wk postoperatively; C, D: There is no significant difference in K_{mean} or in mean change in K_{mean} of the posterior cornea between groups 1 and 2. $^{a}P<0.05$, independent *t*-test; $^{b}P<0.05$, paired *t*-test.

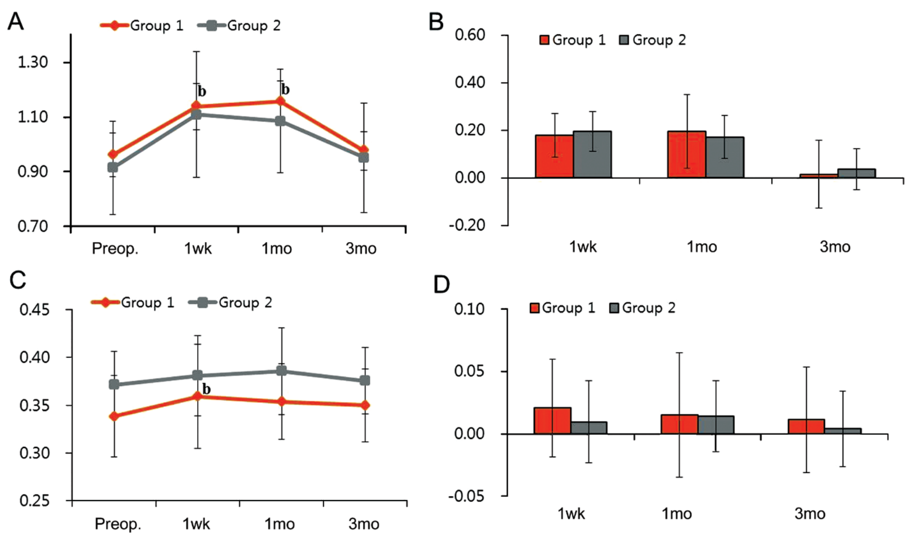

Figure 5 Mean corneal astigmatism and mean changes in corneal astigmatism in groups 1 and 2 A: In group 1, anterior corneal astigmatism increases significantly until 1mo postoperatively; B: The difference in mean change in anterior corneal astigmatism between groups 1 and 2 is not significant after surgery; C: Posterior corneal astigmatism is significantly increased at 1wk postoperatively in group 1; D: There is no significant difference in mean change in posterior corneal astigmatism between groups 1 and 2 postoperatively. $^{b}P<0.05$, paired *t*-test.

The mean change in posterior corneal astigmatism was greater in group 1 at 1wk postoperatively, but there was no statistically significant difference in the mean changes in astigmatism between the two groups (Figure 5D). At 3mo postoperatively, anterior and posterior corneal astigmatism decreased to preoperative values in both groups.

Postoperative Visual Outcomes and Refractive Error Preoperatively, there was no significant difference in mean UCVA between groups 1 and 2 (Table 3). Mean UCVA and BCVA improved significantly after cataract surgery in both groups, with no significant difference between the values for these two parameters at any follow-up assessment. However, there was a significant difference in SE between the two groups at 1wk after cataract surgery. There was a significantly greater myopic change in group 1 than in group 2 at 1wk postoperatively but not at 1 or 3mo postoperatively.

The MNE for the entire study group showed a mean myopic shift of -0.21±0.83 D at 1wk, -0.10±0.70 D at 1mo, and -0.08±0.75 D at 3mo postoperatively; all these values were not significantly different from the target diopter (P=0.131, P=0.242, and P=0.392, respectively). In group 1, MNE showed a myopic shift of -0.32±0.80 D at 1wk postoperatively that was significantly different from the target diopter (P=0.006). The MNE was -0.13±0.67 D at 1mo and 0.15±0.73 D at 3mo postoperatively; there was no significant difference between MNE and the target diopter at these assessments (P=0.181 and P=0.147, respectively). In group 2, the MNE was 0.05±0.83 at 1wk, -0.03±0.79 D at 1mo, and 0.11±0.78 D at 3mo postoperatively; these values were not significantly different from the preoperative target diopter (P=0.766, P=0.888, and P=0.543, respectively).

Table 3 Preoperative and postoperative uncorrected and corrected visual acuity and SE in the two groups

Variables	All patients	Endothelial gap at 1wk		P
		Group 1	Group 2	
Preop.				
UCVA (logMAR)	0.59±0.48	0.61±0.48	0.54±0.49	0.599
CVA (logMAR)	0.45±0.42	0.48±0.43	0.38±0.38	0.338
SE (D)	-1.49±3.83	-1.53±4.31	-1.41±2.40	0.913
Postop. 1wk				
UCVA (logMAR)	0.24±0.22	0.24±0.23	0.23±0.18	0.755
BCVA (logMAR)	0.10±0.13	0.10±0.13	0.12±0.14	0.560
SE (D)	-0.96±1.10	-1.15±1.14	-0.50±0.89	0.026
Postop. 1mo				
UCVA (logMAR)	0.18±0.14	0.19±0.14	0.16±0.13	0.427
BCVA (logMAR)	0.06±0.08	0.05±0.07	0.07±0.10	0.484
SE (D)	-0.85±0.99	-0.95±1.04	-0.58±0.80	0.158
Postop. 3mo				
UCVA (logMAR)	0.16±0.15	0.16±0.17	0.15±0.12	0.693
BCVA (logMAR)	0.04±0.08	0.04±0.08	0.04±0.08	0.991
SE (D)	-0.83±1.01	-0.82±1.06	-0.83±0.96	0.980

UCVA: Uncorrected visual acuity; BCVA: Best corrected visual acuity; SE: Spherical equivalent; Values are presented as mean±SD unless otherwise indicated. P value by independent t-test.

DISCUSSION

The self-sealing CCI technique is probably the most popular and widely accepted approach to performing cataract surgery. However, there is still a concern about the increased risk of endophthalmitis with this procedure when compared with scleral tunnel incision. Self-sealing of the wound provides a barrier that could lowering the risk of endophthalmitis. The recent introduction of AS-OCT has made it possible to record high-resolution images rapidly and easily in a non-contact and non-invasive manner. Understanding the morphologic changes at the incision site would help to prevent postoperative complications and improve wound management. AS-OCT has been used to assess the shape of the cataract incision, and there have been reports of problems with the incision, including detachment of Descemet's membrane, increased corneal thickness, and a posterior corneal wound gap[12-17]. In this study, we evaluated the structural changes at the CCI sites and the surgical outcomes after cataract surgery using AS-OCT.

All images in this study revealed swelling of the corneal stroma at the incision site 1wk after surgery. Fine *et al*[11] assumed that stromal hydration during surgery would cause wound swelling. However, Xia *et al*[18] maintained that the corneal swelling was caused mainly by tissue damage at the wound site during surgery, including the mechanical trauma induced by insertion of surgical instruments and direct damage by phacoemulsification power or transformed heat because wound swelling occurred even without stromal hydration. We believe that the corneal swelling is caused by both stromal hydration and mechanical damage.

The endothelial gap is the internal wound dehiscence of the corneal incision, which may allow for the inoculation of organisms into the aqueous humor, resulting in endophthalmitis and potential visual loss. Theoretically, surgically induced posterior astigmatism may occur due to internal wound dehiscence, which may affect visual outcomes after toric IOL implantation. In this study, an endothelial gap was seen in 56 eyes (70.0%) at 1wk postoperatively. This finding is similar to that of a previous study[12]. Further, we found that endothelial gaps were more common in older patients. Although the preoperative endothelial cell counts were not significantly different between groups 1 and 2, the observed difference in age between patients who did and did not have an endothelial gap may reflect an association between decreased endothelial cell function and aging. A longer incision length and a steeper incision angle correlated significantly with the length and area of the endothelial gap (Figure 3). The cause of the endothelial gap after cataract surgery is not clear yet. Fine *et al*[11]. found that wounds which did not receive stromal hydration were likely to develop internal gaping. Some authors suggested possible explanations for endothelial wound gaping, such as phacoemulsification method, instrument sizing or excessive ultrasound power, corneal stromal edema, and endothelial damage[19-21]. Other authors added intraocular pressure fluctuation as a factor[22-23]. In our study, a longer incision length and a steeper incision angle correlated significantly with the length and area of the endothelial gap (Figure 3). Therefore, it is important to keep in mind, the possibility of an endothelial gap in elderly patients when the incision angle is small or the incision length is long. The maximum corneal thickness was significantly greater in group 1 than in group 2 at 1wk postoperatively. This finding may be attributable to the stromal edema caused by detachment of Descemet's membrane and the endothelial gap. However, there was no difference maximum corneal thickness between the two groups thereafter, which could be related to the decreased likelihood of an endothelial gap at 1 and 3mo after surgery.

We found that the K_{mean} of the anterior cornea was significantly increased in group 1 but not in group 2 at 1wk postoperatively; there was also a significant difference in the mean changes in K_{mean} in the anterior cornea between the two groups at this time. A few studies have focused on the structure of the wound at the posterior cornea and the change in corneal curvature after cataract surgery[20,24]. van Rij and Waring[20] reported that the curvature flattened in the vertical and horizontal meridians in corneas that had undergone experimental posterior wedge resection and suture. In the case of wound retraction in the posterior cornea caused by an endothelial gap, which cause the opposite effect of wedge resection and suture in previous study. This could explain our present finding of a steepened K_{mean} in eyes with an endothelial gap. In contrast, the K_{mean} decreased in patients without an endothelial gap, although not significantly. We speculate that the corneal swelling occurs mainly in the posterior stroma because the anterior stroma is composed of tight interwoven anterior lamellae[24]. The decrease in anterior K_{mean} in group 2 in the early postoperative period in our study may be explained by the increased posterior stromal edema at the corneal incision site and the absence of wound retraction, which may result in flattening of the corneal curvature in response to strong corneal tension in the horizontal direction. Recently, Hayashi *et al*[25] reported on corneal astigmatism and curvature changes post-cataract surgery; they reported that focal flattening in the total and anterior cornea, and focal steepening in the posterior cornea occurred around the clear corneal incision site in the early postoperative period. They also did not disclose a clear mechanism of decreased anterior K value, but they suggested the possibility of wound hydration. This result is consistent with the results of group 2 in this study. Unlike previous studies, anterior corneal steepening and SE myopic changes in group 1 of this study can be explained by the occurrence of the endothelial gap due to internal wound dehiscence. However, Merriam *et al*[26-27] reported no change in corneal curvature after 3-mm temporal CCI. Therefore, further studies are needed to define the exact mechanisms involved in changes of corneal curvature.

In this study, anterior and posterior corneal astigmatism increased significantly in group 1 in comparison with preoperative values and then stabilized during follow-up. Although the difference between groups 1 and 2 was not statistically significant, the mean change in corneal astigmatism was more prominent on the posterior surface 1wk postoperatively, possibly because both corneal edema and the endothelial gap occurred at the posterior cornea (Figure 5). At 3mo postoperatively, the astigmatism was not significantly different from that preoperatively in either group. Giansanti *et al*[28] showed that a 2.75 mm CCI caused only a small change in corneal astigmatism, so the 2.75 mm CCI used in our study may not have had a significant effect on the degree of astigmatism. However, when an endothelial gap occurs, postoperative astigmatism may increase in the early postoperative period, and this should be considered during surgery.

The visual outcome was favorable in both our study groups in terms of the final UCVA and BCVA measurements. It is possible that the corneal wound retraction was not sufficient to cause a statistically significant difference in UCVA or BCVA. However, the SE at 1wk showed more myopic change in group 1 than in group 2 and the difference was statistically significant. The results of the MNE analysis in relation to the target diopter showed a significant myopic shift in group 1 at 1wk postoperatively, which was presumably related to the increase in K_{mean}. There was no statistically significant difference in SE between the 2 groups at 1 and 3mo postoperatively. Therefore, an endothelial gap in the early postoperative period may be associated with an increase in anterior corneal curvature, but this relationship may not persist in the long term.

The main limitation of the study was its relatively small sample size, such that our findings cannot be generalized to all patients who underwent phacoemulsification. In addition, even though all the operations were performed by the same surgeon, cases may still exhibit differences in the corneal thickness, intraocular pressure, shape of wound, process of wound healing, and tissue response against trauma. Despite these limitations, the results that early structural changes after cataract surgery can affect corneal curvature and refraction are meaningful. Another limitation is that subgroup analysis of with-the-rule and against-the-rule astigmatism was not performed. In future large-scale studies, the study samples should be divided into subgroups according to with-the-rule and against-the-rule astigmatism.

In conclusion, in this study, an endothelial gap was more common in older patients and the length and area of the endothelial gap were correlated with increasing incision length and a steep incision angle. When an endothelial gap occurs early in the postoperative period, the anterior corneal curvature may increase and cause a change in SE. Therefore, if the incision length is long or the angle becomes steep in older patients, the appearance of an endothelial gap may lead to changes in initial postoperative refraction and this effect should be considered during surgery.

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Conflicts of Interest: Jin KH, None; **Kim TG,** None.

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