



OPEN Astigmatism-type-specific impact of peripheral corneal thickness on anterior keratometric profile changes after temporal clear corneal incision cataract surgery

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Postoperative astigmatism remains a concern after temporal clear corneal incision (TCCI) cataract surgery, especially in eyes with preexisting corneal astigmatism. This study investigated whether peripheral-to-central corneal thickness ratios can predict anterior corneal astigmatic shifts following surgery and whether these associations vary by preoperative anterior corneal astigmatism type. We retrospectively analyzed 209 eyes from 137 patients who underwent uneventful phacoemulsification with 2.75 mm TCCI and intraocular lens implantation. Preoperative central corneal thickness (CCT), mid-peripheral corneal thicknesses (MPCT, 5–7 mm), and temporal peripheral corneal thickness (TPCT, 7–10 mm) were measured using anterior segment optical coherence tomography (Visante; Carl Zeiss Meditec, Germany). Patients were categorized into with-the-rule (WTR), against-the-rule (ATR), and oblique astigmatism groups based on their preoperative anterior corneal astigmatism. In the WTR group, higher TPCT/CCT and MPCT/CCT ratios showed significant correlations with an increase in postoperative anterior corneal astigmatism ($r = 0.293$, $P = 0.011$; $r = 0.301$, $P = 0.009$). In the oblique group, MPCT/CCT was correlated with changes in flat, steep, and average anterior keratometry. No significant correlations were observed in the ATR group. Receiver operating characteristic analysis identified TPCT/CCT ≥ 1.118 and MPCT/CCT ≥ 1.046 as thresholds for predicting a $\geq +0.25$ diopter increase in postoperative anterior corneal astigmatism in WTR eyes, demonstrating sensitivities of 95.0% and 87.5% and specificities of 34.3% and 45.7%, respectively. These findings suggest that peripheral-to-central corneal thickness ratios may serve as useful predictors of surgically induced anterior corneal astigmatism in patients with WTR astigmatism and can inform preoperative assessment and surgical planning.

Keywords Anterior segment OCT, Astigmatism, Cataract, Corneal thickness, Temporal clear cornea

Cataract surgery is one of the most frequently performed ophthalmic procedures, and recent advances in surgical techniques and intraocular lens (IOL) technologies have significantly enhanced postoperative refractive outcomes and patient satisfaction. Among various surgical approaches, clear corneal incision (CCI) has gained widespread acceptance due to rapid visual recovery and minimal limbal disruption^{1,2}. In particular, temporal clear corneal incision (TCCI) is preferred as it tends to minimize surgically induced astigmatism (SIA)³. Nevertheless, postoperative astigmatism remains a significant concern, especially in eyes with preexisting corneal astigmatism⁴. Previous studies have identified multiple factors influencing SIA after cataract surgery, including incision location, incision size, and individual healing responses^{5,6}; however, the predictive value of peripheral corneal thickness on postoperative refractive outcomes remains inadequately understood.

The cornea maintains structural integrity primarily through stromal collagen fibrils arranged in lamellae, crucial for preserving corneal curvature and resisting biomechanical stressors such as intraocular pressure fluctuations and mechanical forces exerted by eyelids and extraocular muscles⁷. Traditionally, central corneal parameters have received more attention in refractive assessments⁸; however, recent evidence indicates that

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peripheral corneal thickness may significantly influence corneal biomechanical responses and consequently surgical outcomes^{9,10}. Indeed, the peripheral cornea exhibits structural distinctions, characterized by larger fibril diameters and thicker collagen lamellae compared to the central cornea¹¹, potentially providing greater resistance against surgical deformation and postoperative refractive changes.

Several studies have suggested that variations in preoperative peripheral corneal thickness influence the corneal response to surgical incisions^{9,12}. Specifically, eyes with thicker peripheral corneas demonstrate less deformation and more stable postoperative refractive outcomes, while thinner peripheral corneas may experience greater astigmatic shifts after clear corneal incision cataract surgery with two-plane incision at 135°⁹. In addition, a defective clear corneal incision led to increased corneal thickness at the incision site and greater total higher-order aberrations at 6 months after cataract surgery¹³. Despite these observations, comprehensive analyses examining how preoperative peripheral corneal thickness affects postoperative keratometric profiles after TCCI remain limited.

Importantly, corneal astigmatism at baseline can be classified into three distinct patterns: with-the-rule (WTR), against-the-rule (ATR), and oblique astigmatism. Each astigmatism type can be significantly affected by factors such as lid tension and patient age, potentially influencing surgical outcomes¹⁴. Therefore, analyses that do not account for astigmatism patterns and incision orientation may yield ambiguous or limited conclusions regarding the effects of peripheral corneal thickness on postoperative refractive changes following CCI.

Unlike previous studies that explored general relationships between corneal thickness and SIA without stratifying patients by preoperative astigmatism type, our study analyzes WTR, ATR, and oblique astigmatism groups separately to evaluate astigmatism-type-specific biomechanical responses. Additionally, this study exclusively includes patients who underwent cataract surgery with a consistent TCCI orientation, reducing variability related to incision placement. Using anterior segment optical coherence tomography (AS-OCT) and automated anterior keratometry, we aim to investigate whether peripheral corneal thickness parameters—such as peripheral thickness alone or peripheral-to-central thickness ratios—can effectively predict postoperative keratometric changes and if these relationships differ across the three astigmatic patterns.

Results
Demographics and baseline corneal thickness and anterior keratometric profiles

Demographics and baseline corneal thickness and anterior keratometric profiles in each group are compared and shown in Table 1.

A total of 209 eyes from 137 patients undergoing temporal clear corneal incision cataract surgery were included in the study. Patients were divided into three groups based on the type of preoperative anterior corneal astigmatism: WTR group (75 eyes from 58 patients), ATR group (103 eyes from 72 patients), and oblique group (31 eyes from 30 patients). The mean age of participants differed slightly but significantly across the three groups (WTR: 68.2 ± 10.0 years [yrs], ATR: 72.6 ± 8.1 yrs, Oblique: 69.5 ± 10.3 yrs; *P* = 0.029). Sex distribution

Parameters	Groups based on anterior corneal astigmatism			P value
	WTR	ATR	Oblique	
No. of eyes (patients)	75 (58)	103 (72)	31 (30)	–
Age (yrs)	68.2 ± 10.0	72.6 ± 8.1	69.5 ± 10.3	0.029*
Sex [male:female (% female)]	21:37 (63.8%)	33:39 (54.2%)	11:19 (63.3%)	0.479
Laterality [OD:OS (% OS)]	33:42 (56.0%)	55:48 (46.6%)	14:17 (54.8%)	0.422
Corneal thickness profiles				
TPCT (µm)	610.9 ± 40.6	613.9 ± 40.7	621.4 ± 46.1	0.494
MPCT (µm)	558.2 ± 36.3	560.4 ± 35.5	567.1 ± 34.0	0.502
CCT (µm)	526.3 ± 36.4	526.3 ± 33.8	530.9 ± 30.5	0.791
TPCT/CCT	1.16 ± 0.06	1.17 ± 0.06	1.17 ± 0.07	0.762
MPCT/CCT	1.06 ± 0.04	1.07 ± 0.03	1.07 ± 0.04	0.638
TPCT/MPCT	1.10 ± 0.02	1.10 ± 0.02	1.10 ± 0.03	0.967
Anterior keratometric profiles				
FK (D)	44.39 ± 1.43	43.85 ± 1.42	44.18 ± 1.66	0.051
SK (D)	45.29 ± 1.45	44.76 ± 1.51	44.85 ± 1.62	0.063
AK (D)	44.84 ± 1.41	44.31 ± 1.45	44.51 ± 1.61	0.056
AST (D)	0.90 ± 0.65	0.91 ± 0.51	0.67 ± 0.56	0.110

Table 1. Baseline demographics and the corneal thickness and anterior keratometric profiles before cataract surgery in patients enrolled in the WTR, ATR and Oblique groups. WTR, With-the-rule astigmatism; ATR, Against-the-rule astigmatism; TPCT, Temporal peripheral corneal thickness; MPCT, Mid-peripheral corneal thickness; FK, Anterior corneal flat keratometry; SK, Anterior corneal steep keratometry; AK, Anterior corneal average keratometry; AST, Anterior corneal astigmatism; CCT, Central corneal thickness. **P* < 0.05. Analysis of variance (ANOVA) and chi-square test.

(percentage of female participants: WTR, 63.8%; ATR, 54.2%; Oblique, 63.3%; $P=0.479$) was comparable among groups.

Preoperative corneal thickness measurements using AS-OCT showed no statistically significant differences among groups. Specifically, TPCT was $610.9 \pm 40.6 \mu\text{m}$ (WTR), $613.9 \pm 40.7 \mu\text{m}$ (ATR), and $621.4 \pm 46.1 \mu\text{m}$ (Oblique) ($P=0.494$). Similarly, MPCT values were $558.2 \pm 36.3 \mu\text{m}$, $560.4 \pm 35.5 \mu\text{m}$, and $567.1 \pm 34.0 \mu\text{m}$, respectively ($P=0.502$). CCT values were also comparable across groups (WTR: $526.3 \pm 36.4 \mu\text{m}$, ATR: $526.3 \pm 33.8 \mu\text{m}$, Oblique: $530.9 \pm 30.5 \mu\text{m}$; $P=0.791$). Additionally, thickness ratios (TPCT/CCT, MPCT/CCT, TPCT/MPCT) did not show significant differences among groups ($P=0.762$, $=0.638$, and $=0.967$, respectively).

Baseline anterior keratometric profiles also demonstrated no statistically significant differences among groups. Specifically, anterior corneal flat keratometry (FK) values were $44.39 \pm 1.43 \text{ D}$ (WTR), $43.85 \pm 1.42 \text{ D}$ (ATR), and $44.18 \pm 1.66 \text{ D}$ (Oblique), approaching borderline significance ($P=0.051$). Similarly, anterior corneal steep keratometry (SK) measurements showed a comparable pattern with WTR at $45.29 \pm 1.45 \text{ D}$, ATR at $44.76 \pm 1.51 \text{ D}$, and Oblique at $44.85 \pm 1.62 \text{ D}$ ($P=0.063$). Anterior corneal average keratometry (AK) was also slightly higher in the WTR group ($44.84 \pm 1.41 \text{ D}$) than in ATR ($44.31 \pm 1.45 \text{ D}$) and Oblique ($44.51 \pm 1.61 \text{ D}$) groups, but this difference was statistically insignificant ($P=0.056$). Preoperative anterior corneal astigmatism (AST) values were similar among groups (WTR: $0.90 \pm 0.65 \text{ D}$, ATR: $0.91 \pm 0.51 \text{ D}$, Oblique: $0.67 \pm 0.56 \text{ D}$; $P=0.110$).

Postoperative changes in anterior keratometric profiles

At 1 month after surgery, distinct patterns of change in anterior keratometric profiles were observed across astigmatism types. In the WTR group, postoperative changes showed significant decrease of FK (change $[\Delta]$: $-0.38 \pm 0.61 \text{ D}$, $P<0.001$) and AK (Δ : $-0.25 \pm 0.50 \text{ D}$, $P<0.001$), but increase of AST (Δ : $+0.27 \pm 0.69 \text{ D}$, $P<0.001$). SK did not change perioperatively ($P=0.127$). In the ATR group, SK (Δ : $-0.17 \pm 0.37 \text{ D}$, $P<0.001$), AK (Δ : $-0.08 \pm 0.31 \text{ D}$, $P=0.007$), AST (Δ : $-0.17 \pm 0.46 \text{ D}$, $P<0.001$) decreased significantly 1 month after surgery, but FK did not change perioperatively ($P=0.947$). The Oblique group demonstrated significant decrease in both FK (Δ : $-0.25 \pm 0.39 \text{ D}$, $P=0.001$) and AK (Δ : $-0.18 \pm 0.38 \text{ D}$, $P=0.014$). Among the three groups, the postoperative change in AST was most pronounced in the WTR group (Table 2).

Correlation between peripheral corneal thickness profiles and the postoperative anterior keratometric profile changes

In the WTR group, among the peripheral corneal thickness profiles, the TPCT/CCT and MPCT/CCT ratio showed a significant positive correlation with postoperative changes in AST (TPCT/CCT: $r=0.293$, $P=0.011$; MPCT/CCT: $r=0.301$, $P=0.009$) (Table 3). Postoperative changes of FK, SK and AK did not correlate with all of corneal thickness profiles. In the ATR group, all of postoperative anterior keratometric profile changes did not demonstrate any significant correlations between preoperative corneal thickness profiles (Table 3).

However, the Oblique astigmatism group showed significant correlations primarily involving the MPCT/CCT ratio. Specifically, MPCT/CCT was positively correlated with the postoperative changes in FK ($r=0.362$, $P=0.046$), SK ($r=0.400$, $P=0.026$), and AK ($r=0.428$, $P=0.016$) (Table 3). Other indices—such as TPCT, MPCT, CCT, TPCT/CCT, and TPCT/MPCT—did not show any significant associations with postoperative keratometric changes, suggesting that mid-peripheral corneal thickness relative to the center may be especially influential in cases of oblique astigmatism.

Predictive values of peripheral-to-central corneal thickness ratios for postoperative anterior corneal astigmatism in the WTR group

Because baseline corneal thickness profiles correlated with postoperative AST changes only in the WTR group (Table 3), further analyses were conducted in this group to address the clinical importance of postoperative astigmatism prediction, particularly in the era of toric IOL use. To elucidate the clinical relevance of peripheral corneal thickness ratios, we compared preoperative TPCT/CCT and MPCT/CCT ratios between eyes with a postoperative AST increase of $\geq +0.25 \text{ D}$ and those with $< +0.25 \text{ D}$. Among the 75 eyes in the WTR group, 40 eyes showed an AST increase $\geq +0.25 \text{ D}$, whereas 35 eyes did not. As shown in Table 4, both the TPCT/CCT ratio and the MPCT/CCT ratio were significantly higher in eyes with an AST increase $\geq +0.25 \text{ D}$ than in those with smaller changes (TPCT/CCT: 1.18 ± 0.05 vs. 1.14 ± 0.07 , $P=0.013$; MPCT/CCT: 1.07 ± 0.03 vs. 1.05 ± 0.05 , $P=0.008$).

We then performed receiver operating characteristic (ROC) curve analyses to identify possible cutoffs for predicting clinically meaningful postoperative astigmatism changes in WTR eyes (Table 5). For TPCT/CCT, the area under the curve (AUC) was 0.644 (95% confidence interval [CI]: 0.514–0.773, $P=0.033$), and an optimal cutoff of 1.118 provided a sensitivity of 95.0% and a specificity of 34.3%, resulting in a Youden's J of 0.293. Alternative cutoffs, such as 1.130 or 1.160, showed slightly lower sensitivity but higher specificity, indicating

Variable	Groups based on anterior corneal astigmatism		
	WTR	ATR	Oblique
Postoperative change of AST	$+0.27 \pm 0.69 \text{ D}$	$-0.17 \pm 0.46 \text{ D}$	$+0.14 \pm 0.39 \text{ D}$
P value (pre AST vs. post AST)	$<0.001^*$	$<0.001^*$	0.109

Table 2. The postoperative change of anterior corneal astigmatism (AST) 1 month after the cataract surgery in the WTR, ATR, and Oblique groups. WTR, With-the-rule astigmatism; ATR, Against-the-rule astigmatism; pre, Preoperative; post, Postoperative. $^*P<0.05$. Wilcoxon signed-rank test.

V_s	WTR group							
	Δ FK		Δ SK		Δ AK		Δ AST	
	r	P value	r	P value	r	P value	r	P value
TPCT (μm)	-0.116	0.320	-0.022	0.850	-0.074	0.527	0.127	0.278
MPCT (μm)	-0.088	0.451	-0.095	0.417	-0.102	0.386	0.046	0.698
CCT (μm)	0.001	0.995	-0.169	0.146	-0.092	0.435	-0.080	0.496
TPCT/CCT	-0.074	0.530	0.224	0.053	0.092	0.431	0.293	0.011*
MPCT/CCT	-0.089	0.447	0.211	0.069	0.065	0.582	0.301	0.009*
TPCT/MPCT	-0.010	0.930	0.179	0.125	0.099	0.397	0.180	0.123
V_s	ATR group							
	Δ FK		Δ SK		Δ AK		Δ AST	
	r	P value	r	P value	r	P value	r	P value
TPCT (μm)	-0.145	0.146	-0.095	0.342	-0.139	0.164	0.076	0.450
MPCT (μm)	-0.157	0.116	-0.028	0.780	-0.113	0.259	0.148	0.139
CCT (μm)	-0.160	0.109	-0.016	0.875	-0.120	0.229	0.181	0.069
TPCT/CCT	0.014	0.890	-0.108	0.282	-0.039	0.695	-0.138	0.167
MPCT/CCT	-0.043	0.672	-0.119	0.232	-0.075	0.453	-0.070	0.483
TPCT/MPCT	0.045	0.654	-0.107	0.285	-0.025	0.804	-0.181	0.068
V_s	Oblique group							
	Δ FK		Δ SK		Δ AK		Δ AST	
	r	P value	r	P value	r	P value	r	P value
TPCT (μm)	-0.042	0.823	0.155	0.404	0.073	0.695	0.227	0.221
MPCT (μm)	-0.029	0.877	0.164	0.378	0.085	0.649	0.224	0.225
CCT (μm)	-0.270	0.142	-0.080	0.668	-0.187	0.315	0.174	0.350
TPCT/CCT	0.229	0.214	0.311	0.089	0.307	0.094	0.141	0.448
MPCT/CCT	0.362	0.046*	0.400	0.026*	0.428	0.016*	0.115	0.538
TPCT/MPCT	-0.051	0.786	0.062	0.741	0.012	0.950	0.124	0.505

Table 3. Correlations of the preoperative corneal thickness profiles and the postoperative change of anterior keratometric profiles 1 month after the cataract surgery in the WTR, ATR, and Oblique groups. WTR, With-the-rule astigmatism; ATR, Against-the-rule astigmatism; FK, Anterior corneal flat keratometry; SK, Anterior corneal steep keratometry; AK, Anterior corneal average keratometry; AST, Anterior corneal astigmatism; TPCT, Temporal peripheral corneal thickness; MPCT, Mid-peripheral corneal thickness; CCT, Central corneal thickness. Δ indicates the postoperative change from preoperative values. * $P < 0.05$. Spearman's rank correlation test (WTR and ATR groups) and Pearson's correlation test (Oblique group).

Variables	WTR group		P value
	Δ AST $< +0.25\text{D}$	Δ AST $\geq +0.25\text{D}$	
No. of eyes	35	40	–
Mean value of Δ AST ^a	-0.19 ± 0.44	0.68 ± 0.61	$< 0.001^*$
TPCT/CCT ^b	1.14 ± 0.07	1.18 ± 0.05	0.013^*
MPCT/CCT ^b	1.05 ± 0.05	1.07 ± 0.03	0.008^*

Table 4. Difference of change of the preoperative values of temporal peripheral corneal thickness (TPCT)-to-central corneal thickness (CCT) ratio and mid-peripheral corneal thickness (MPCT)-to-CCT ratio according to the postoperative change of anterior corneal astigmatism (AST) with a cut-off value of $+0.25\text{D}$ in the WTR group. WTR, With-the-rule astigmatism; AST, Anterior corneal astigmatism; TPCT, Temporal peripheral corneal thickness; MPCT, mid-peripheral corneal thickness. Δ indicates the postoperative change from preoperative values. * $P < 0.05$. ^aMann–Whitney U test. ^bStudent's t-test.

a potential trade-off depending on clinical priorities. Meanwhile, MPCT/CCT yielded an AUC of 0.651 (95% CI: 0.524–0.779, $P = 0.024$) with the best cutoff at 1.046, giving a sensitivity of 87.5%, specificity of 45.7%, and a Youden's J of 0.332. Additional thresholds (e.g., 1.050 or 1.056) again demonstrated variable balances between sensitivity and specificity.

Discussion

Our study investigated the role of AS-OCT-based peripheral corneal thickness profiles in influencing keratometric outcomes after TCCI cataract surgery, emphasizing variations according to preoperative astigmatism types. We

WTR group								
Outcome	Corneal thickness profiles	AUC	95% confidence interval	P value	Cutoff	Sensitivity (%)	Specificity (%)	Youden's J
Postoperative change of AST $\geq +0.25$ D	TPCT/CCT	0.644	0.514–0.773	0.033*	> 1.118	95.0	34.3	0.293
					> 1.130	87.5	40.0	0.275
					> 1.143	75.0	51.4	0.264
					> 1.160	67.5	57.1	0.246
					> 1.179	52.5	68.6	0.211
	MPCT/CCT	0.651	0.524–0.779	0.024*	> 1.046	87.5	45.7	0.332
					> 1.050	75.0	45.7	0.207
					> 1.056	67.5	51.4	0.189
					> 1.071	50.0	60.0	0.100
					> 1.076	45.0	74.3	0.193

Table 5. Receiver operating characteristic (ROC) curve analysis of the preoperative values temporal peripheral corneal thickness (TPCT)-to-central corneal thickness (CCT) ratio and mid-peripheral corneal thickness (MPCT)-to-CCT ratio in patients with the postoperative change of anterior corneal astigmatism (AST) $\geq +0.25$ D from the preoperative AST as compared to the postoperative AST change $< +0.25$ D in the WTR group. WTR, With-the-rule astigmatism; TPCT, Temporal peripheral corneal thickness; MPCT, Mid-peripheral corneal thickness; CCT, Central corneal thickness; AUC, area under curve; AST, Anterior corneal astigmatism. * $P < 0.05$.

identified distinct patterns based on astigmatism orientation, suggesting that peripheral corneal thickness may contribute differentially to postoperative anterior keratometric changes. Eyes with WTR astigmatism and higher peripheral-to-central thickness ratios tended to show greater increases in postoperative corneal cylindrical power, whereas those with oblique astigmatism demonstrated significant associations between mid-peripheral corneal thickness ratios and reductions in anterior keratometric values. By contrast, eyes with ATR astigmatism did not exhibit notable correlations, underscoring the possibility that astigmatism-type-specific mechanisms underpin these refractive outcomes.

Previous studies have emphasized the importance of corneal biomechanics in predicting and managing SIA after cataract surgery. However, most prior research has focused on incision characteristics such as type, location, and size, rather than detailed corneal thickness profiles^{15,16}. CCT is frequently examined due to its relevance in intraocular pressure measurements and detection of corneal pathologies¹⁷, but peripheral corneal thickness remains under-investigated in relation to postoperative refractive outcomes. Our findings suggest that peripheral corneal biomechanical properties, reflected by peripheral-to-central thickness ratios, significantly influence corneal stability after temporal incisions. Specifically, higher TPCT/CCT and MPCT/CCT ratios in WTR eyes may indicate relatively robust peripheral lamellae that help maintain corneal curvature under usual mechanical loads. Once a temporal incision disrupts these thicker collagen arrangements, it can lead to a disproportionate redistribution of tension, thus producing a more pronounced cylindrical shift. Although previous research focusing on central prepupillary regions suggested that denser collagen packing can alter local biomechanical and optical outcomes¹⁸, our extrapolation to the peripheral cornea remains indirect. Nevertheless, these findings collectively imply that corneal areas with greater lamellar density or thickness may be more susceptible to abrupt shape changes when structural continuity is disrupted, aligning with the elevated cylindrical shifts observed in thicker peripheral profiles.

Among the three groups, only the WTR group showed a significant correlation between postoperative changes in AST and the TPCT/CCT or MPCT/CCT ratio. This may be partly explained by the fact that TCCI typically induces a greater increase in AST in WTR eyes as shown in Table 2, whereas ATR and oblique eyes tend to show minimal change or even a reduction in AST. This directional susceptibility in the WTR group may have enhanced the detectability of associations with peripheral corneal thickness profiles.

Interestingly, some literature contradicts our observations. For example, one recent study analyzed eyes undergoing phacoemulsification with a 2.2-mm temporal clear corneal incision at 135°, using total keratometry measured by AS-OCT⁹. In that study, thicker peripheral corneas were associated with smaller SIA, in contrast to our findings. However, their analysis did not stratify patients by preoperative astigmatism type and treated corneal thickness as a continuous variable without directionality. Another earlier study utilized self-sealing CCIs made at 120° with various incision widths and similarly found no significant relationship between peripheral corneal thickness and postoperative SIA¹². Differences in incision parameters and lack of astigmatism-type stratification may partly explain the divergence from our results. By contrast, our study explicitly stratified subjects into WTR, ATR, and oblique astigmatism groups, utilized a consistent incision size (2.75 mm) and uniform temporal incision location, aiming to minimize such confounding factors and clarify astigmatism-type-specific biomechanical responses.

From a clinical standpoint, peripheral thickness measurements could refine surgical planning. Currently, incision strategies and toric IOL calculations tend to focus on total astigmatism magnitude and axis¹⁶. However, our results indicate that incorporating peripheral thickness ratios, especially in WTR or oblique astigmatism, may help predict excessive postoperative cylinder or significant keratometric reductions, guiding more personalized interventions—such as altering incision width or location. Notably, our study also performed ROC analyses,

providing practical cut-off values for peripheral-to-central thickness ratio (TPCT/CCT) and mid-peripheral-to-central thickness ratio (MPCT/CCT) to predict clinically significant postoperative cylindrical shifts (≥ 0.25 D). These ROC-derived cut-off values offer an additional practical advantage, enabling surgeons to more objectively and quantitatively anticipate postoperative refractive outcomes in clinical practice.

Despite these insights, our study has several limitations. Its retrospective design and the relatively small sample size in the oblique astigmatism group restrict the generalizability of our findings. Additionally, the evaluation period was limited to 1 month postoperatively, potentially missing longer-term corneal remodeling processes. Another limitation is our exclusive reliance on anterior keratometric values obtained using a conventional autorefractor keratometer; thus, we could not evaluate total corneal astigmatism or posterior corneal surface changes, which modern imaging devices like Scheimpflug systems or anterior segment swept-source OCT can measure. Furthermore, since this study did not employ vectorial analysis of astigmatism, changes in axis orientation could not be fully assessed. Although patients were stratified by astigmatism type and underwent surgery with a consistent incision location, this remains a limitation when interpreting subtle axis-dependent effects, particularly in eyes with oblique astigmatism. Future prospective studies incorporating total keratometry measurements and advanced corneal biomechanical indices, such as corneal hysteresis or resistance factor, over extended follow-up periods would provide further clarification regarding whether peripheral thickness itself is the key determinant or simply a surrogate for broader biomechanical properties.

In conclusion, our findings suggest that peripheral-to-central corneal thickness ratios (TPCT/CCT and MPCT/CCT) may serve as useful predictors of postoperative astigmatic changes following TCCI cataract surgery, particularly in eyes with WTR astigmatism. Notably, our ROC analyses provide specific cutoff values that may aid surgeons in preoperative planning by identifying eyes at risk for clinically meaningful postoperative cylindrical shifts (≥ 0.25 D). This contributes practical value by allowing more informed, data-driven customization of incision strategy or toric IOL use based on individualized corneal profiles. Nevertheless, we acknowledge the need for further validation and direct biomechanical assessments to substantiate these preliminary observations. This perspective may ultimately enable more tailored surgical plans aimed at optimizing refractive outcomes across diverse astigmatic presentations.

Methods

Study ethics

Adherence to the principles in the Declaration of Helsinki was ensured throughout the entire investigation process. Approval for the research protocol was obtained from the Institutional Review Board (IRB) of Chung-Ang University Hospital (Approval No. 2103-001-19,355). Given the retrospective nature of the study, the need for informed consent was waived by the IRB of Chung-Ang University Hospital.

Subjects

This study included patients who underwent cataract surgery with a 2.75 mm TCCI, phacoemulsification, and IOL implantation between April 2019 and September 2020. All surgeries were uneventful and sutureless. Patients were included regardless of IOL type; both toric and multifocal IOLs were allowed. All patients had AS-OCT (Visante; Carl Zeiss Meditec, Zena, Germany) performed within 4 weeks prior to surgery, and autorefractor keratometer (KR-8900, Topcon, Tokyo, Japan) measurements of anterior corneal keratometry taken within 4 weeks before surgery and again at 1 month postoperatively. Patients were excluded if they had a history of any ocular surgery, particularly corneal refractive surgery or pterygium excision, as well as corneal trauma, infection, opacity, keratoconus or any history of contact lens wear.

Based on the preoperative automated keratometry readings, anterior corneal astigmatism was classified as WTR astigmatism if the steep meridian was between 60° and 120° , ATR astigmatism if the steep meridian was between 150° and 180° , and oblique astigmatism in all other cases. Accordingly, patients were divided into three groups: WTR, ATR, and Oblique.

Corneal thickness and anterior keratometric profiling

CCT was defined as the average thickness measured in the central 2-mm zone using the pachymetry mode of the Visante AS-OCT device. The mean corneal thickness at the 7–10 mm diameter zone on the temporal side was designated as TPCT, and the mean corneal thickness at the 5–7 mm diameter zone on the temporal side was designated as MPCT (Fig. 1).

Anterior keratometric profiles, including FK (diopters [D]), SK (D), AK (D), and AST (D), were measured using the autorefractor keratometer. Three repeated measurements were taken, and the average was used for analysis.

Study design

This retrospective chart review focused on preoperative corneal thickness profiles and perioperative anterior keratometric profiles in eyes undergoing uncomplicated phacoemulsification and IOL implantation. The analyses were structured as follows:

1. Collection of baseline corneal thickness measurements (CCT, TPCT, MPCT, TPCT/CCT, MPCT/CCT, TPCT/MPCT) and perioperative anterior keratometric profiles (FK, SK, AK, AST).
2. Investigation of correlations between these corneal thickness profiles and postoperative anterior keratometric profile changes in the WTR, ATR, and Oblique groups.
3. ROC curve analysis of baseline corneal thickness profiles for predicting a clinically significant postoperative AST increase ($\geq +0.25$ D) in the WTR group.

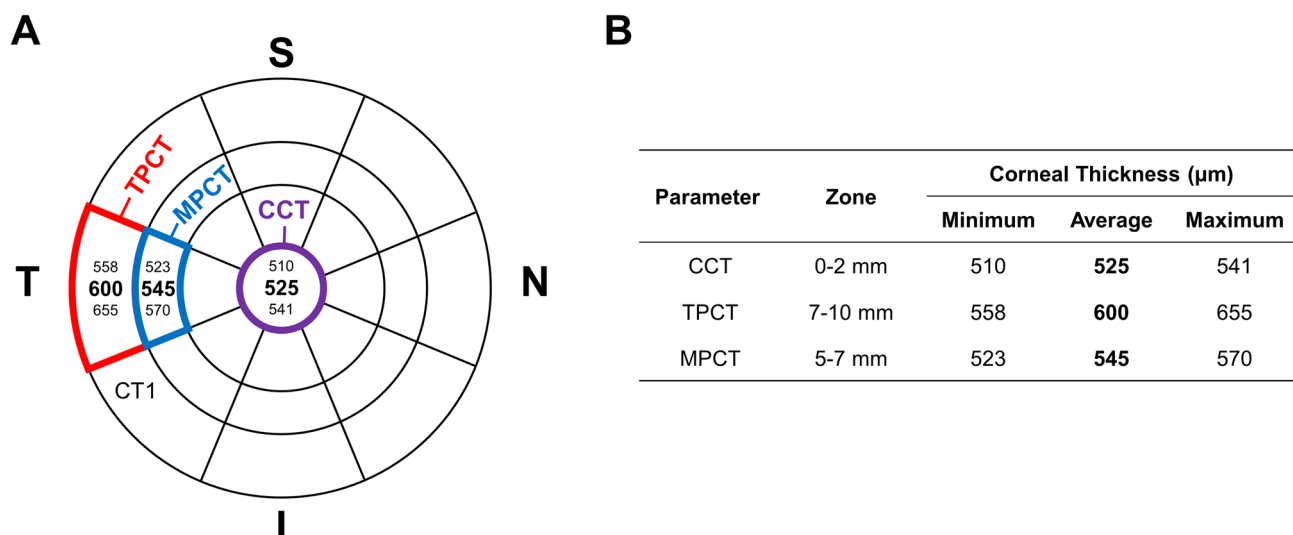


Fig. 1. Corneal thickness zones and reference ranges used in this study. **(A)** Schematic depiction of the cornea divided into concentric zones measured by anterior segment optical coherence tomography (AS-OCT). The innermost purple ring (0–2 mm) denotes the central corneal thickness (CCT). The mid-peripheral zone (5–7 mm) on the temporal side, highlighted in blue, is designated as mid-peripheral corneal thickness (MPCT), and the outer temporal peripheral zone (7–10 mm), shown in red, is designated as temporal peripheral corneal thickness (TPCT). The bolded values in each zone represent the mean corneal thickness, with the smaller numbers indicating the minimum and maximum thicknesses measured in that zone. **(B)** Summary table of the minimum, average (bold), and maximum corneal thickness (in micrometers) for each zone (CCT, TPCT, MPCT) derived from AS-OCT measurements in the study population.

- Determination of potential cutoff values for the baseline corneal thickness profiles to anticipate a $\geq +0.25$ D increase in postoperative AST.

Surgical technique

All operations were performed using standard phacoemulsification under topical anesthesia by a single surgeon (KWK). A 2.75 mm TCCI was created using a triplanar incision technique, followed by continuous curvilinear capsulorhexis. Lens fragmentation and aspiration were carried out using the Centurion® phacoemulsification system (Alcon Laboratories, Fort Worth, TX, USA). The incision was left sutureless, and postoperative treatment included topical antibiotic and corticosteroid eye drops according to standard cataract surgery protocols.

Statistical analysis

Statistical analyses were performed using Prism software Ver. 10.0.2 (GraphPad, La Jolla, CA, USA; www.graphpad.com). Continuous variables were expressed as mean $\pm$ standard deviation. For all statistical analyses, the choice of parametric or non-parametric tests was based on the distribution of the data. If the normality assumption was met, parametric tests were used; otherwise, non-parametric alternatives were applied. Parametric one-way analysis of variance (ANOVA) was used to compare measurements among the three astigmatism groups. For inter-group comparisons, the parametric Student's t-test or the non-parametric Mann–Whitney U test was applied. For the analysis of perioperative change in anterior keratometric profiles, the parametric paired t-test or the non-parametric Wilcoxon signed-rank test was applied. Categorical variables were compared using the chi-square test. Correlation analyses were performed using Pearson's correlation test for parametric data and Spearman's rank correlation test for non-parametric data. ROC curves were generated to illustrate sensitivity and specificity across a range of cutoff values. The optimal cut-off values were determined by calculating the Youden Index (sensitivity + specificity – 1), which identifies the threshold that maximizes the combined sensitivity and specificity. A P value < 0.05 was considered statistically significant.

Data availability

The datasets generated and analyzed in the current study are available from the corresponding author on reasonable request.

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Author contributions

KWK designed the study. SHL collected the data. SHL and KWK analyzed the data. JYO and KWK drafted the manuscript. YSC and KWK critically revised the manuscript. All authors approved the final manuscript for submission.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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