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CLINICAL INVESTIGATION

Prediction of corneal curvature radius after pterygium surgery using anterior segment optical coherence tomography

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Abstract

Purpose To investigate the validity of a multiple regression equation to predict postoperative corneal curvature radius (K) in simultaneous cataract and pterygium surgery using preoperative factors, including preoperative K.

Study design Retrospective study.

Methods Seventy eyes of 58 patients who had undergone initial pterygium removal at the Hayashi Eye Hospital between June 2014 and December 2017 were included in this study. In all eyes, the shape of the cornea could be measured using anterior segment optical coherence tomography 2 months after surgery. The independent variables were determined using a multiple regression equation that predicted the average postoperative K on the basis of a single regression analysis of the average postoperative K and each preoperative parameter. A multiple regression equation was then formulated, and leave-one-out cross-validation was used to determine its validity.

Results Five independent variables were selected from a single regression analysis, and the multiple regression equation was formulated as follows. prediction of average K = 0.278 + (0.272 × central anterior K) + (0.276 × upper anterior K) + (0.329 × lower anterior K) + (0.113 × average posterior K) – (0.410 × horizontal pterygium size). These five variables were validated using leave-one-out cross-validation. The difference between the prediction average K and the average postoperative K, as determined using the multiple regression equation, 83% of cases had a difference ≤ 0.50 D.

Conclusions We confirmed the validity and utility of our multiple regression equation for predicting postoperative K from the K before pterygium surgery.

Keywords Pterygium · simultaneous cataract and pterygium surgery · Predicted corneal curvature radius · anterior segment optical coherence tomography

Introduction

Pterygium is a disorder in which bulbar conjunctival tissue grows over the cornea in a wing shape, affecting the shape of the cornea. It often occurs concurrently with the formation of a cataract [1]; because the corneal curvature radius (K value) after pterygium removal cannot be predicted, the general surgical practice is to remove the pterygium first, and perform cataract surgery later (once the K value has stabilized) [2, 3]. Although a surgical procedure for simultaneous cataract and pterygium removal has been established, greater myopic refractive error than predicted is known to occur following this procedure [4, 5]; thus, clinicians hesitate to perform simultaneous surgery. However, simultaneous surgery rapidly restores both visual function and appearance, in addition to shortening the treatment period; therefore, it should be more widely practiced [2–5]. The calculation of a multiple regression formula for postoperative K values, based on those measured by preoperative automated keratometer, is reported as a method for managing the problem of refractive error in these cases [6]; however, automated keratometer requires a 3 mm area in diameter for measurements. Thus, it may not be possible to measure the K value in cases of advanced pterygium that has invaded the measurement area. Anterior-segment optical coherence tomography (AS-OCT), however, is capable of measuring values from the center of the cornea to its periphery, if these are not covered by the

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pterygium. Moreover, AS-OCT can measure the posterior surface curvature of the cornea. Our objective in this study was to formulate a multiple regression equation to predict the postoperative average K value of the anterior surface, using the K value before pterygium surgery measured by AS-OCT, and to confirm its validity using retrospective clinical data.

Subjects and Methods

The subjects were patients with pterygium growing from the nasal side, who underwent pterygium removal and conjunctival pedicle flap grafting at Hayashi Eye Hospital between June 2014 and December 2017, and who underwent measurement by AS-OCT, 2 months postoperatively. Patients were excluded if they had not been examined within 2 months of surgery, if pterygium recurred, or if they suffered from a disorder other than pterygium that affected the shape of the cornea, recurrent pterygium, including pterygium growing elsewhere than on the nasal side. This was a retrospective study screened by the Ethical Review Board of Hayashi Eye Hospital and approved on the basis of its adherence to the Declaration of Helsinki.

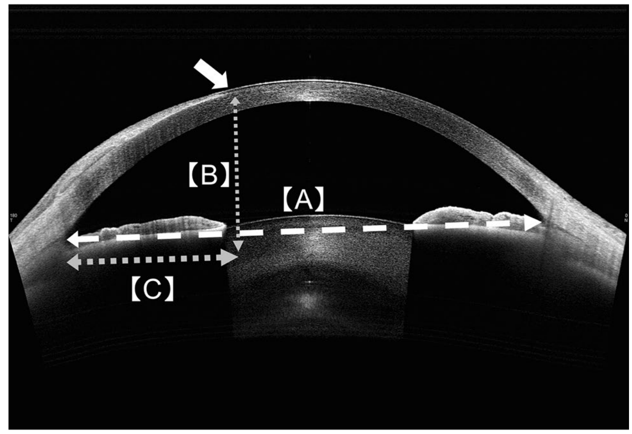

Fig. 1 Calculation of horizontal pterygium size by anterior segment optical coherence. Calculation of horizontal pterygium size using horizontal cross-section by SS-1000:CASIA and CASIA 2. **a** Distance from temporal side angle recess to nasal side angle recess(horizontal diameter of the cornea, mm). **b** A perpendicular drawn from the high reflection of the tip of the pterygium. **c** Distance from the nasal angle recess to the perpendicular drawn from the tip of the pterygium (pterygium diameter, mm). ↓ The tip of pterygium, the position where high reflection is interrupted Horizontal pterygium size = $\frac{C}{A}$

Surgical techniques

The surgical procedure comprised blunt detachment of the pterygium tissue, followed by the removal of abnormal Tenon's capsule tissue. It concluded with the formation of a conjunctival pedicle from below, which was slid upward and sutured with 8-0 vicryl sutures.

K values were measured within 1 month before pterygium surgery and 2 months postoperatively by AS-OCT, using a CASIA: SS-1000 or CASIA 2 (Tomey, Nagoya, Japan) in corneal map mode. The parameters investigated for the formulation of the multiple regression equation were the average K values for a 3-mm diameter area on both anterior and posterior surfaces; the K values at the center, as well as points 1.5 mm superior and inferior to the center; the K value on the temporal side; and the horizontal pterygium size (HPS).

The HPS was calculated as the ratio of the pterygium diameter to the angle recess distance, with the angle recess distance defined as the horizontal diameter of the cornea (mm) and the pterygium distance as the X-axis component from the nasal angle recess to the tip of the pterygium, measured by AS-OCT (Fig. 1) in horizontal cross-section.

The HPS was selected as one of the independent variables of the multiple regression equation to calculate the predicted average K value of the postoperative pterygium anterior surface (Prediction Ave K). Several reports indicate that variation in K is associated with increases in HPS[4–7]. Moreover, in the present study, other independent variables were unclear. Therefore, the correlation between each preoperative K value and the average postoperative K value was checked, as was the collinearity between each of the preoperative K values. A multiple regression model was created with data from 69 eyes, excluding 1 eye from the original 70, to verify the accuracy of the model built with 70 eyes; a leave-one-out cross-validation was repeated 70 times to validate the exclusion in this model. The diopter conversion [8] used a keratometric index of 1.3375 to determine the difference in the K value of the Prediction Ave K and the difference between the postoperative average K values of the anterior surface in order to find a classification accuracy ≦0.50 D . It is considered clinically useful due to the refractive error of the intraocular lens.

The difference between the Prediction Ave K calculated from the multiple regression equation model and the postoperative average K value of the anterior surface values and the difference between the preoperative and postoperative average K values of the anterior surface values were then compared with the proportions of differences ≦0.50 D, between 0.51 D and 1.00 D, and ≧1.01 D. Furthermore, the group in which measurements were made using an automated keratometer was compared with the group in which such measurements were not possible.

Statistical analysis was performed with statistical software StatView for Macintosh, Version 5.0; SAS Institute Inc. Pearson's correlation coefficient was used to test the correlations between the following parameters: between various preoperative K values and the postoperative average K value of the anterior surface. A correlation coefficient of 0.9 was considered to indicate collinearity. Multiple regression analysis was used to calculate Predicted Ave K, independent variables with a correlation coefficient of 0.7 in simple regression analysis. The paired t-test was used to compare each of the preoperative and postoperative K values, and the Chi-squared test was used to compare (1) the postoperative average K value of the anterior surface values with the preoperative values, the postoperative average K value of the anterior surface value with Prediction Ave K, and (2) the group in which measurements were made using an automated keratometer with the group in which this measurement was not possible. Welch's t-test was used to compare the HPS between the group in which measurements were made using an automated keratometer and the group in which such measurement was not possible. For all tests, $P < 0.05$ was regarded as significant.

Results

Seventy eyes of 58 patients (29 men and 29 women, aged 57.22 ± 13.00 years) were included in this study. HPS was 29.67% ± 6.68% (10.54 – 41.61%) (Table 1). Significant differences were seen between each preoperative and postoperative K value, except at the central and lower posterior surface. Particularly large changes were seen in the anterior surface average, the central anterior surface, and the temporal side of the anterior surface (Table 1). All preoperative K values of the anterior and posterior surfaces were significantly correlated with the postoperative average K values of the anterior surface, and the correlation coefficient was ≧0.6 in all cases except the K values of the temporal side of the anterior surface and the HPS (Table 2). In the assessment of collinearity between factors prior to multiple regression analysis, the average K value of the anterior surface was collinear with the K value of the central anterior surface, the average K value of the posterior surface was collinear with the K values of the central posterior surface and upper posterior surface, and the K value of the central posterior surface was collinear with the K value of the upper posterior surface (Table 3). The postoperative average K value of the anterior surface was set as the dependent variable, while the following four factors with a correlation coefficient of ≧0.7 K were adopted as independent variables on the basis of collinearity: the K value of the central anterior surface ($R = 0.863$, $P < 0.001$), the K value of the upper anterior surface ($R = 0.845$, $P < 0.001$), the K value of the lower anterior surface ($R = 0.879$, $P < 0.001$), the average K value of the posterior surface ($R = 0.768$, $P < 0.001$), and the HPS ($R = 0.263$, $P = 0.028$). The correlation coefficients were as follows: $R = 0.961$, $R2 = 0.923$, $P < 0.001$, and the following multiple regression equation was formulated (Table 4).

Prediction Ave K = 0.278 + (0.272 × K value of the central anterior surface) + (0.276 × K value of the upper anterior surface) + (0.329 × K value of the lower anterior surface) + (0.113 × average K value of the posterior surface) – (0.410 × HPS)

The classification accuracy of the multiple regression model, verified with leave-one-out cross-validation, was as follows: the difference between the postoperative average K values of the anterior surface and Prediction Ave K was ≦0.50 D for 58/70 eyes (83%) .

The results of the multiple regression model indicated that the difference between the Prediction Ave K and the postoperative average K values of the anterior surface was 0.00 ± 0.07 mm (-0.14 to 0.15 mm), while with the Diopter, it was 0.01 ± 0.38 D, and the absolute value was 0.32± 0.21 D. Of the 70 eyes, 58 (83%) showed a difference ≤0.50 D, while 12 eyes (17%) had a difference within the range of

Table 1 Preoperative and postoperative K values

Parameter	Preoperative Average ± SD	2 Mo postop Average ± SD	*P* value
A-Ave (mm)	7.93±0.29	7.69±0.22	< 0.001*
A-Ave (D)	42.60±1.57	44.02±1.26	< 0.001*
A-Center (mm)	7.94±0.27	7.69±0.23	< 0.001*
A-Upper (mm)	7.67±0.26	7.71±0.24	0.0414*
A-Lower (mm)	7.62±0.22	7.69±0.25	< 0.001*
A-Temporal (mm)	8.04±0.66	7.68±0.24	< 0.001*
P-Ave (mm)	6.43±0.25	6.47±0.24	< 0.001*
P-Center (mm)	6.47±0.29	6.49±0.24	0.3825
P-Upper (mm)	6.41±0.30	6.34±0.27	< 0.001*
P-Lower (mm)	6.38±0.28	6.38±0.26	0.8384
P-Temporal (mm)	6.40±0.27	6.55±0.25	< 0.001*

Ave average, A- anterior surface, P- posterior surface, * *P* <0.05, Paired t-test

Table 2 Correlation between preoperative parameter and postoperative average K value of the anterior surface

Parameter	Anterior		Posterior	
	R	*P* value	R	*P* value
Ave	0.828	< 0.001*	0.768	< 0.001*
Center	0.863	< 0.001*	0.687	< 0.001*
Upper	0.845	< 0.001*	0.669	< 0.001*
Lower	0.879	< 0.001*	0.694	< 0.001*
Temporal	0.441	< 0.001*	0.630	< 0.001*
HPS	0.263	0.028*	NA	NA

Ave average, HPS horizontal pterygium size, * *P* < 0.05, Pearson's correlation coefficient

Table 3 Collinearity of independent variables for constructing multiple regression equation

Parameter	A-Ave	A-Center	A-Upper	A-Lower	A-Temporal	P-Ave	P-Center	P-Upper	P-Lower	P-Temporal
A-Center	0.972**									
A-Upper	0.682**	0.717**								
A-Lower	0.775**	0.804**	0.690**							
A-Temporal	0.580**	0.573**	0.198	0.338**						
P-Ave	0.717**	0.742**	0.607**	0.681**	0.587**					
P-Center	0.712**	0.723**	0.492**	0.591**	0.763**	0.957**				
P-Upper	0.662**	0.663**	0.512**	0.634**	0.564**	0.926**	0.906**			
P-Lower	0.647**	0.677**	0.663**	0.626**	0.400*	0.842**	0.778**	0.773**		
P-Temporal	0.369**	0.411**	0.487**	0.573**	0.054	0.639**	0.484**	0.510**	0.466**	
HPS	0.545**	0.546**	0.221	0.291*	0.326**	0.280*	0.320**	0.257*	0.319**	0.040

A- anterior surface, P- posterior surface, HPS horizontal pterygium size,* $P < 0.05$, ** $P < 0.01$, Pearson's correlation coefficient

Table 4 Result of multiple regression analysis

R	0.961			
R^2	0.923			
Parameter	regression coefficient	standard error	t ratio	*P* value
intercept	0.278	0.274	1.013	0.5027
A-Center K(mm)	0.272	0.069	3.934	0.0002*
A-Upper K(mm)	0.276	0.046	6.045	< 0.0001*
A-Lower K(mm)	0.329	0.062	5.330	< 0.0001*
P-Ave K(mm)	0.113	0.047	2.423	0.0182*
HPS(%)	-0.410	0.149	-2.750	0.0077*

Predicted Ave K = 0.278 + 0.272 × A-Center K + 0.276 × A-Upper K + 0.329 × A-Lower K + 0.113 × P-Ave K – 0.410 × HPS

Ave average, A- anterior surface, P- posterior surface, HPS horizontal pterygium size, * $P < 0.05$, Multiple regression analysis

0.51 to 1.00 D. No eyes (0%) had a difference ≥1.01 D. The difference between the preoperative and postoperative average K values of the anterior surface was -1.41 ± 0.88 D, and the corresponding absolute value was 1.45 ± 0.82 D. Nine eyes (13%) had a difference of ≦0.50 D, 10 eyes (14%) had a difference between 0.51 and 1.00 D, and 51 eyes (73%) had a difference ≧1.01 D, indicating a significant difference from the Prediction Ave K (P < 0.001) (Fig. 2).

In the comparison between patients in whom automated keratometry was performed (47 eyes; 67.1%) and those in whom it could not be performed (23 eyes; 32.9%), the HPS was 28.54% ± 7.06% (10.54%–39.49%) in patients in whom automated keratometry was performed, and 31.97% ± 5.24% (20.56%–41.61%) in patients in whom it could not be performed (P = 0.0361). The difference in absolute value between Prediction Ave K and the postoperative average K value of the anterior surface in patients in whom automated keratometry could be performed was 0.33 ± 0.22 D, with 37 eyes (79%) that had a difference of ≦0.50 D and 10 eyes (21%) that had a difference between 0.51 and 1.00 D. The difference in absolute value in patients in whom automated keratometry could not be performed was 0.29 ± 0.19 D, with 21 eyes (91%) that had a difference of ≦0.50 D and two eyes (9%) that had a difference between 0.51 and 1.00 D. This did not constitute a significant difference (P = 0.1896) (Fig. 3).

Discussion

In this study, we used a multiple regression equation to calculate postoperative predicted K values from preoperative K values (prior to pterygium surgery) and demonstrated its high predictive value.

In this study, the AS-OCT angle recess distance, rather than the anterior eye slit, was used to determine the HPS. This was because the corneal diameter was measured using White to White to determine the size of the implantable collamer lens. However, several recent reports have also used angle recess distance by AS-OCT [9]. The difference between White to White and the angle recess distance is around 0.14 mm; this is considered an acceptable error, even when using the angle recess distance as the corneal diameter. White to White is also considered a simpler method, as clinicians can simultaneously determine the angle recess distance from the AS-OCT horizontal cross-section and the edge of the pterygium.

The independent variables of the multiple regression equation were selected from among variables that had higher correlation coefficients with the postoperative average K value of the anterior surface. Variables that had collinearity were selected from among those with a high single regression coefficient. Tomidokoro et al. [7] formulated a regression equation to compare the HPS with preoperative and postoperative changes in spherical diopter power using TMS-2. However, the correlation coefficient was low (R = 0.598), and the authors report that

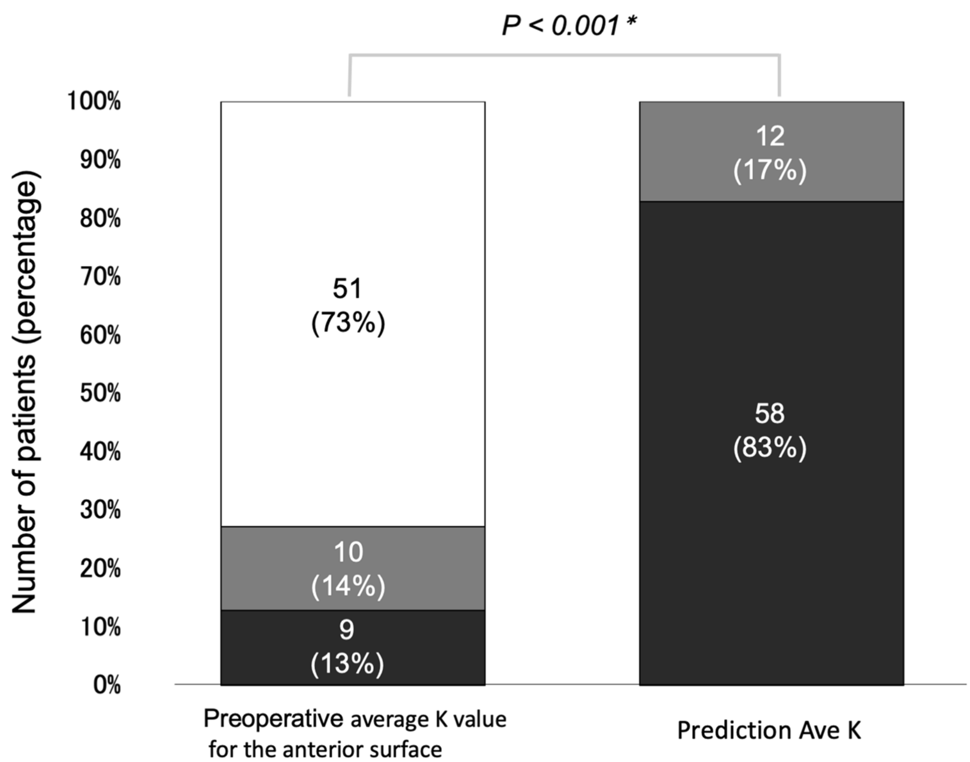

Fig. 2 Difference between postoperative average K value of the anterior surface and preoperative average K value of the anterior surface and postoperative average difference between K value of the anterior surface and Prediction Ave K. ■ ≦0.50 D, ■ 0.51–1.00 D, □ ≧1.01D. * Statistically significant difference. Chi-squared test

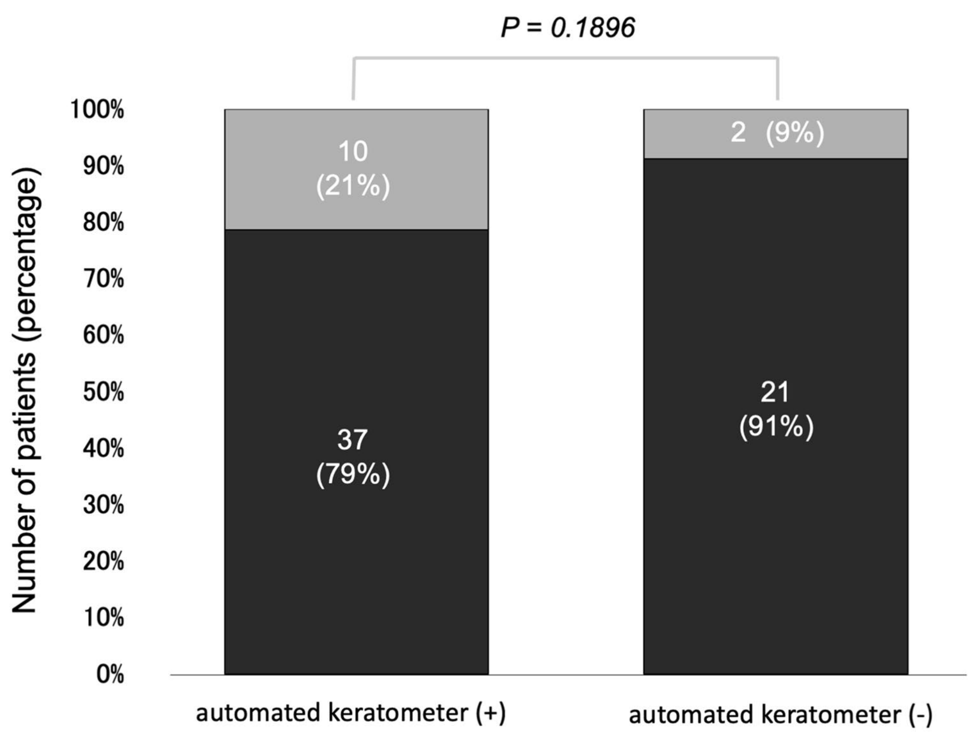

Fig. 3 Difference between postoperative average K of the anterior surface and Prediction Ave K by measurable group and impossible group of automated keratometer. ■ ≦0.50 D, ■ 0.51–1.00 D. * Statistically significant difference. Chi-squared test

postoperative prediction was difficult using the HPS alone, although the HPS was a significant independent variable when considering the effect on changes in cornea shape due to the penetration depth of the pterygium. Ultimately, five independent variables were selected on the basis of collinearity between them: the K values of the central anterior surface, upper anterior surface, and lower anterior surface, the average K value of the posterior surface, and the HPS. The multiple regression equation was then formulated.

Kim et al. [6] formulated a multiple regression equation to predict K values after pterygium surgery, using an automated keratometer. The parameters in their equation were the level of preoperative astigmatism, pterygium length, and vertical and horizontal K values. They performed calculations using separate vertical and horizontal multiple regression equations; they calculated K values as the average of these separate equations. Their method was highly accurate, with a prediction average K value that was within 1.00 D of the actual average K value in 100% of cases; however, this method is only applicable to patients in whom automated keratometry measurements are feasible. Automated keratometry could not be performed for 23/70 (32.9%) of the eyes in our study, with many patients exhibiting high HPS. The results of automated keratometry are not displayed as weak and strong principal meridians, but can only be calculated by the device displaying them horizontally and vertically; this limitation suggests that this method is not universally applicable. In our study, the absolute difference between the postoperative average K value of the anterior surface and the Predicted Ave K was also <1.00 D in 100% of cases. Therefore, if the intraocular lens power is calculated based on the Prediction Ave K of the multiple regression equation for simultaneous pterygium and cataract surgery, then the refractive error will likely fall within 1.00 D. Furthermore, when patients in whom measurements were made using an automated keratometer were compared with those in whom such measurements were not possible, the measurement accuracy was equivalent in both groups, and the results were good in the group in which measurements were not possible. Thus, all patients could be handled using this method, as these calculations were possible in all patients who had AS-OCT only, and the calculations did not depend on the HPS.

In this study, we formulated a multiple regression equation to predict the average postoperative K value from preoperative K values, and confirmed its validity using leave-one-out cross-validation. However, the study was limited in that it was based on a single procedure performed by a single surgeon. It is therefore unclear whether the method used in this study is applicable to other surgical techniques. Finally, the actual refractive error was not investigated in cases involving simultaneous pterygium and cataract surgery, so further studies on simultaneous cataract surgery are required.

Conflicts of interest S. Takahashi, None; S. Manabe, None; N. Ota, None; K. Hayashi, None.

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