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Accuracy of Various Formulas for Intraocular Lens Calculation in Keratoconus Eyes with Prior Intrastromal Corneal Ring Segment Implantation

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Abstract

Aim: To study the performance of different formulas for calculating intraocular lens (IOL) power in patients with keratoconus who previously underwent intracorneal ring segment (ICRS) implantation.

Materials & Methods: Sixteen eyes undergoing phacoemulsification after ICRS implantation were selected. Based on postoperative refractive errors and implanted lens data, the ideal lenses (those that would achieve a result closest to emmetropia) were calculated. This analysis was performed using the Barrett RX calculator available on the APACRS website, targeting emmetropia. Using preoperative biometric data, several formulas were applied to calculate the lens to be used. The magnitude of the error between the calculated lens power (using each formula) and the ideal lens was determined. The following formulas were evaluated: Barrett TK Cone, Barrett Universal II, Haigis, Holladay II, Hoffer QST, SRK-T, SRK II, Holladay I, Hoffer Q, Binkhorst, Kane, Kane KC, and PANACEA.

Results: A total of 16 eyes met the inclusion criteria. Considering the mean absolute prediction error, the formulas achieved the following results (in diopters): Barrett TK 1.1 (SD 1.31); Barrett Universal II 1.46 (SD 1.33); Haigis 1.51 (SD 1.65); Holladay II 2.27 (SD 1.73); Hoffer QST 2.33 (SD 2.30); SRK-T 1.95 (SD 2.50); SRK II 2.00 (SD 2.41); Holladay I 2.05 (SD 2.14); Hoffer Q 2.36 (SD 1.87); Binkhorst 2.19 (SD 1.88); Kane 1.75 (SD 1.85); Kane KC 1.28 (SD 1.60); and PANACEA 1.71 (SD 1.53).

Conclusion: IOL calculation in keratoconus patients previously submitted to ICRS implantation is challenging due to biometric changes that affect power prediction. In this study, the Barrett TK formula (adjusted for keratoconus) showed the lowest mean absolute error and standard deviation, suggesting greater precision for this group of patients. Kane KC and Barrett Universal II also demonstrated satisfactory performance, while Holladay II, Hoffer QST, and SRK II showed higher mean errors and variability.

Clinical Significance: Biometric irregularities in keratoconus eyes after ICRS implantation make IOL calculation complex. The Barrett TK formula (adjusted for keratoconus) provided the most accurate results, representing a valuable option to improve refractive outcomes in this challenging surgical scenario.

Keywords: Keratoconus; Intracorneal Ring Segments; Intraocular Lens Power Calculation; Phacoemulsification.

Introduction

Keratoconus is a disorder in which the cornea assumes a conical shape due to progressive thinning and protrusion. It is typically a bilateral and progressive condition. Although it was considered for many years a non-inflammatory disease, recent studies have investigated the role of inflammatory enzymes in its pathogenesis [1].

The prevalence of keratoconus varies widely depending on the geographic region and diagnostic methods used. With the introduction of more sensitive diagnostic tools and the widespread use of corneal tomography for refractive surgery screening, the condition has been shown to be more common than previously believed. Recent studies suggest a prevalence of approximately 1 in 375 individuals in some populations, compared to earlier estimates of 1 in 2,000 [2].

Keratoconus typically begins at puberty, has a variable rate of progression, and tends to stabilize after the fourth decade of life. It can be classified according to severity—based on keratometry, pachymetry, corneal elevation, and visual acuity—or by morphology (oval, globus, or nipple-shaped). Treatment is centered on two main goals: halting disease progression and restoring vision.

Among the therapeutic options, intracorneal ring segment (ICRS) implantation plays an important role. Intracorneal implants were first conceptualized by Barraquer in the 1950s for refractive surgery. In 1980s and 1990s, Ferrara developed the modern corneal ring, initially intended to correct myopia and astigmatism, and after, it started to be widely used to regularize ectatic corneas [3].

A cornea with keratoconus undergoes surface changes after corneal ring implantation. There is a tendency for a reduction in central curvature and the creation of an area of greater curvature in an annular shape, corresponding to the location where the intrastromal segment was implanted [6]. These changes can be observed in the corneal topography image below:

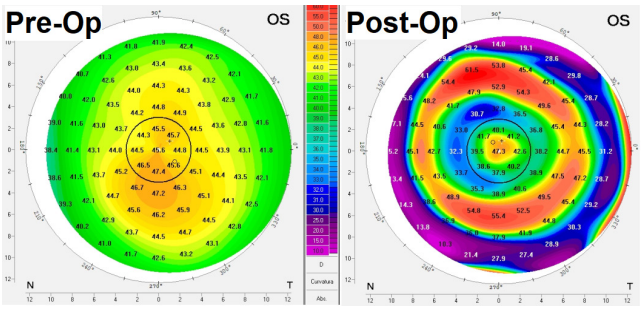

Figure 1: Corneal topography images showing changes in morphology when comparing pre- and post-operative conditions. Implanted ring: Softring (hydrophilic acrylic ring) 300 microns thick.

The corneal changes typically induced by ring implantation can alter the intraocular lens calculations, requiring studies to select which formula is most appropriate/accurate in this situation.

The corneal characteristics is one of the most important data for the IOL calculations. Changes in corneal curvature can alter the determination of the ELP (effective lens position) and alter the intraocular lens selection. Thus, for biometric calculations, eyes that have undergone ICRS implantation should be studied separately due to their very peculiar characteristics. It is possible that formulas that show the best performance in IOL calculations in patients with keratoconus may not maintain the same performance in keratoconus patients who have undergone ICRS implantation. Therefore, calculating the power of the intraocular lens (IOL) after ring surgery remains a huge challenge.

Materials and Methods

A multicenter retrospective analysis was performed to evaluate refractive errors in eyes with implanted corneal rings that underwent phacoemulsification surgery with IOL implantation. Taking into account the postoperative refractive error and the diopter of the implanted IOL, it is possible to calculate what the ideal lens would have been to achieve emmetropia (for this, the Barrett RX formula was used).

Using preoperative data, several biometric calculation formulas were tested to analyze which one would suggest the diopter that most closely approximated the refractive power of the ideal lens.

The inclusion criteria were eyes that underwent implantation of spherical monofocal IOLs and that had previously undergone intracorneal ring implantation (ICRS). The data for the lens calculation should have been obtained through optical biometry.

The exclusion criteria were: eyes that received IOLs other than spherical monofocal lenses, eyes without prior ICRS implantation, eyes with insufficient biometric data for Barrett RX calculation, or eyes with biometric parameters that prevented IOL power calculation.

A total of 17 eyes from eligible patients were initially evaluated. One eye was excluded due to extremely high corneal curvature, which prevented calculation using the Barrett RX calculator, leaving 16 eyes included in the final analysis.

Preoperative biometric measurements, including keratometry, axial length, and anterior chamber depth, were recorded for each eye. The IOL Master was used in 15 eyes and the AL-Scan (NIDEK biometer) in 1 eye. Postoperative keratometry was assumed to be equal to preoperative values (induced astigmatism was not considered in the calculations).

The "IDEAL IOL POWER" for each eye was determined using the Barrett RX calculator available on the APACRS website, aiming for emmetropia (0 diopters).

Using each patient's preoperative information, the "CALCULATED IOL POWER" was then predicted using the following formulas: Barrett TK (adjusted for keratoconus), Barrett Universal II, Haigis, Holladay II, Hoffer QST, SRK-T, SRK II, Holladay I, Hoffer Q, Binkhorst, Kane, and Kane KC.

The "ABSOLUTE PREDICTION ERROR" was obtained by the difference between the "IDEAL IOL POWER" and the "CALCULATED IOL POWER" for each formula (for this analysis, it was not considered whether the error found had a positive or negative sign). The formulas that presented the lowest mean absolute error and the lowest standard deviation were considered the most accurate for this specific patient population. Standard statistical analyses were applied, including the calculation of the mean, standard deviation, and comparative evaluation of errors between the formulas.

Results

The mean age of the included patients was 60 ± 9 years. Biometric measurements revealed a mean axial length (AL) of 24.22 ± 1.04 mm, a mean anterior chamber depth (ACD) of 3.30 ± 0.34 mm, and a mean keratometry (K) of 46.96 ± 4.63 D.

Based on postoperative refractive results, nine eyes became myopic (nearsighted) after cataract surgery, while seven became hyperopic (farsighted). The mean postoperative spherical equivalent (SE) considering the sign (hyperopic or myopic) was −0.30 ± 1.28 D, whereas the mean absolute spherical equivalent, regardless of sign, was 1.0 ± 0.72 D.

The mean absolute prediction error (MAE) and standard deviation (SD) for each intraocular lens (IOL) power calculation formula are summarized below:

The lowest mean prediction errors were obtained with the Barrett TK Cone (1.10 ± 1.31 D), Kane KC (1.28 ± 1.60 D), and Barrett Universal II (1.46 ± 1.33 D) formulas, indicating the best overall accuracy among the methods evaluated. Intermediate results were observed with the Haigis (1.51 ± 1.65 D), PANACEA (1.71 ± 1.53 D), Kane (1.75 ± 1.85 D), SRK/T (1.95 ± 2.50 D), SRK-II (2.00 ± 2.41 D), Holladay I (2.05 ± 2.14 D), and Binkhorst (2.19 ± 1.88 D) formulas. The highest mean errors were found with Holladay II (2.27 ± 1.73 D), Hoffer QST (2.33 ± 2.30 D), and Hoffer Q (2.36 ± 1.87 D).

FORMULA	MEAN ABSOLUTE PREDICTION ERROR (MAE)	STANDARD DEVIATION (SD)
Barrett TK Cone	1.10 D	± 1.31 D
Kane KC	1.28 D	± 1.60 D
Barrett Universal II	1.46 D	± 1.33 D
Haigis	1.51 D	± 1.65 D
Panacea	1.71 D	± 1.53 D
Kane	1.75 D	± 1.85 D
SRK/T	1.95 D	± 2.50 D
SRK-II	2.00 D	± 2.41 D
Holladay I	2.05 D	± 2.14 D
Binkhorst	2.19 D	± 1.88 D
Holladay II	2.27 D	± 1.73 D
Hoffer QST	2.33 D	± 2.30 D
Hoffer Q	2.36 D	± 1.87 D

TABLE 1: For each formula: mean magnitude of the error obtained between the calculated lens and the ideal lens.

When analyzing the refractive tendency of each formula, positive prediction errors were interpreted as hyperopic outcomes and negative values as myopic. The smallest hyperopic shifts were found with the Kane KC (+0.22 D) and Barrett TK Cone (+0.45 D) formulas, while moderate hyperopic tendencies were observed with Barrett Universal II (+1.19 D), Haigis (+1.10 D), Kane (+1.44 D), SRK/T (+1.14 D), Holladay I (+1.75 D), and Binkhorst (+2.02 D). The greatest hyperopic deviations occurred with Holladay II (+2.20 D), Hoffer QST (+2.19 D), and Hoffer Q (+2.27 D). Only the SRK-II formula demonstrated a slight myopic bias (−0.43 D).

Among the formulas evaluated, variations were observed in both the magnitude of the refractive prediction error and the tendency toward hyperopic or myopic outcomes. These data summarize the demographic, biometric, and refractive characteristics of the included eyes, as well as the performance of each IOL calculation formula, providing a foundation for the comparative analysis.

Discussion

The use of currently available and widely used formulas for intraocular lens (IOL) calculation in eyes with regular corneas is highly reproducible, with up to 80–90% of cases achieving a final spherical equivalent within ±0.50 D[4]. However, in eyes with keratoconus, the proportion of cases achieving a final spherical equivalent within ±0.50 D decreases to approximately 40–50%[4]. Calculating IOL power in patients with keratoconus undergoing cataract surgery remains challenging due to several factors. Among the variables that influence the final dioptric value of the lens are the keratometric index, which assumes a normal relationship between the anterior and posterior corneal surfaces—often not observed in keratoconic eyes—and the irregularity of corneal curvature across different meridians[4].

Another key factor is that most formulas estimate the effective lens position based on models of normal eyes. In ectatic eyes, the relationships between corneal curvature, axial length, and anterior chamber depth differ, limiting formula reproducibility. Irregularities of the tear film, more frequent in keratoconus, may also act as confounding factors[4].

Postoperative refractive errors in keratoconic eyes are common, with a predominance of hyperopic outcomes in many series[4]. In eyes with intracorneal ring segment implantation, which aims to regularize the corneal surface and consequently influences variables such as the keratometric index and anterior chamber depth, the pattern of residual refractive error appears different. In the present study, nine eyes showed myopic outcomes and seven eyes hyperopic outcomes, indicating a slight predominance of myopia, which contrasts with the hyperopic tendency typically observed in keratoconic eyes without ring segments.

Among the formulas evaluated, Barrett TK Cone demonstrated the lowest mean absolute error, followed by Kane KC and Barrett Universal II, while formulas such as Holladay II, Hoffer Q, and SRK II showed higher errors[5]. The results highlight that formulas specifically adjusted for keratoconus, like Kane KC and Barrett TK Cone, provide more reliable refractive outcomes in eyes previously submitted to intracorneal ring segment implantation[5].

Despite providing new insights, the study has some limitations, including the small sample size, the lack of stratification according to keratoconus severity, and the use of postoperative keratometry values assumed equal to preoperative measurements. Moreover, variability in biometric data acquisition across centers could influence IOL calculation.

The motivation for this study was the suspicion that the most suitable formulas for use in patients with keratoconus might not be the best for use in eyes after corneal ring implantation. However, this suspicion was not confirmed. This study showed that the best formulas used for calculations in patients with keratoconus (without any surgery) continued to perform optimally, even after ring implantation surgery.

Conclusion

In summary, this study demonstrates that in keratoconic eyes previously treated with intracorneal ring segments, the choice of IOL calculation formula significantly impacts refractive outcomes. Formulas such as Barrett TK Cone and Kane KC appear to offer superior predictive accuracy, supporting their use in this specific patient population and achieving the study objective of identifying the most effective formulas for IOL calculation in this challenging scenario.

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