66 IOL Power Calculation in Keratoconus

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Keratoconus is a progressive disorder characterised by central or paracentral corneal thinning and ectasia. The changes in the keratoconic cornea affect multiple aspects of IOL power calculation and keratoconus remains one of the last major challenges existing in IOL power calculation. There are several factors which, when combined, lead to inaccurate results including the following:

1. **Corneal Power Measurement Issues**

   The keratometry value that is displayed on biometry devices is based on an assumed ratio of the anterior to the posterior cornea. For most eyes, this anterior-to-posterior ratio remains reasonably accurate; however, in keratoconus, this is not the case. The change in shape of the cornea means that the assumed ratio is incorrect which leads to an incorrect keratometry value as "measured" by corneal biometry.

   Additionally, biometry devices have difficulty in producing repeatable measurements of keratoconic corneas which worsens with the degree of keratoconus [1].

2. **IOL Formula Calculation Errors**

   The error in the keratometry values in keratoconus patients is propagated in two ways in the majority of IOL formulas. Most formulas use keratometry values as one of the factors in predicting the effective lens position (ELP), and hence, any error in keratometry leads to an error in the ELP. Given the importance of ELP to IOL power calculation, this leads to significant errors.

   Additionally, the keratometry error is also included in the vergence/thick lens equation, so even if the ELP is calculated entirely independently of the keratometry value, the remainder of the equation will still require use of the erroneous keratometry, thus leading to errors in IOL power calculation.

3. **Difficulty in Refraction**

   Keratoconus patients are notoriously difficult to refract with a study showing a 6× higher difference in test-retest refractions in keratoconus patients compared to normal myopes [2]. This difficulty in refraction makes it difficult to create keratoconus specific adjustments for IOL formulas as the target is not as well defined as in other difficult-to-predict conditions such as post-LASIK.

4. **Other Issues**

   Other issues which contribute to the lack of understanding on IOL power calculation in keratoconus include small sample sizes of published studies and difficulty defining which patients have true keratoconus rather than form fruste keratoconus.

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Approaches to IOL Power Calculation in Keratoconus

The significant barriers to accuracy in keratoconus patients, poor understanding on how to conduct IOL power studies, and small patient sample sizes have limited the refractive outcomes in keratoconus patients.

Keratoconus leads to a hyperopic prediction error which has been well established in studies by Watson et al. [3] and Hashemi et al. [1] However, these early studies into IOL power calculation often had significant issues such as measuring with a mixture of optical biometry, contact ultrasound, and immersion ultrasound or calculating the prediction error using target refraction rather than the predicted refraction for each formula. Although the issues with keratoconus patients were somewhat understood, the evidence available to guide decision making was lacking—the general consensus being to use the SRK II or SRK/T [4] and to use standard keratometry values if the average corneal power became too excessive [3]. The introduction of clear guidelines and detailed instruction on how to properly conduct an IOL power study [5] as well as the widened availability of optical biometry and increased availability of larger datasets from electronic medical record systems has allowed researchers to significantly improve our understanding of keratoconus patients including which IOL power formula is the most accurate in these patients.

The first paper in keratoconus patients to follow the correct guidelines on IOL power calculation studies was done by Savini et al. in JCRS [6]. They used optical biometry in 41 eyes of 41 patients and demonstrated that the SRK/T formula was the most accurate of all formulas and that there was no additional benefit of using the Barrett Universal 2 formula in keratoconus patients. The study additionally splits patients into the Krumeich classification based on average keratometry (stage 1: less than or equal to 48.0 dioptres [D]; stage 2: 48.01–53.0 D, and stage 3: greater than 53 D). This split was used in early studies [3] and has continued to be used in the largest keratoconus IOL power studies. Savini demonstrated that the amount of hyperopic error worsened with the stage of keratoconus (+0.44 D in stage 1 up to +3.01 D in stage 3 for the SRK/T formula) and that the accuracy of IOL power calculation worsened with an increasing stage of keratoconus (the SRK/T having 61.9% within 0.50 D in stage 1, 30.8% in stage 2, and 14.3% in stage 3, whereas the Barrett had 42.9% in stage 1, 15% in stage 2, and 0% in stage 3).

Another recent paper by Wang et al. [7] in the AJO in 73 eyes of 73 patients confirmed these initial results found by Savini. The hyperopic errors worsened with the stage of keratoconus (+0.12 for stage 1 to +2.51 for stage 3 when using the SRK/T formula). They used the same classification system as Savini; however, in stage 1 and 2 patients, they found that the Barrett was more accurate than the SRK/T. In stage 3 patients, they were unable to calculate many patients using the Barrett as the keratometry values exceeded the limits of the online calculator. The SRK/T was more accurate than the other formulas studied. Again, the accuracy of the formulas worsened with increasing keratoconus (48% within 0.50 D in stage 1; 18% in stage 2; and 0% in stage 3 for the SRK/T formula).

New Methods for IOL Power Calculation in Keratoconus

Although the issues with IOL power calculation in keratoconus have been known for a long time, only very recently specific adjustments to IOL formulas have been made to improve results. This is a significant contrast to post-refractive IOL formulas of which there are numerous.

The Kane keratoconus formula utilises modified anterior corneal radii of curvature that better represents the true anterior/posterior ratio in keratoconic eyes while also minimising the effect of corneal power on the ELP calculation. It works using standard IOLMaster biometry and requires only the variables used in the standard Kane formula (AL, K, ACD and patient gender with optional variables LT and CCT). The Kane keratoconus formula is designed to be used with the same IOL constant, given the impossibility of a surgeon obtaining a large enough sample of post-operative eyes with keratoconus for a specific IOL to perform optimisation.

This formula was first presented at the 15th IPC meeting in Napa with an article in *Ophthalmology* in 2020 [8]. This article described the largest cohort of keratoconus patients with 146 eyes of 146 patients who all had IOLMaster biometry. This study confirmed the findings of Savini et al. [6] and Wang et al. [7] with hyperopic refractive errors that worsened with the stage of keratoconus for the conventional formulas. The paper demonstrated the similar performance of the SRK/T and the Barrett Universal 2 in keratoconus patients with no significant difference found between the SRK/T and the Barrett in this patient population. The study found that the SRK/T (but not the Barrett) was better than all other conventional formulas studied. The Kane keratoconus formula had the best results achieving 8.3% more patients within 0.50 than the SRK/T and 7.1% more within 0.50 D than the Barrett in stage 1 eyes. In stage 2, it demonstrated as additional 5.4% for Barrett and 13.5% for SRK/T within 0.50 D. In stage 3 eyes, it achieved 20% more within 0.50 D compared with the Barrett and 12% more than the SRK/T. In stage 3, it had 32% more within 1.00 D compared with the Barrett and 28% more than the SRK/T. The study demonstrated a slight hyperopic refractive surprise in stage 2 patients +0.53 D but no significant hyperopic refractive surprise in stage 3 patients (+0.02 D for the Kane keratoconus formula compared with +1.72 D for Barrett and +1.86 D for the SRK/T) (Fig. 66.1).

The Barrett True K formula for keratoconus was first published in 2021. The formula incorporates the posterior corneal power and central corneal thickness to improve post-operative prediction in keratoconus. The formula uses the posterior corneal astigmatism either predicted or measured if available. There is only one study on the accuracy of the formula by Ton and Barrett et al. [9] in JCRS which used 32 eyes of 23 patients. The Barrett True-K formula for keratoconus was created based on some of the cases that were used in this study which makes it difficult to accurately assess the results of the study for the Barrett True-K formula for keratoconus. As expected, the study demonstrated good results with Barrett True K formula for keratoconus with 96.9% of patients within 1.00 D with the predicted PCA. The Barrett True-K formula for keratoconus with measured PCA and Kane

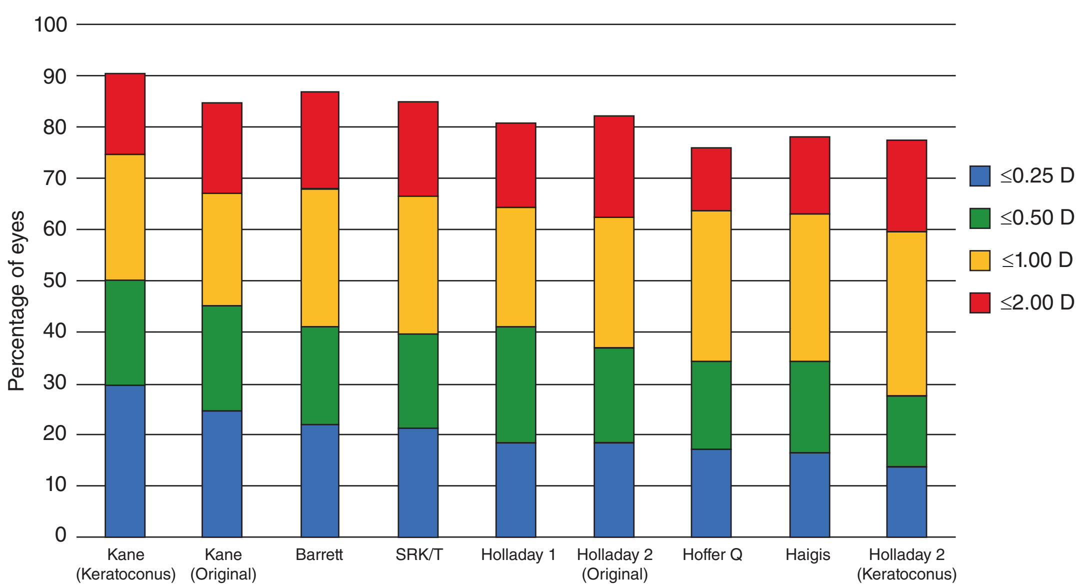

Fig. 66.1 Stacked histograms comparing the percentage of cases within a given diopter range of predicted spherical equivalent refraction outcome for the entire data set (adapted from Kane et al. [8] with permission)

keratoconus formula has the same number of eyes within 1.00 D (90.6%). The number of patients in the study was inadequate to allow subgroup analysis. Excluding the Barrett True-K formula (which was created using some of the patients in the study), the Kane keratoconus formula had the lowest standard deviation, lowest MAE, and the mean error closest to zero confirming the findings of the largest keratoconus IOL power study. The study included eight eyes with an average keratometry reading over 48 D. Comparing the Kane versus the Kane keratoconus formula in these eyes showed a reduction in the mean absolute error from 1.54 for the original Kane formula to 0.54 D for the Kane keratoconus formula as well as change from a high hyperopic prediction error +1.11 D to a low myopic prediction error −0.15 D.

Conclusion

After many years of little progress in IOL power calculation in keratoconus, attention in this important field has now increased. For surgeons aiming to select a target refraction for their keratoconus patient, Table 66.1 can give guidance on the appropriate refractive aim for the three most accurate IOL formulas for keratoconus patients to reduce the risk of an undesirable hyperopic refractive outcome. A myopic refractive outcome is preferred especially if the patient will require a contact lens as a myopic lens has greater flexibility in terms of vault and lens diameter compared with hyperopic lenses. The Kane keratoconus formula should be used in keratoconus patients with either the Barrett or SRK/T formulas being the next most accurate. There is currently not enough available evidence to recommend the Barrett True-K formula for keratoconus. The management of patient expectation should be central to the informed consent of these patients and reasonable figures to discuss with patients (when using the Kane keratoconus formula) are: 60% within 0.50 D if the average keratometry is <48 dioptres; 40% if the average keratometry is 48–53; and 25% if the average keratometry is >53 D.

Table 66.1 Refractive aim based on average keratometry to avoid hyperopic refractive surprise for the 3 most accurate IOL formulas in keratoconus

	≤48 D	48–53 D	53–59 D	>59 D
Kane keratoconus formula	Plano	−0.50 DS	−1.00 DS	−1.50 to 2.00 DS
Barrett	−0.50 DS	−1.00 DS	−2.50 DS	−3.00 to 4.00 DS
SRK/T	−0.50 DS	−1.00 DS	−2.50 DS	−3.00 to 4.00 DS

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