



Review

# Intraocular lens power calculation in keratoconus; A review of literature

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## Abstract

**Purpose:** To review the published literature regarding cataract surgery in keratoconus (KCN) patients with emphasis on challenges encountered during intraocular lens (IOL) power calculation and their solutions.

**Methods:** A literature review was performed to investigate all the relevant articles on the advancements of IOL calculations in KCN patients.

**Results:** Cataract surgery in keratoconic eyes can improve patients' refraction, and proper patient selection and IOL calculation methods are necessary to get the best results. The main problem in KCN patients is unreliable biometric measurements. It is more difficult to make conclusions in more advanced keratoconic corneas, as the steep keratometric values in these eyes will result in the selection of a low-power IOL. Presence of a low-power IOL will yield in extreme postoperative hyperopia, and IOL exchange might be mandatory. In cases in which keratoplasty may be needed in the future, contact lens fitting can help surgeons make a better decision preoperatively. Axial length (AL) measurements may have better repeatability and reproducibility than keratometry (K) readings in keratoconic eyes. SRK II formula may provide the most accurate IOL power in mild KCN. There is still not a comprehensive consensus of which formula is the best one in moderate and severe KCN, as the literature is limited in this subject.

**Conclusions:** Various methods of IOL power calculation optimization and recommendations may hold the key to improve surgical outcomes in keratoconic eyes. There are multiple sources of biometric error in KCN patients, hence IOL calculation methods may not be as efficient as expected in these eyes.

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**Keywords:** Intraocular lens power; Cataract; Keratoconus; Keratoconic; Corneal ectasia

## Introduction

Keratoconus (KCN) is bilateral corneal ectasia characterized by progressive thinning and conical protrusion of the cornea.<sup>1</sup> Its classic histopathological features are epithelial basement membrane deposition, stromal thinning, and defects in Bowman's layer.<sup>2,3</sup> KCN may lead to visual impairment due to multiple consequences like irregular astigmatism, high myopia, and cataract.<sup>4</sup>

There are still ongoing debates on staging of KCN. A method of KCN staging has been reported by Amsler-Krumeich, and it was an acceptable classification method for many authors worldwide; however, it did not include tomographic and biomechanical indices.<sup>5</sup> Thebpatiphat classification of KCN severity which has been cited in literature frequently<sup>6</sup> is mild [maximum keratometry less than 48.00 diopter (D)], moderate (maximum keratometry equal to or more than 48.00 D but less than 52.00 D), and severe (maximum keratometry equal to or more than 52.00 D).

Visual correction in mild cases can be achieved by using glasses or rigid gas permeable (RGP) contact lenses as corneal distortion progresses. In correction of visual impairment of moderate to severe KCN, contact lenses remain as the mainstay of treatment. Also besides the RGP lenses, several surgical

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techniques such as intracorneal ring segment (ICRS) implantation,<sup>7–9</sup> toric phakic intraocular lens (toric PIOL),<sup>10–17</sup> refractive lens exchange (RLE), and different combinations of these procedures are introduced for visual rehabilitation.<sup>18–21</sup>

However, in progressive KCN, two management dilemmas arise: halting the progression of disease and improving visual function. Corneal collagen cross-linking (CXL) is an established treatment available to retard or at least slow KCN progression.<sup>18</sup>

At the very end-stages, corneal graft becomes inevitable, which for KCN patients means possibility of repeated operations due to failure or even rejection of transplanted cornea. At least 10% of KCN patients may require some kind of corneal graft.<sup>5</sup> Hypothetically, keratocyte progenitor stem cells have shown a bright future for rehabilitation of the cornea.<sup>20</sup>

A proportion of KCN patients will develop cataract, even in younger ages than the normal population. They are more prone to cataract than the general population due to association with atopy and use of some medications.<sup>6</sup> Nuclear sclerosis cataract is the most common variant.<sup>22,23</sup> Therefore, as KCN patients get older, cataract becomes a more probable etiology for their low vision.

Despite the fact that any surgical intervention in eyes with KCN may increase the risk of irreversible and progressive corneal ectasia, cataract surgery in severe cases could not be delayed. In some patients, there is a necessity to do a simultaneous cataract surgery and corneal transplantation.<sup>24</sup> This concomitancy of cataract and KCN provides an extra challenge for the anterior segment surgeon regarding IOL power calculation, keratometry (K) readings, and its interpretation, determining the accurate astigmatism axis, axial length (AL) measurement, and other intraoperative and postoperative dilemmas.<sup>25</sup>

Before performing any surgical operations on eyes with established KCN, stability of disease and its stage should be considered. Performing minimally invasive one-step surgical operation is ideal in KCN cases. To improve surgical and refractive outcomes, contact lenses, ICRS, CXL, and lamellar or penetrating keratoplasty (PKP) can all be utilized in cataract surgery based on the stage of disease.<sup>22</sup> Therefore, appropriate patient selection and comprehensive preoperative evaluation of corneal stability is of great importance for assessing patients with concomitant cataract and KCN.<sup>24,26</sup>

In this paper, we aimed to review the current published literature regarding cataract surgery in KCN patients with an emphasis on challenges encountered during IOL power calculation and solutions the authors found worldwide. This review focused on papers concerning use of monofocal, non-premium IOL in cataract surgery. The routine processes of IOL power calculation, their findings, and outcomes are summarized in this review to help ophthalmologists manage patients with concomitant KCN and cataract efficiently.

## Methods

A comprehensive search of databases on PubMed, Scopus (Elsevier's abstract and citation database), and Google Scholar

was done for the purpose of writing this review. Key words were as follows: keratoconus, keratoconic, astigmatism, toric, lens, intraocular lens, IOL, calculation formula, calculation method, cataract surgery, phacoemulsification, Pentacam, Lenstar, and Orbscan. All articles were retrieved using the MeSH (Medical Subject Headings) terms in PubMed and also from Google Scholar and Web of Science databases. Restrictions on sex, age, and language or journal type were not applied. More emphasis was put on articles published from 2000 until the date of search (December 2018), but previous studies were also reviewed and included if they met the inclusion criteria. Inclusion criteria were consideration of KCN as the subject of calculation error, undergoing cataract surgery in such patients, and having artificial lens implanted with measurement devices and formulas mentioned. Exclusion criteria were study of disease in non-human subjects and not clarification of IOL power calculation method. A total of 646 articles were gathered from the search engines initially. The abstracts were reviewed for consideration of inclusion in the study by two of the authors (N.A. and N.M.) and then reviewed finally by other authors (L.G. and A.H.). After initial analysis, 123 articles were included in the study, out of which 54 had the most relevant information for the purposes of this review.

## Results

### *Considerations in intraocular lens calculation methods for cataract surgery*

IOL power calculation in KCN patients has shown to be complex, unpredictable and the most challenging part of preoperative considerations. Like other patients undergoing cataract surgery, for determining an accurate IOL power, it is imperative to precisely determine K and AL readings regardless of which calculation formula is used.

Due to multiple sources of biometric error in KCN patients, like high and irregular astigmatism, accurate K and AL readings may be uncertain or, in some cases, impossible.<sup>22</sup> Therefore, IOL calculation methods in KCN patients may not be as efficient as in non-KCN eyes.<sup>23</sup>

### *Keratometry reading*

All standard IOL calculation formulas are grounded on keratometric values basically. In K readings, both anterior and posterior corneal curvatures should be considered. Accurate measurement of the mean K is essential for correct determination of IOL power, although to determine the progression of disease or the effect of treatment after any surgery; therefore periodic paraclinical examinations are necessary for KCN patients.<sup>27</sup> Selection of a paraclinical device with an acceptable measurement repeatability is crucial for efficient follow-up of KCN patients.

Manual and automated keratometry (e.g. Placido disk-based corneal topography) are very common methods worldwide, but they can only examine the anterior surface of cornea and

therefore cannot measure posterior surface curvature. Hence, newer technologies including optical coherence tomography (OCT) and rotating Scheimpflug devices were developed to measure the posterior corneal curvature in clinical practice.<sup>28–30</sup>

The advantage of elevation-based topography devices, the most common of which are Pentacam (Oculus GmbH, Wetzlar, Germany) and Galilei (Ziemer Ophthalmic Systems Port, Switzerland), is that they analyze both the anterior and posterior corneal curvatures and calculate the total corneal power (TCP) without assumptions.<sup>31</sup> This advantage is also reported to be important in IOL power calculation for rare posterior KCN cases undergoing cataract surgery.<sup>32,33</sup> There are valuable maps generated from such devices like the true net power (TNP) map, TCP map, and equivalent K-readings (EKR). TNP maps measure the refractive power of the anterior and posterior cornea to estimate the corneal power within a specific corneal area. This helps better selection of K values needed for IOL power calculation. Therefore, to predict the appropriate IOL power, TNP extracted from the Orbscan II (scanning-slit corneal topographer, Bausch and Lomb, Rochester, NY) or the Pentacam may be extremely helpful.<sup>33</sup> EKR values are based on elevation topography maps. These values focus on the center of cornea and balance corneal curvature irregularities to correct keratometric values by an equation using the anterior and posterior corneal powers.<sup>34</sup>

The general rule in topography systems and automated or manual keratometry methods is to use a corneal refraction index of 1.3375, although this may not be always true in eyes with certain conditions like KCN or eyes that have had laser refractive surgery.<sup>22,33</sup>

The visual axis of keratoconic eyes might not pass through the steepest part of the cornea, and hence K readings could be less precise, especially if corneal surface is distorted. As the radius of curvature reduces, the effect of K error increases. Also, the irregularity of tear film reflex makes it difficult to identify reliable and repeatable K values.<sup>2</sup> Automated keratometry has a better repeatability than the manual ones, but we may still encounter the same problems as in manual keratometry. In comparison to keratometers, more points are measured on the anterior corneal surface by topography systems. However, simulated K values (Sim K) measured with such devices at the 3 mm central zone of cornea could be inaccurate in KCN patients because of corneal irregularity.<sup>2</sup>

In clinical practice for detection of K based on manifest refraction, a method similar to Jackson cross cylinder method can be used, which helps to choose the optimal power of the cylinder. The difference between the two keratometric values should ideally match the value of the manifest cylinder. In this method, usually the mean objective astigmatism value based on measured K [subtracting flat curvature (K2) from steep curvature (K1)] is reduced to more subjective values. Although such method lacks reproducibility, it could be considered in KCN patients with cataract in which precise manifest refraction may not be feasible.<sup>34</sup>

Hashemi et al.<sup>27</sup> examined the repeatability of 5 devices based on 5 different measurement techniques including Pentacam, EyeSys (placido topographer, EyeSys vision, Houston,

Texas, USA), Orbscan, IOL Master (Carl Zeiss Meditec AG, Jena, Germany), and Javal manual keratometer to measure the corneal power in 45 KCN patients. In summary, their study found that in KCN cases with a maximum K of 55.00 D or less, Pentacam had better repeatability and the Javal manual keratometer was the next more reliable device. However, when the maximum K was greater than 55.00 D (advanced KCN) all imaging systems mentioned above, showed weak repeatability. The authors concluded that such findings stemmed from measurement error and unreliable K readings.

In 2012, Nidek introduced a new biometry device combining optical interference and Scheimpflug principle (AL-Scan, Nidek Co., Ltd.) for performing ocular measurements. The device optically measures eye parameters such as the central corneal thickness (CCT), anterior chamber depth (ACD), and AL. In a study by Yagci et al.,<sup>35</sup> the repeatability of the flat K and steep K values measured by AL-scan was high in both normal and keratoconic eyes. However, the steep K had less reproducibility in keratoconic eyes, a finding consistent with Hashemi et al.'s study.<sup>27</sup>

Watson et al.<sup>2</sup> found that biometry in keratoconic eyes usually underestimates the IOL power and overestimates the corneal power, hence inclination to a postoperative hyperopia. In their mild and moderate KCN cases, when actual K readings were used for IOL power calculation, 60.00% and 41.90% of the eyes had a postoperative refraction within 1.00 D of the target spherical equivalent, respectively. In severe KCN, actual K values resulted in a less predictable refractive outcomes in comparison to standard K (43.25 D) value.<sup>2</sup> Due to high keratometric values measured and also low-power or even negative-power IOLs implanted in the eye, postoperative hyperopia could be the result of surgery in advanced KCN cases and surprise both patient and surgeon. Hence, Watson et al. suggested considering using standard K (43.25 D) for severe KCN group and actual K for mild and moderate KCN subjects.<sup>2</sup>

It is important to consider that in severe cases with a possible need for keratoplasty in the future, low-power IOL implantation during cataract surgery leads to extreme post-keratoplasty hyperopia and hence making IOL exchange mandatory. In contrast to cataract surgery alone, all parameters which have a role in IOL power determination may alter following the keratoplasty procedure, therefore increasing the risk of unanticipated refractive errors.<sup>36</sup>

Thebpatiphat et al.<sup>23</sup> analyzed the results of cataract surgery in 12 eyes with KCN. They reported no advantage of topography-derived K over standard K in mild cases and showed a myopic error in advanced cases.

Zvornicanin et al. published their report of a KCN patient undergoing cataract surgery with toric IOL and found that the manual keratometry gives the most precise results in corneal astigmatism evaluation in comparison to IOL Master, Pentacam, and autokeratometer.<sup>2,24</sup>

#### *Axial length*

Axial elongation has been shown to contribute to myopia in KCN patients. Therefore, in KCN, a precise biometric

calculation of AL is important for IOL power calculation and achieving desired refractive outcomes and patient satisfaction after cataract surgery.<sup>35,37,38</sup>

Alio et al.<sup>4</sup> found stronger correlation of final spherical equivalent with AL than the preoperative K readings in KCN patients. This finding may suggest an even greater influence of AL readings in postoperative refractive results.

The decentered apex of a cornea in KCN makes visual axis estimation uncertain and challenging. Since manifest visual axis should be perfectly aligned for IOL calculation, optical measurements are often superior to other methods due to better patient's fixation.<sup>22</sup> Yagci et al.<sup>35</sup> evaluated repeatability and reproducibility of AL-scan, in normal and keratoconic eyes in their study in 2013. They found that both repeatability and reproducibility of AL measurements in keratoconic eyes were high and comparable to similar assessments in normal eyes.

#### *Intraocular lens power calculation formulas*

IOL calculation formulas are based on keratometric values; therefore, correct measurement of mean K is very important for such purpose. Most common calculation formulas have been developed either on normal population data or on normal eye optics.<sup>6</sup> Therefore, in KCN patients such formulas cannot be considered as reliable as expected. Hoffer Q, Holladay I, and SRK/T formulas indirectly determine the effective lens position (ELP). Hence in eyes with longer AL and a steep K measurement which a deeper anterior chamber is expected, IOL is considered to have a more posterior ELP. Such a posterior IOL position could result in a hyperopic shift after surgery if we use abovementioned formulas.

The 4<sup>th</sup> generation formulas are theoretically considered an improvement over the previous formulas in order to calculate IOL power in all eyes but especially in abnormal ones. Holladay II, Haigis, Olsen, and Barrett are examples of this generation.<sup>39,40</sup> An increased number of variables in these formulas could help to improve the ELP calculation. Holladay II formula created by Jack Holladay, adjusts the recommended IOL power more by including factors like AL, corneal power, white to white (WTW), ACD, lens thickness, age, and preoperative refraction data. Although it remains theoretical, it has a strong base of 3500 patients in 35 study centers. It tends to be more precise in eyes with extreme findings, and it may also prove to be more accurate in variable ELP cases.<sup>22</sup> The Haigis formula requires the measured ACD value, and the Barrett formula needs lens thickness and WTW measurement. There are publications that suggest Holladay II formula to be more accurate than other formulas when ELP is variable.<sup>22</sup> Newer generation formulas like Barrett Universal II and the radial basis function (RBF) calculator are promising, but larger studies in ectatic corneas are still needed.<sup>41</sup>

In mild KCN, SRK II formula may provide IOL power more accurately than other formulas, suggested in a retrospective study by Thebpatiphat et al.<sup>23</sup> It is generally accepted that SRK/T formula gives more accurate results in myopic eyes in comparison to SRK II; this concept is

important because KCN and myopia are often linked together.<sup>22</sup> Similarly, in a limited case series published by Zare Mehrjerdi et al.,<sup>6</sup> SRK II was found to be the most reliable and ideal formula for IOL power calculation in patients with various stages of KCN irrespective of AL classification. The SRK II formula showed the most reliable outcomes in all stages of KCN in their study, although the reliability was less in severe stages of KCN.<sup>6</sup> In another study by Hashemi et al., the lowest refractive error was obtained with corneal topography-derived keratometry, manual keratometry, and the SRK/T formula in patients with mild KCN.<sup>22,42,43</sup> That study concluded that least error in IOL power calculation in non-progressive KCN is detected by using K derived from the 3 mm central zone in axial map of corneal topography and use of SRK/T formula.<sup>42</sup> Then the best formula suggested in a study conducted by Hashemi et al. differs from those by Thebpatiphat et al. and Zare Mehrjerdi et al., as mentioned above.<sup>23</sup> According to less accuracy of IOL calculation in moderate and severe KCN, there is no consensus about which formula is the best. Indeed, none of the formulas offer good predictability in advanced KCN. A recent report from Ophthalmology Times in 2015 suggests simple ways to find appropriate formulas in IOL power calculation for eyes with KCN. First, if corneal power is less than 47.00 D, surgeons could consider using the Holladay II formula with the double-K adjustment or the Hoffer Q if that adjustment is not available. In these cases, a target postoperative refraction of  $-1.00$  D could be considered. Second, for eyes with a corneal power between 47.00 and 50.00 D, surgeons may use the SRK/T formula with a target refraction of  $-1.50$  D. Finally, for eyes with a higher corneal power, none of the formulas seemed to have a good accuracy, and the only recommendation could be probably not to use the actual corneal power. In such cases, authors reported much better results with use of standard K value (43.25 D) with a mean target refraction of  $-1.80$  D.<sup>44</sup> Despite the general concept that modern IOL power formulas are more accurate because they incorporate more variables to enhance the accuracy of IOL power calculations, simple regression formulas interestingly still show good reliability in KCN patients.<sup>6</sup>

A summary of the previous papers on the topic of IOL power calculation in keratoconic eyes is presented in [Table 1](#).

#### **Discussion**

Cataract surgery in keratoconic eyes can improve patients' refraction and also quality of life but proper patient selection and more importantly proper IOL calculation method comprise the best results. As a critical preoperative step, the surgeon should choose a suitable IOL power formula in each patient and at the same time be meticulous regarding accuracy of keratometry and optical biometry.

Ophthalmologists need to be familiar with the special planning for IOL power calculation in patients with KCN. Recent studies have suggested that new preoperative therapeutic methods including CXL or ICRS implantation may help

**Table 1**  
**Review of studies on intraocular lens (IOL) power calculations in keratoconus (KCN) patients.**

Author	Year of publication	Study design	Number of eyes	KCN stage <sup>a</sup>	Age ± SD (years)	Follow-up (months)	IOL type	IOL calculation formula	Keratometry	UDVA	CDVA	Astigmatism (D)	Spherical equivalent	Efficacy index	Safety index	Postoperative refraction within ± 0.50 D (%)	Postoperative refraction within ± 1.00 D (%)	Recommendations	
Celikkol et al. <sup>45</sup>	1996	Case report	2	I	56	N.A.	AMO SI-30NB	SRK/T	Standard keratometry in one eye and videokeratography in fellow eye	N.A.	20/25	N.A.	-1.50	N.A.	N.A.	N.A.	N.A.	Determining IOL powers with videokeratography-derived K-values might be more accurate than standard keratometry in patients with KCN.	
Leccisotti <sup>46</sup>	2006	Prospective non-comparative interventional case series	34	I, II	56.70 ± 10.40	17.40 ± 5.10	Non-toric	Holladay II	Topography	0.48 ± 0.25 (decimal)	0.76 ± 0.23 (decimal)	1.22 ± 1.37	-1.31 ± 1.08	0.87	1.38	9	47	Intraoperative autorefractometry is recommended to improve refractive outcomes.	
Thebpatiphat et al. <sup>23</sup>	2007	Retrospective case series	12	I, II, III, IV	55.30 ± 11.80	3	Non-toric	Acrysof SA60AT	SRK, SRK II, SRK/T	0.63 ± 0.47	0.21 ± 0.13	N.A.	-1.44 ± 1.69 (mild), -5.85 ± 3.94 (moderate)	N.A.	N.A.	N.A.	N.A.	IOL calculation is more predictable in mild KCN than in moderate and severe cases.	
Navas et al. <sup>47</sup>	2009	Case report	3	N.A.	55 and 46	12	Toric		SRK II	Topography	20/25	N.A.	0.50	-0.50, 0.00	N.A.	N.A.	N.A.	Toric IOLs may provide excellent outcomes in patients with stable and non-progressive corneal ectasia.	
Jaimes et al. <sup>48</sup>	2011	Retrospective review	19	N.A.	48.15 ± 6.60	7.89 ± 6.61	Toric		SRK II	Topography interferometry (IOL Master)	0.29 ± 0.23	0.11 ± 0.12	1.36 ± 1.17	-0.46 ± 1.12	0.87	1.22	38	85	Toric IOL implantation may be an effective therapeutic option in the optical rehabilitation of patients with stable and non-progressive KCN.
Nanavaty et al. <sup>49</sup>	2012	Retrospective non-comparative case series	12	I, II, III	63.40 ± 3.50	9.00 ± 8.80	Toric	AT TORBI 709 M, AcriTec	Company proprietary software	N.A.	20/40	20/30	0.60 ± 1.10	0.10 ± 0.60	N.A.	N.A.	N.A.	N.A.	Pseudophakic toric IOLs are an effective option and provide good vision in eyes with stable mild to moderate KCN and cataract.
Watson et al. <sup>2</sup>	2013	Retrospective case series	92	I, II, III, IV	59	33	Non-toric		SRK/T	Keratometer	N.A.	0.30 (mild), 0.20 (moderate), 0.20 (severe)	N.A.	-1.00 (mild), -1.50 (moderate), -5.40 (severe)	N.A.	N.A.	N.A.	60 (stage I), 41.90 (stages II,III), N.A. (stage IV)	Using the actual K values with a target of low myopia is a suitable option for spherical IOL selection for eyes with a mean K of ≤55 D. When there is severe KCN, the use of actual K values can result in a large hyperopic error and the use of standard K value in these eyes should be considered.
Alio et al. <sup>4</sup>	2014	Retrospective case series	17	I, II	56.60 ± 12.50	9.10 ± 5.54	Toric		Hoffer Q, SRK/T	Keratometer	0.32 ± 0.38	0.20 ± 0.36	1.40 ± 1.13	-0.62 ± 0.97	1.38 ± 0.58	1.17 ± 0.66	N.A.	N.A.	Using corneal topography data and standard formulas for the calculation of the IOL power is a safe and effective procedure regarding keratometric stability, visual and refractive results.
Tamaoki et al. <sup>32</sup>	2015	Retrospective case series	4	I	74.80 ± 13.00	N.A.	SN6AT5, N4-18 YG KS-Ni KS-AiN	SRK/T	Autokeratometer and partial coherence interferometry (IOL Master)	Not mentioned as pooled data of 4 patients	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	The real corneal power values that take both the anterior and posterior corneal curvatures into consideration should be applied for IOL power calculations in cases with posterior KCN.

(continued on next page)

Table 1 (continued)

Author	Year of publication	Study design	Number of eyes	KCN stage <sup>a</sup>	Age ± SD (years)	Follow-up (months)	IOL type	IOL calculation formula	Keratometry	UDVA	CDVA	Astigmatism (D)	Spherical equivalent	Efficacy index	Safety index	Postoperative refraction within ± 0.50 D (%)	Postoperative refraction within ± 1.00 D (%)	Recommendations	
Hashemi et al. <sup>42</sup>	2015	Prospective case series	23	I, II, III, IV	59.00 ± 12.80	3	Toric AcrySof	Hoffer Q (AL < 22 mm), SRK II (22–24.5 mm), Holladay I (24.5–26 mm), SRK/T (>26 mm)	Keratometer topography	0.27 ± 0.18 (mild), 0.34 ± 0.19 (moderate), 0.38 ± 0.29 (severe)	0.16 ± 0.09 (mild), 0.18 ± 0.12 (moderate), 0.35 ± 0.13 (severe)	1.83 ± 0.90 (mild), 1.25 ± 0.96 (moderate), 4.67 ± 2.31 (severe)	−0.58 ± 0.95 (mild), −0.34 ± 0.90 (moderate), 0.50 ± 0.58 (severe)	N.A.	N.A.	N.A.	N.A.		The use of toric IOLs resulted in desirable vision and refraction in the cataract surgery of patients with non-progressive KCN. As for determining the IOL power, it seems that keratometry derived from the 3 mm central zone in the axial map of corneal topography using the SRK/T formula has the lowest error.
Kamiya et al. <sup>50</sup>	2016	Prospective case series	19	I, II	63.10 ± 9.10	3	Toric	SRK/T	Keratometer	0.46 ± 0.33	−0.01 ± 0.09	0.70 ± 0.60	N.A.	N.A.	N.A.	68	95	Toric IOL implantation for mild KCN patients having RGP lens intolerance appears to be effective for reducing refractive astigmatism without a significant induction of corneal higher order aberrations.	
Doroodgar et al. <sup>3</sup>	2017	Prospective case series	10	I, II	53.40 ± 6.65	6	Non-preloaded M type and preloaded MP type trifocal toric	Manufacturer's online calculator ZCALC	N.A.	0.04 ± 0.04	0.10 ± 0.07	N.A.	−5.20 ± 1.49	N.A.	N.A.	50	90	Trifocal AT LISA 939 MP IOLs provided appropriate distance, near and intermediate visual results. Prediction of the refractive results and optical performances were good.	
Kamiya et al. <sup>51</sup>	2018	Retrospective review	101	I, II, III, IV	61 (median)	1	Toric in mild cases and non-toric in the rest	SRK/T	Partial coherence interferometer (IOL Master)	0.35	0.00	N.A.	−1.75	N.A.	N.A.	36	63	Large amount of hyperopic shift occurred in advanced KCN patients, when the keratometric readings were used for the IOL power calculation, and that a slight, but significant, myopic shift occurred, when total corneal refractive power was used.	

KCN: Keratoconus; SD: Standard deviation; IOL: Intraocular lens; UDVA: Uncorrected distance visual acuity; CDVA: Corrected distance visual acuity; D: Diopter; AL: Axial length; K: Keratometry; RGP: Rigid gas permeable; N.A.: Not applicable. Results were expressed as mean ± SD. Only the postoperative outcomes are presented in the table.

<sup>a</sup> Amsler–Krumeich classification.

to provide more predictable and stable outcomes after cataract surgery.<sup>10,52–54</sup>

The main problem in KCN patients is unreliable biometric measurements. It is more difficult to make conclusions in more advanced keratoconic corneas, as the steep keratometric values in these eyes will result in the selection of a low-power IOL and can lead to postoperative refractive hyperopia. Presence of a low-power IOL will yield in extreme postoperative hyperopia, and IOL exchange might be mandatory.<sup>22</sup> In cases in which keratoplasty may be needed in the future, contact lens fitting can help surgeons to make a better decision preoperatively.

Newer devices are being studied to improve corneal power measurement and improve IOL calculations. Some of these new technologies are the Pentacam AXL which adds new features to the corneal tomography device, including the AL measurement and IOL power calculation for spherical and toric IOLs. Optovue Cornea Advance (Optovue Inc, CA, USA) can measure corneal power based on direct anterior and posterior corneal curvature measurements through OCT technology. Such advancements in devices' and IOL design technology will make IOL power calculations safer and more predictable, therefore increasing the probability of successful postoperative achievements regarding expectations of both surgeons and patients.

Finally, some useful guidance tips are summarized here for ophthalmologists to carry out a more reliable IOL power calculation in KCN patients during cataract surgery:

- Before performing any surgical operation on eyes with established KCN, make sure of stability of disease process and stage of the KCN.
- Appropriate patient selection and comprehensive preoperative evaluation of corneal stability is of greatest importance for assessing patients with concomitant cataract and KCN.
- Performing minimally invasive and one-step surgical operation is ideal in KCN cases.
- In mild to moderate KCN (maximum K  $\leq$  55.00 D), Pentacam and Javal manual keratometer show better repeatability in keratometric measurements. When the maximum K is greater than 55.00 D (advanced KCN), most imaging systems show weak repeatability.
- It is recommended to consider using standard K (43.25 D) for severe KCN and actual K for mild and moderate KCN in order to calculate IOL power.
- AL measurements may have better repeatability and reproducibility than K readings in keratoconic eyes.
- SRK II formula may provide the most accurate IOL power in mild KCN.
- There is still not a comprehensive consensus about which formula is the best in moderate and severe KCN.

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