



Current Trends in Modern Visual Intraocular Lens Enhancement Surgery in Stable Keratoconus: A Synopsis of Do's, Don'ts and Pitfalls

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ABSTRACT

Keratoconus is a relatively common ectatic, non-inflammatory corneal disorder that involves gradual visual deterioration through progressive alteration of the shape of the cornea. The corneal thinning, irregular astigmatism and higher order aberrations that occur as the disease progresses pose major challenges in the visual rehabilitation of such patients. This paper summarizes the current literature regarding the results of visual enhancement procedures in patients with stable keratoconus treated with standalone anterior or posterior chamber phakic intraocular lens implantation and monofocal, toric or multifocal toric intraocular lens implantation following phacoemulsification for age-related cataract extraction or refractive lens exchange.

Keywords: Intraocular lens surgery; Keratoconus; Phakic IOL implantation

INTRODUCTION

Keratoconus (KC) is a non-inflammatory disorder of the eye that usually starts during puberty and gradually stabilizes during adolescence, resulting in corneal thinning, irregular astigmatism and visual impairment [1]. It is essentially a bilateral condition with an asymmetrical presentation that leads to a protrusion in either the central or the inferior cornea and is characterized by corneal scarring, among other findings [2]. The aetiology of the disease is still debated, although it is considered to be a multifactorial condition that can arise from genetic, metabolic, immunological, endocrinological, cellular and environmental factors, any of which may trigger the onset of the disease [3]. Keratoconus affects approximately 1 out of 2000 people, although the prevalence and incidence may differ between geographical regions and populations [1, 4–9]. According to recent epidemiological studies, the incidence and prevalence of KC around the world is on the rise [4, 6–9], resulting in a need for closer follow-up and a lower threshold for corneal cross-linking (CXL), especially in younger individuals. The effectiveness of CXL at stabilizing KC progression is well documented [10–13]. The number of young people affected with KC

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worldwide is increasing, and visual correction of these patients is crucial. During the progression of KC, myopia, astigmatism and higher order aberrations (HOAs) distort the visual quality of the patient [14]. The visual management of KC can vary from soft contact lenses and spectacles in early cases to rigid gas-permeable (RGP) contact lenses, phototherapeutic keratectomy (PTK) or photorefractive keratectomy (PRK) combined with CXL and intrastromal corneal ring segments (ICRS) in moderate cases, and to deep anterior lamellar keratoplasty (DALK) or full-thickness corneal transplantation (PK) in very advanced disease [1]. With the advent of modern topography-guided normalization procedures combined with high-fluence CXL, a large number of patients with early or moderate KC have been successfully and safely managed [15, 16]. However, such procedures are not considered to be applicable to a large proportion of KC patients with presbyopia or age-related cataract. The present paper summarizes the available literature on the visual rehabilitation of patients with stable KC treated with standalone anterior or posterior chamber phakic intraocular lens implantation (pIOLs) and monofocal, toric and multifocal toric intraocular lens implantation (IOL) following phacoemulsification for age-related cataract extraction or refractive lens exchange (RLE). This article is based on previously conducted studies and does not contain any studies with human participants or animals performed by any of the authors.

GENERAL CONSIDERATIONS BEFORE IMPLEMENTING PHAKIC IOL PROCEDURES

Anterior or posterior chamber pIOL implantation may be considered as a viable surgical solution for improving the vision of KC patients in certain circumstances, primarily if the patient is RGP contact lens intolerant, but also in cases of stable refraction with no sign of KC progression; in cases of highly irregular astigmatism, such as those that occur with advanced disease; and in cases where biometrical parameters allow safe implantation of the lens. pIOLs

may correct spherocylindrical error, but they are not able to correct HOAs such as vertical coma, spherical aberration or trefoil [14, 17, 18]. Postoperative complications may include cataract formation, secondary glaucoma, uveitis, corneal endothelial cell loss, iris atrophy, and traumatic dislocation of the pIOL, resulting in further surgery [19, 20]. There are two widely known types of pIOLs: one type enabling anterior chamber implantation and the other allowing posterior chamber implantation.

ANTERIOR CHAMBER IRIS-CLAW FIXATED PHAKIC INTRAOCULAR LENS IMPLANTATION

Anterior chamber pIOLs (AC pIOLs) include the Artisan/Verisyse non-foldable and the Artiflex/Veriflex foldable iris-fixated pIOLs as well as the equivalent toric models (Ophtec BV). These AC pIOLs are fixated anteriorly to the iris by enclavation. These devices correct a fair amount of spherical error and sufficiently improve the uncorrected distance visual acuity (UDVA), but the astigmatic correction achieved with them may be insufficient due to the limited cylindrical range provided by these models [17], or, depending on the model (foldable or non-foldable), the surgically induced astigmatism (SIA) may deviate substantially from the target induced astigmatism (TIA) [21, 22]. The procedure usually involves local combined with anterior chamber anesthesia. Depending on the model (foldable or non-foldable), the main limbal incision may range from 3 to 4 mm for Artiflex and from 5 to 6 mm for Artisan Myopia [23]. The IOL is centred at 12 o'clock, and a single laser iridotomy is performed on the peripheral iris at 1 or 11 o'clock at least 1 week prior to surgery, or an iridectomy is carried out during the implantation to avoid pupillary block. In toric models, the calculation can be done online via Articalc provided by Ophtec BV. We found five articles in PubMed on standalone Artisan/Artiflex implantation in KC patients [23–27]. These results are summarized in Table 1. In an investigation of 36 eyes and 24 KC patients in total, Kato et al. reported an improvement of 1.39 ± 0.42 to 0.02 ± 0.21

Table 1 Summary of results of anterior chamber phakic intraocular lens implantation in keratoconic eyes

Author	pIOL	Eyes (<i>n</i>)	KC stage	Follow-up (months)	Mean change from baseline to last follow-up visit			Predictability SE		
					UDVA	CDVA	Sphere (D)	Cylinder (D)	Within ± 0.5 D (%)	Within ± 1.00 D (%)
Budo et al.	Artisan toric	6	n.a.	6	n.a.	0.2 (decimal)	11.3	2.42	20	66.67
Moshirfar et al.	Verisyse	2	n.a.	5 and 2	0.58 (decimal)	0.08 (decimal)	13.4	0.62	0	50
Venter et al.	Artisan	18	n.a.	Range: 6–12	n.a.	0.20 (decimal)	4.67	3.93	61.1	83.3
Sedaghat et al.	Artisan	16	n.a.	14.2 (range: 6–28)	0.71 (decimal)	0.14 (decimal)	12.47	0.87	33.33	53.33
Kato et al.	Artisan Artiflex	36	n.a.	12	1.32 (LogMAR)	n.a.	n.a.	1.82	63.6	83.6

LogMAR (logarithm of the minimum angle of resolution) UDVA at 1 month after surgery and no significant change thereafter ($P < 0.001$). The best spectacle-corrected visual acuity (BSCVA) at 1 year after surgery improved by four lines in one eye (2.8%), two lines in four eyes (11.1%) and one line in nine eyes (25.0%), remained unchanged in 19 eyes (52.8%), and decreased by one line in three eyes (8.3%) from the preoperative value. The baseline manifest refraction improved from -8.38 ± 3.42 dioptres (D) to -0.39 ± 0.91 D at 1 week and -0.42 ± 0.89 D at 1 month, and showed no significant change thereafter ($P < 0.001$). Manifest refraction at 1 month postoperatively was within ± 0.5 D of the target refraction in 35 eyes (63.6%), within ± 1.0 D in 46 eyes (83.6%) and within ± 2.0 D in 53 eyes (96.4%). The baseline astigmatism of 2.44 ± 2.25 D (0–8.0 D) improved to 0.93 ± 0.97 D (0–3.5 D) at 1 week and 0.62 ± 0.69 D (0–2.5 D) at 1 month, and remained stable thereafter [23]. The authors concluded that AC pIOLs (Artisan Myopia 6/8.5, Artiflex 6/8.5 and the toric 5/8.5 model) are effective, safe and predictable for implantation in KC patients, and can significantly improve the visual function of such patients. For a small case series of six KC eyes that underwent Artisan toric pIOL implantation, Budo et al. reported visual improvement in five out of six KC eyes, and a significant reduction in spherical equivalent refraction in all eyes ($P = 0.03$). The authors suggested that Artisan toric pIOL implantation represents an alternative approach for astigmatism and myopia correction in RGP contact lens intolerant KC patients, and that it should be considered as an intermediate surgical solution before proceeding with PK [24]. Similar results were presented by Moshirfar and Venter et al. based on a small case series study and a case report, from which they concluded that Artisan AC pIOL implantation is a safe and predictable procedure with minimal complications [25] that should be considered in certain KC patients as an alternative surgical option before proceeding with PK [26]. For a small prospective case series of 16 eyes with stable KC and a mean follow-up of 14.2 ± 7.8 months, Sedaghat et al. reported significant UDVA and corrected distance visual

acuity (CDVA) improvements, with all patients achieving a final UDVA of 20/40 or better and 84.6% achieving a final CDVA of 20/32 or better ($P < 0.0001$ and $P < 0.002$, respectively). Minor complications occurred in two eyes (sterile uveitis), but no data on endothelial cell loss following implantation was evaluated. Endothelial cell loss following any intraocular lens surgery poses a significant threat that could lead to a further decrease in vision and additional corneal surgery, especially in KC patients following pIOL implantation [19, 20, 28].

POSTERIOR CHAMBER PHAKIC INTRAOCULAR LENSES

In many patients, posterior chamber phakic intraocular lenses (PC pIOLs) are an excellent choice for correcting moderate to high myopia, hyperopia and astigmatism due to their safety, predictability and effectiveness [19, 20, 28–31]. For instance, implantation of the Visian ICL PC pIOL implantable collamer lens from STAAR Surgical is performed under local anesthesia through a 3.0–3.2 mm clear corneal incision (CCI) along the horizontal axis (0–180°). After inflating the AC with viscoelastics, the Visian ICL is inserted and placed gently under the iris and above the crystalline lens. The Visian ICL has a central hole that facilitates constant aqueous humour flow between the anterior and posterior chambers, meaning that it is not necessary to create an iridectomy intraoperatively in order to prevent a pupillary block, in contrast to previous models. The power and toricity of the ICL are usually pre-calculated by the company or can be calculated by the surgeon via the astigmatism decomposition method or using the online calculator from STAAR Surgical. The implantation of ICLs into KC eyes for visual improvement in a standalone procedure has undergone far more evaluation than the implantation of AC pIOLs [32–36]. A summary of the results of ICL implantation performed as standalone surgery is presented in Table 2. In 2008, Alfonso et al. were among the first to evaluate the efficacy, predictability and safety of myopic ICL implantation as a standalone procedure to correct myopia associated

Table 2 Summary of the results of posterior chamber phakic intraocular lens implantation in keratoconic eyes

Author	pIOL	Eyes (n)	KC stage	Follow-up (months)	Mean change from baseline to last follow-up visit			Predictability SE		
					UDVA	CDVA	Sphere (D)	Cylinder (D)	Within ± 0.5 D (%)	Within ± 1.00 D (%)
Alfonso et al.	ICL	25	n.a.	12	n.a.	0.05 (decimal)	8.6	0.71	84	100
Kamiya et al.	Toric ICL	2	n.a.	3	0.79 (decimal)	0.4 (decimal)	9.1	3.25	50	100
Alfonso et al.	Toric ICL	30	I–II	12	0.66 (decimal)	0.07 (decimal)	3.62	3.07	93.3	100
Kamiya et al.	Toric ICL	27	I–II	6	1.66 (LogMAR)	0.07 (LogMAR)	n.a.	2.47	85	96
Kurian et al.	ICL	10	I–III	6	0.52 (LogMAR)	0.11 (LogMAR)	5.20	2.15	30	70
	Toric ICL									

with KC, based on a prospective, non-comparative, interventional case series study with 12 months of follow-up in 25 KC eyes and 16 patients. The preoperative myopia ranged from -3.00 to -18.00 D, and the astigmatism from -0.50 to -3.00 D. In all cases, the main incision performed during implantation was made on the steepest meridian of the cornea in an attempt to reduce the astigmatism. The mean postoperative UDVA and BSCVA were 0.17 ± 0.19 and 0.12 ± 0.12 LogMAR, respectively, with BSCVA showing a statistically significant improvement compared to baseline ($P = 0.0021$). The mean postoperative spherical equivalent refraction was 0.32 ± 0.55 D, with five eyes gaining one or more lines and 18 eyes not losing any lines in the Snellen chart at 12 months [32]. In the same year, Kamiya et al. implanted toric ICLs into two patients with stable KC and contact lens intolerance. The authors reported remarkable improvements in UDVA and BSCVA after 1 year and concluded that toric ICL implantation could be a reliable surgical option for the correction of myopia and astigmatism associated with KC [33]. Two years later, their conclusion was confirmed by Alfonso et al. based on data from a prospective study in which toric ICL implantation was performed in 30 KC eyes (21 patients) and the results were evaluated over a 12-month period [34]. At 12 months, 86.7% of the eyes were within ± 0.50 D and all eyes were within ± 1.00 D of the attempted refraction. Astigmatic values were significantly reduced, with 83.3% and 86.7% of eyes being within ± 0.50 D for J0 and J45, respectively. The mean Snellen UDVA was 0.81 ± 0.20 , and the mean CDVA was 0.83 ± 0.18 . The cumulative CDVA was 20/40 or better in 29 eyes (96.7%) and 20/25 or better in 22 eyes (73.3%). Additionally, Kamiya et al. performed a 3-year retrospective study of the results of toric ICL implantation in 21 eyes of 11 patients with stable KC and rigid contact lens intolerance, and reported that 67% and 86% of the eyes were within ± 0.5 and ± 1.0 D of the targeted correction and the UDVA and CDVA were -0.06 ± 0.11 and -0.12 ± 0.09 LogMar, respectively, following implantation. The efficacy and predictability of these results were also

confirmed, with no significant change in the manifest refraction (ANOVA, $P = 0.989$) or in keratometry ($P = 0.951$), indicating that toric ICL implantation in KC patients is beneficial in terms of safety, efficacy and predictability [35]. However, Kurian et al. [36] carried out a case series studying the visual quality of KC patients following Visian ICL implantation and reported that, although major improvements in the spherocylindrical error were seen, the modulation transfer function (MTF) was inversely correlated with secondary coma ($P = 0.026$), negative vertical coma ($P = 0.014$), the root mean square (RMS) of total aberrations ($P = 0.010$) and HOAs ($P = 0.015$). The objective scatter index (OSI) was also directly correlated with secondary coma ($P = 0.021$), secondary trefoil ($P = 0.016$), the root mean square (RMS) of total aberrations ($P = 0.032$) and HOAs ($P = 0.050$), suggesting that the associated aberrations had an adverse impact on the ultimate visual quality [35].

COMPARISON OF IMPLANTATION STABILITY BETWEEN IRIS-CLAW FIXATED PHAKIC AND POSTERIOR CHAMBER PHAKIC INTRAOCULAR LENSES

Both of these procedures are regarded as viable and relatively safe, with excellent refractive outcomes in stable KC patients. However, a very important factor in ICL implantation is size selection. Oversized or undersized ICLs can lead to various complications such as anterior chamber deformation, which in turn can result in decentration or rotation, final central vault deviations, cataract formation, mechanical trauma and pigment dispersion syndrome, refractive errors, glare and diplopia. Boxer Wachler et al. [37] compared two methods of preoperatively measuring 16 eyes in 11 patients for final optimized ICL length selection: the sulcus to sulcus (STS) and the white to white (WTW) methods. The mean postoperative vault was 1.03 ± 0.72 corneal thickness in the WTW group and 1.18 ± 0.35 corneal thickness in the STS

group ($P = 0.61$). The study concluded that both methods provided equally good results in terms of postoperative final vault prediction, but the STS method provided higher vault predictability results, although the difference between the two methods was not statistically significant. Other studies have also highlighted the importance of ICL size selection; for instance, the decentration measured via ultrasound biomicroscopy examination (UBM) was found to be up to 11% [38]. Similar studies have reported lens rotations of up to 18.5° in the first year [39]. These findings raised concerns regarding the stability of the toric model that would predominantly affect refractive outcomes and lead to further surgeries. As a result of this, it was suggested by Baumeister et al. that the horizontal WTW diameter is determined most accurately by the IOLMaster (Carl Zeiss Meditec). In this study, the mean rotation of the ICL was 0.9° [40]. In another study, it was reported that postoperative rotation after toric ICL implantation was less than 5° in 74% of eyes and less than 11° after 8 months [41]. In general, the anterior iris-claw fixated phakic IOL has shown greater stability in terms of rotation [42, 43], with less than 2° of postoperative rotation at 6 months, but spontaneous or trauma-induced dislocations have been reported [44]. In two studies comparing these methods, Baumeister et al. found that the iris-fixated pIOL had better positional stability than posterior chamber pIOLs [45]. Therefore, the iris-fixated pIOL is particularly interesting for astigmatic correction. In a subsequent study [46], Alió et al. concluded that both methods provided equally good results, although a decrease in the quality of the retinal image as a result of HOAs was reported for the pIOL group. There were no statistical differences between the iris-claw and the pIOL/toric pIOLs in terms of stability and safety results. The efficacy index was better for the iris-claw group, but the difference was not statistically significant ($P = 0.058$).

GENERAL CONSIDERATIONS BEFORE PHACOEMULSIFICATION IN KC

A large number of KC patients live long enough to potentially develop presbyopia, and an even larger number already suffer from age-related cataract. In some of these patients, a CXL procedure to stabilize the cornea may have already been performed; if not, ageing will eventually naturally stabilize the cornea. Nevertheless, ophthalmologists around the world are challenged by cases involving KC patients with impaired visual function who seek a surgical solution for their presbyopia, or KC patients who are affected by age-related cataracts and are in need of surgery. pIOL surgery is not recommended in such patients for obvious reasons; instead, lens extraction through phacoemulsification should be performed. There are two major concerns regarding cataract extraction surgery in KC patients: calculating the power of the IOL [47–51], and the incidence of retinal detachment (RD) following cataract surgery, especially in younger and highly myopic patients or following posterior capsule rupture (PCR) [52–55]. Regarding the IOL power calculation, the most challenging part is the accurate measurement of keratometric values (K values) due to the astigmatic power irregularity of the cornea itself between the cone apex and the peripheral cornea. This leads to considerable deviation in the IOL calculation and poor postoperative visual outcomes. In an initial case report of two KC patients, it was suggested [47] that combining IOL calculation formulae such as SRK/T and Holladay II with videokeratography-derived K values may result in a more accurate IOL power calculation than using standard keratometry values in patients with keratoconus. In a more recent case report [48], it was reported that the IOL power calculation from conventional keratometry is inaccurate in patients with posterior KC and results in postoperative hyperopia because the localized posterior elevation of the cornea is not considered. A new approach to IOL power calculation that used a variable keratometric index in an attempt to correct for errors associated with the

keratometric estimation of the corneal power in KC was proposed. The author concluded that the use of a single index value to calculate the total corneal power in KC seems to be imprecise and leads to inaccuracies in the detection and classification of this corneal condition. Furthermore, this study highlighted other important biometrical parameters involved in the calculation of corneal power in KC, such as the corneal thickness [49]. In a retrospective review of 4621 eyes that underwent cataract extraction, Tamaoki et al. was able to identify four eyes diagnosed with posterior KC by comparing the anterior to the posterior corneal curvature (A/P) ratio as measured by anterior segment optical coherence tomography (AS-OCT) to partial coherence interferometry (PCI) *K* values. The authors suggested that applying the PCI *K* values for these eyes in the IOL calculation resulted in hyperopia, and that this could be avoided by applying the total refractive corneal power measured with AS-OCT instead. The study concluded that real corneal power values that take both the anterior and the posterior corneal curvatures into consideration should be applied in IOL power calculations for cases with posterior keratoconus [50]. Despite the differences between the results obtained in the above studies, it is recommended that the total true refractive corneal power should be applied in IOL power calculations. Also, since the power IOL calculation for KC patients is rather challenging as it involves so many parameters, it is best to have stable KC that is centred as much as possible. This can be achieved by combining stabilizing procedures such as CXL and ICRS, which ultimately yields more stable *K* values and better predictability of postoperative refraction [56].

MONOFOCAL SPHERICAL IOL IMPLANTATION

In the previous section we discussed the challenges of IOL power calculation and the parameters involved in KC patients. In 2006 Leccisotti presented a prospective non-comparative interventional series study with a 12-month follow-up of 34 consecutive eyes of

20 patients with stage I–II KC who underwent RLE for myopia correction in Sienna, Italy [57]. The intraocular lens power was calculated by ultrasound (US) biometry and the Holladay II formula, targeting a residual myopic astigmatism. The *K* values were obtained via axial topographic maps. The dioptric power of the steepest meridian over the central 3 mm of the cornea was denoted *K*₁, and the dioptric power of the flattest meridian over the central 3 mm of the cornea was denoted *K*₂. Each meridian power was calculated by averaging its two semi-meridian values, always considering the central 3 mm. The author reported a statistically significant improvement in the mean spherical equivalent ($P < 0.05$, Student's *t* test and 95% CI -8.26 to -11.18 D) from a baseline of -11.0 ± 4.65 D (range -5.75 to -22) to -1.31 ± 1.08 D (range -0.25 to -4.5) at 12 months. This change was reflected in the efficacy results, as the mean BSCVA baseline shifted from 0.55 ± 0.20 to a mean Snellen UDVA of 0.48 ± 0.25 , while the mean BSCVA at 12 months improved to 0.76 ± 0.23 ($P < 0.05$; 95% CI 0.19–0.25) compared to baseline. The mean defocus equivalent also reduced from a baseline of 12.0 ± 4.64 D (range 6.50–23 D) to 1.94 ± 1.57 D (range 0.25–5.5 D) at 12 months. The difference was also statistically significant ($P < 0.05$, Student's *t* test; 95% CI, 8.63 to 11.46 D). Twenty-two of 34 eyes (65%) were within ± 2.0 D of the defocus equivalent, 16 of 34 (47%) were within ± 1.0 D, and 3 of 34 eyes (9%) were within ± 0.5 D. Posterior vitreous detachment (9%) and dysphotopsia phenomena (15%) were the predominant minor complications reported, with a 6.3% loss of corneal endothelial cell density at 12 months. The reported safety index was 1.38, and the efficacy index was 0.87. The study concluded that RLE is safe and predictable for treating myopia in stage I–II KC, but that US biometry was inaccurate in almost one-third of eyes. A more recent retrospective study of 92 eyes of 64 KC patients who underwent cataract extraction surgery and spherical IOL implantation by Watson et al. [58] at Moorfields Hospital revealed that it was possible to use the actual *K* values and a target of low myopia for spherical IOL selection in eyes with a mean *K* of ≤ 55 D. In this study, 35 eyes

had stage I KC (mean $K < 48$ D), 40 had stage II–III KC (mean K 48–55 D) and 17 had stage IV KC (mean $K > 55$ D). Actual K values were used for all eyes with stage I–III KC, with a target refraction of -1.0 D in stage I and -1.5 D in stage II–III, resulting in mean biometry prediction errors (BPEs) of 0.0 D and $+0.3$ D, respectively. In stage IV KC, actual K values were used in eight of 17 eyes, achieving a mean target refraction of -5.4 D, which resulted in a mean BPE of $+6.8$ D. In the other nine eyes, a standard K value of 43.25 D was used, with a mean target refraction of -1.8 D, which resulted in a mean BPE of $+0.6$ D. The study concluded that the use of actual K values can result in substantial hyperopic error in stage IV KC, so standard K values should be used for these eyes instead [58]. Kamiya et al. retrospectively analyzed 102 eyes of 71 consecutive KC patients and concluded that large hyperopic shifts occurred when actual keratometric readings were used in the IOL power calculation, especially in advanced keratoconic patients, but that slight, albeit significant, myopic shifts occurred when the total corneal refractive power was used ($P = 0.013$) [59]. In this study, wide variations in prediction errors associated with different calculation formulae were observed, with the SRK/T formula yielding the best prediction error (ANOVA, $P = 0.004$). Significant differences in prediction error were seen between the SRK/T formula and the Haigis formula ($P = 0.027$, Dunnett's test) and between the SRK/T formula and the Hoffer Q formula ($P = 0.031$). Significant differences were also reported in the percentage of eyes within ± 1.0 D of the targeted correction when results obtained using the SRK/T and the Haigis formulae were compared ($P = 0.005$, Fisher's exact test), and when the results obtained with the SRK/T and the Hoffer Q formulae were compared ($P = 0.024$). The SRK/T formula yielded 36% of eyes within ± 0.5 D of the targeted correction, as compared to 22% using the Haigis formula, 27% using Holladay I, 27% using Holladay II, 21% using the Hoffer Q formula and 25% using SRK II. Similarly, SRK/T yielded 63% of eyes within ± 1.0 D of the targeted correction, as compared to 42% using the Haigis formula, 51% using Holladay I, 51%

using Holladay II, 46% using the Hoffer Q formula and 49% using SRK II [59].

TORIC MONOFOCAL IOL IMPLANTATION

Toric IOLs are an excellent technology for correcting residual astigmatism following cataract surgery. Currently available toric IOLs correct regular astigmatism, but the implantation of these IOLs into eyes with corneal ectasia may not be suitable. In general, KC is still regarded by many to be a contraindication for toric IOL implantation [60]. In KC patients with irregular astigmatism, calculating the power of a toric IOL and proper alignment can be very challenging, and even with perfect alignment, there will still be a significant amount of irregular astigmatism that could induce further HOAs due to complex coupling of the toricity of the IOL with the corneal irregularity. Nonetheless, many studies have reported the successful implantation of toric IOLs into KC patients. In a case report, Luck noted the successful treatment of a patient with pellucid marginal degeneration (PMD, 10.9 D of keratometric astigmatism on Scheimpflug imaging) through the implantation of an ultrahigh-power customized bitoric AT.Comfort 646TLC IOL ($-0.5 + 16.0 \times 170$). The preoperative UDVA improved from a baseline of 6/120 to 6/9 and the CDVA from 6/24 to 6/6, with a manifest refraction of $+0.25 + 1.25 \times 150$ [61]. Similar results have also been presented in many case reports focussing on patients with KC who underwent toric IOL implantation [62–64]. These case reports provided the initial evidence that toric IOL implantation can be used to correct irregular astigmatism and to improve visual function in patients with mild-to-moderate stable KC and cataracts [64]. Bigger retrospective studies were then carried out to confirm the initial published data [65–68]. Jaimes et al. [65] retrospectively analyzed 19 eyes and 13 consecutive patients and reported the surgical outcomes of patients with non-progressive KC who underwent RLE and toric IOL implantation over a follow-up period of 7.89 ± 6.61 months. The mean sphere reduced from -5.25 ± 6.40 D at

baseline to 0.22 ± 1.01 D ($P < 0.001$) postoperatively, and the baseline cylinder of 3.95 ± 1.30 D decreased to 1.36 ± 1.17 D postoperatively ($P < 0.001$). Similarly, the mean spherical equivalent refraction decreased from -7.10 ± 6.41 preoperatively to -0.46 ± 1.12 D postoperatively ($P < 0.001$), and the mean Snellen UDVA increased from 1.35 ± 0.36 D at baseline (20/447) to 0.29 ± 0.23 D postoperatively (20/39) ($P < 0.001$). In the same fashion, Navathy et al. [66] reported on a case series of 12 eyes from nine patients with stable mild-to-moderate KC and cataract who underwent pseudophakic toric IOL implantation (AT TORBI 709 M, Acri-Tec). They observed an UDVA of 20/40 or better in 75% and a CDVA of 20/40 or better in 83.3% of eyes. Postoperative mean refractive sphere (pre- vs postoperative: -4.80 ± 5.60 vs 0.30 ± 0.50 D) and cylinder (pre- vs postoperative: 3.00 ± 1.00 D vs 0.70 ± 0.80 D) values were significantly better ($P < 0.01$, respectively). Alió et al. [67] investigated 17 eyes (10 patients) that were diagnosed with stable KC treated with microincision cataract surgery (MICS) and toric IOL implantation, and reported efficacy and safety indices of 1.38 ± 0.58 and 1.17 ± 0.66 , respectively. They concluded that MICS surgery using corneal topography data and the standard formulae to calculate the IOL power is a safe and effective procedure regarding keratometric stability and visual and refractive results. The first prospective study to report astigmatic and HOA results after toric IOL implantation for mild non-progressive KC with cataract came from Kamiya et al. [68]. In 19 eyes of 19 consecutive patients, statistically significant improvements were observed in LogMAR UDVA and CDVA from baseline to 3 months postoperatively (Wilcoxon test $P < 0.001$), respectively, with a postoperative UDVA of better than 20/32. The achieved spherical equivalent correction was within ± 0.5 D of the targeted correction in 13 (68%) eyes and within ± 1.0 D in 18 (95%) eyes. The refractive astigmatism was significantly decreased from -1.92 ± 1.73 D preoperatively to -0.70 ± 0.60 D postoperatively ($P = 0.006$), while the corneal astigmatism changed from 2.89 ± 1.30 D preoperatively to 2.98 ± 1.09 D

postoperatively ($P = 0.492$), which was not a statistically significant shift. The corneal HOA for a 4-mm pupil barely changed from 0.47 ± 0.23 μm preoperatively to 0.52 ± 0.26 μm postoperatively ($P = 0.211$); again, not a statistically significant increase. The conclusion of this study was that toric IOL implantation into RGP contact lens intolerant patients with mild KC appears to be an effective method of reducing refractive astigmatism without significantly inducing corneal HOAs.

TORIC MULTIFOCAL IOL IMPLANTATION

Nowadays, spectacle independence and visual restoration for near, intermediate and far distances can be achieved with great success in patients with regular corneal astigmatism and presbyopia or cataracts through toric multifocal IOL implantation [69, 70]. In an already aberrated cornea, such as that generated by an ectatic disease, a further increase in HOAs can result in further visual dysfunction for the patient, so this treatment is generally not recommended in such patients. Still, promising reports are beginning to surface. We were able to locate a case report from Molteno et al. of two patients with stable KC who underwent toric IOL implantation. This report noted improvements in UDVA and CDVA, with a mean binocular UDVA of 20/25 and 20/30 in cases 1 and 2, respectively, and residual refraction within ± 0.5 D of emmetropia in both cases, suggesting that multifocal toric intraocular lens implantation may be useful in selected cases of stable KC [71].

DISCUSSION

Technological advancement and rigorous medical research over the years have prompted a new era of surgical options and solutions for KC patients. In this paper, we have summarized the results of current technologies performed as standalone procedures in patients with stable KC and RGP contact lens intolerance. Anterior and posterior pIOL implantation seems

to be an effective, predictable, reversible and relatively safe surgical solution in cases of stable stage I–II KC, and represents an intermediate step before proceeding with partial or full-thickness corneal transplantation. Although such surgical procedures have numerous associated complications, patient selection and preoperative calculations of the power and toricity of such devices have greatly improved through the effective use of technology over the last few decades, enabling us to perform surgery with greater safety and predictability. In regard to cataract surgery following the implantation of any IOL (spherical or toric), the biggest challenges seem to be accurately measuring the keratometry and calculating the IOL power. In addition, the incidence of RD following cataract surgery, especially in young and highly myopic patients, or following PCR as a complication [52–55], should be seriously considered prior to surgery. Despite the availability of modern corneal topography devices, obtaining reproducible K values in advanced disease ($K > 55$ D) can be a very challenging task [72, 73], and errors could result in poor visual outcomes and unexpected hyperopia [48, 59]. The anterior and posterior corneal curvature readings and true corneal power measurements should be considered when calculating the IOL power for patients with prosterior KC [50, 59], or actual biometry K values should be used to target low myopia (-1.0 to -1.5 D) in eyes with a mean K of ≤ 55 D [58]. Regarding formula selection, SRK/T seems to yield better results than other known formulae. Toric IOL technology seems to be effective in early and moderate stable KC, and there is a lot of evidence that it is a good surgical option. Although the efficacy and reproducibility of visual outcomes following multifocal toric IOL implantation in regular presbyopic patients is well documented [69, 70], the lack of evidence that such treatment is beneficial in KC eyes [71] suggests that prudence is wise until such evidence becomes available in the future.

CONCLUSIONS

Surgical visual rehabilitation in younger or older KC patients is considered to be a challenging surgical field. Current technology has enabled us to achieve far better results than those realized only a decade ago. Nevertheless, patient selection, accurate preoperative measurements and appropriate IOL selection according to the age and needs of the patient appear to be key to achieving optimal results following surgery.

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REFERENCES

- Vazirani J, Basu S. Keratoconus: current perspectives. *Clin Ophthalmol*. 2013;7:2019–30.
- Romero-Jiménez M, Santodomingo-Rubido J, Wolffsohn JS. Keratoconus: a review. *Cont Lens Anterior Eye*. 2010;33(4):157–66 **quiz 205**.
- Avetisov SÉ, Novikov IA, Pateiuk LS. Keratoconus: etiological factors and accompanying manifestations. *Vestn Oftalmol*. 2014;130(4):110–6.
- Ferdi AC, Nguyen V, Gore DM, Allan BD, Rozema JJ, Watson SL2. Keratoconus natural progression: a systematic review and meta-analysis of 11 529 eyes. *Ophthalmology*. 2019;126(7):935–45.
- Kennedy RH, Bourne WM, Dyer JA. A 48-year clinical and epidemiologic study of keratoconus. *Am J Ophthalmol*. 1986;101(3):267–73.
- Godefrooij DA, de Wit GA, Uiterwaal CS, Imhof SM, Wisse RP. Age-specific incidence and prevalence of keratoconus: a nationwide registration study. *Am J Ophthalmol*. 2017;175:169–72.
- Bak-Nielsen S, Ramlau-Hansen CH, Ivarsen A, Plana-Ripoll O, Hjortdal J. Incidence and prevalence of keratoconus in Denmark—an update. *Acta Ophthalmol*. 2019. <https://doi.org/10.1111/aos.14082>.
- Xu L, Wang YX, Guo Y, You QS, Jonas JB. Beijing Eye Study Group. Prevalence and associations of steep cornea/keratoconus in Greater Beijing. The Beijing Eye Study. *PLoS One*. 2012;7(7):e39313.
- Torres Netto EA, Al-Otaibi WM, Hafezi NL, Kling S, Al-Farhan HM, Randleman JB, Hafezi F. Prevalence of keratoconus in paediatric patients in Riyadh, Saudi Arabia. *Br J Ophthalmol*. 2018;102(10):1436–41.
- Vastardis I, Pajic-Eggspuehler B, Nichorlis C, Mueller J, Pajic B. Recent innovations in collagen corneal cross-linking; a mini review. *Open Ophthalmol J*. 2017;31(11):217–24.
- Ozer MD, Batur M, Mesen S, Tekin S, Seven E. Long-term results of accelerated corneal cross-linking in adolescent patients with keratoconus. *Cornea*. 2019;38(8):992–7.
- Buzzonetti L1, Petrocelli G, Valente P, Iarossi G, Ardia R, Petroni S, Parrilla R. Iontophoretic transepithelial collagen cross-linking versus epithelium-off collagen cross-linking in pediatric patients: 3-year follow-up. *Cornea*. 2019;38(7):859–63.
- Kim TG, Kim KY, Han JB, Jin KH. The long-term clinical outcome after corneal collagen cross-linking in Korean patients with progressive keratoconus. *Korean J Ophthalmol*. 2016;30(5):326–34.
- Miháltz K, Kovács I, Kránitz K, Erdei G, Németh J, Nagy ZZ. Mechanism of aberration balance and the effect on retinal image quality in keratoconus: optical and visual characteristics of keratoconus. *J Cataract Refract Surg*. 2011;37(5):914–22.
- Kanellopoulos AJ, Asimellis G. Keratoconus management: long-term stability of topography-guided normalization combined with high-fluence CXL stabilization (the Athens Protocol). *J Refract Surg*. 2014;30(2):88–93.
- Gretnzelos MA, Kounis GA, Diakonis VF, Siganos CS, Tsilimbaris MK, Pallikaris IG, Kymionis GD. Combined transepithelial phototherapeutic keratectomy and conventional photorefractive keratectomy followed simultaneously by corneal crosslinking for keratoconus: Cretan protocol plus. *J Cataract Refract Surg*. 2017;43(10):1257–62.
- Esteve-Taboada JJ, Domínguez-Vicent A, Ferrer-Blasco T, Alfonso JF, Montés-Micó R. Posterior chamber phakic intraocular lenses to improve visual outcomes in keratoconus patients. *J Cataract Refract Surg*. 2017;43(1):115–30.
- Piñero DP, Alió JL, Alesón A, Escaf M, Miranda M. Pentacam posterior and anterior corneal aberrations in normal and keratoconic eyes. *Clin Exp Optom*. 2009;92(3):297–303.
- Sanders DR, Vukich JA, Doney K, Gaston M. Implantable Contact Lens in Treatment of Myopia Study Group. US Food and Drug Administration clinical trial of the Implantable Collamer Lens for moderate to high myopia. *Ophthalmology*. 2003;110(2):255–66.
- Huang D, Schallhorn SC, Sugar A, Farjo AA, Majumdar PA, Trattler WB, Tanzer DJ. Phakic intraocular lens implantation for the correction of myopia: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2009;116(11):2244–58.

21. Couillet J, Guëll JL, Fournié P, Grandjean H, Gaytan J, Arné JL, Malecaze F. Iris-supported phakic lenses (rigid vs foldable version) for treating moderately high myopia: randomized paired eye comparison. *Am J Ophthalmol*. 2006;142(6):909–16.
22. Dick HB, Budo C, Malecaze F, Güell JL, Marinho AA, Nuijts RM, Luyten GP, Menezo JL, Kohnen T. Foldable Artiflex phakic intraocular lens for the correction of myopia: 2-year follow-up results of a prospective European multicenter study. *Ophthalmology*. 2009;116(4):671–7.
23. Kato N, Toda I, Hori-Komai Y, Sakai C, Arai H, Tsubota K. Phakic intraocular lens for keratoconus. *Ophthalmology*. 2011;118(3):605–6.
24. Budo C, Bartels MC, Van Rij G. Implantation of Artisan toric phakic intraocular lenses for the correction of astigmatism and spherical errors in patients with keratoconus. *J Refract Surg*. 2005;21(3):218–22.
25. Moshirfar M, Grégoire FJ, Mirzaian G, Whitehead GF, Kang PC. Use of Verisyse iris-supported phakic intraocular lens for myopia in keratoconic patients. *J Cataract Refract Surg*. 2006;32(7):1227–32.
26. Venter J. Artisan phakic intraocular lens in patients with keratoconus. *J Refract Surg*. 2009;25(9):759–64.
27. Sedaghat M, Ansari-Astaneh MR, Zarei-Ghanavati M, Davis SW, Sikder S. Artisan iris-supported phakic IOL implantation in patients with keratoconus: a review of 16 eyes. *J Refract Surg*. 2011;27(7):489–93.
28. Kohnen T, Kook D, Morral M, Güell JL. Phakic intraocular lenses: part 2: results and complications. *J Cataract Refract Surg*. 2010;36(12):2168–94.
29. Uusitalo RJ, Aine E, Sen NH, Laatikainen L. Implantable contact lens for high myopia. *J Cataract Refract Surg*. 2002;28(1):29–36.
30. Sanders DR, Doney K, Poco M. ICL in Treatment of Myopia Study Group. United States Food and Drug Administration clinical trial of the Implantable Collamer Lens (ICL) for moderate to high myopia: three-year follow-up. *Ophthalmology*. 2004;111(9):1683–92.
31. Pesando PM, Ghiringhello MP, Di Meglio G, Fanton G. Posterior chamber phakic intraocular lens (ICL) for hyperopia: ten-year follow-up. *J Cataract Refract Surg*. 2007;33(9):1579–84.
32. Alfonso JF, Palacios A, Montés-Micó R. Myopic phakic STAAR collamer posterior chamber intraocular lenses for keratoconus. *J Refract Surg*. 2008;24(9):867–74.
33. Kamiya K, Shimizu K, Ando W, Asato Y, Fujisawa T. Phakic toric Implantable Collamer Lens implantation for the correction of high myopic astigmatism in eyes with keratoconus. *J Refract Surg*. 2008;24(8):840–2.
34. Alfonso JF, Fernández-Vega L, Lisa C, Fernandes P, González-Méijome JM, Montés-Micó R. Collagen copolymer toric posterior chamber phakic intraocular lens in eyes with keratoconus. *J Cataract Refract Surg*. 2010;36(6):906–16.
35. Kamiya K, Shimizu K, Kobashi H, Igarashi A, Komatsu M, Nakamura A, Kojima T, Nakamura T. Three-year follow-up of posterior chamber toric phakic intraocular lens implantation for the correction of high myopic astigmatism in eyes with keratoconus. *Br J Ophthalmol*. 2015;99(2):177–83.
36. Kurian M, Nagappa S, Bhagali R, Shetty R, Shetty BK. Visual quality after posterior chamber phakic intraocular lens implantation in keratoconus. *J Cataract Refract Surg*. 2012;38(6):1050–7.
37. Boxer Wachler BS, Vicente LL. Optimizing the vault of collagen copolymer phakic intraocular lenses in eyes with keratoconus and myopia: comparison of 2 methods. *J Cataract Refract Surg*. 2010;36(10):1741–4.
38. García-Feijoó J, Jiménez Alfaro I, Cuiña-Sardiña R, Méndez-Hernandez C, Benítez del Castillo JM, García-Sánchez J. Ultrasound biomicroscopy examination of posterior chamber phakic intraocular lens position. *Ophthalmology*. 2003;110:163–72.
39. Koivula A, Taube M, Zetterström C. Phakic refractive lens: two-year results. *J Refract Surg*. 2008;24:507–15.
40. Baumeister M, Terzi E, Ekici Y, Kohnen T. Comparison of manual and automated methods to determine horizontal corneal diameter. *J Cataract Refract Surg*. 2004;30:374–80.
41. Park SC, Kwun YK, Chung E-S, Ahn K, Chung T-Y. Postoperative astigmatism and axis stability after implantation of the STAAR Toric Implantable Collamer Lens. *J Refract Surg*. 2009;25:403–9.
42. Tehrani M, Dick HB, Schwenn O, Blom E, Schmidt AH, Koch H-R. Postoperative astigmatism and rotational stability after Artisan toric phakic intraocular lens implantation. *J Cataract Refract Surg*. 2003;29:1761–6.
43. Maloney RK, Nguyen LH, John ME. Artisan phakic intraocular lens for myopia; short-term results of a prospective, multicenter study; the Artisan Lens Study Group. *Ophthalmology*. 2002;109:1631–41.

44. Yoon H, Macaluso DC, Moshirfar M, Lundergan M. Traumatic dislocation of an Ophtec Artisan phakic intraocular lens. *J Refract Surg.* 2002;18:481–3.
45. Baumeister M, Bühren J, Kohnen T. Position of angle-supported, iris-fixated, and ciliary sulcus-implanted myopic phakic intraocular lenses evaluated by Scheimpflug photography. *Am J Ophthalmol.* 2004;138:723–31.
46. Alió JL, Peña-García P, Abdulla GF, Zein G, Abu-Mustafa SK. Comparison of iris-claw and posterior chamber collagen copolymer phakic intraocular lenses in keratoconus. *J Cataract Refract Surg.* 2014;40:383–94.
47. Celikkol L, Ahn D, Celikkol G, Feldman ST. Calculating intraocular lens power in eyes with keratoconus using videokeratography. *J Cataract Refract Surg.* 1996;22(4):497–500.
48. Park DY, Lim DH, Chung TY, Chung ES. Intraocular lens power calculations in a patient with posterior keratoconus. *Cornea.* 2013;32(5):708–11.
49. Camps VJ, Piñero DP, Caravaca-Arens E, de Fez D, Pérez-Cambrodí RJ, Artola A. New approach for correction of error associated with keratometric estimation of corneal power in keratoconus. *Cornea.* 2014;33(9):960–7.
50. Tamaoki A, Kojima T, Hasegawa A, Nakamura H, Tanaka K, Ichikawa K. Intraocular lens power calculation in cases with posterior keratoconus. *J Cataract Refract Surg.* 2015;41(10):2190–5.
51. Bozorg S, Pineda R. Cataract and keratoconus: minimizing complications in intraocular lens calculations. *Semin Ophthalmol.* 2014;29(5–6):376–9.
52. Russell M, Gaskin B, Russell D, Polkinghorne PJ. Pseudophakic retinal detachment after phacoemulsification cataract surgery: ten-year retrospective review. *J Cataract Refract Surg.* 2006;32(3):442–5.
53. Colin J, Robinet A, Cochener B. Retinal detachment after clear lens extraction for high myopia: seven-year follow-up. *Ophthalmology.* 1999;106(12):2281–4 (**discussion 2285**).
54. Petousis V, Sallam AA, Haynes RJ, Patel CK, Tyagi AK, Kirkpatrick JN, Johnston RL. Risk factors for retinal detachment following cataract surgery: the impact of posterior capsular rupture. *Br J Ophthalmol.* 2016;100(11):1461–5.
55. Day AC, Donachie PHJ, Sparrow JM, Johnston RL. Royal College of Ophthalmologists' National Ophthalmology Database: United Kingdom National Ophthalmology Database Study of Cataract Surgery: Report 3: pseudophakic retinal detachment. *Ophthalmology.* 2016;123(8):1711–5.
56. Moshirfar M, Walker BD, Birdsong OC. Cataract surgery in eyes with keratoconus: a review of the current literature. *Curr Opin Ophthalmol.* 2018;29(1):75–80.
57. Leccisotti A. Refractive lens exchange in keratoconus. *J Cataract Refract Surg.* 2006;32(5):742–6.
58. Watson MP, Anand S, Bhogal M, Gore D, Moriyama A, Pullum K, Hau S, Tuft SJ. Cataract surgery outcome in eyes with keratoconus. *Br J Ophthalmol.* 2014;98(3):361–4.
59. Kamiya K, Iijima K, Nobuyuki S, Mori Y, Miyata K, Yamaguchi T, Shimazaki J, Watanabe S, Maeda N. Predictability of intraocular lens power calculation for cataract with keratoconus: a multicenter study. *Sci Rep.* 2018;8(1). <https://doi.org/10.1038/s41598-018-20040-w>.
60. Kugler LJ, Sztipanovits D, Wang M. Contraindications to implantation of toric IOLs. *Refract Eyecare.* 2011;15(3):26–8.
61. Luck J. Customized ultra-high-power toric intraocular lens implantation for pellucid marginal degeneration and cataract. *J Cataract Refract Surg.* 2010;36(7):1235–8.
62. Sauder G, Jonas JB. Treatment of keratoconus by toric foldable intraocular lenses. *Eur J Ophthalmol.* 2003;13(6):577–9.
63. Navas A, Suárez R. One-year follow-up of toric intraocular lens implantation in forme fruste keratoconus. *J Cataract Refract Surg.* 2009;35(11):2024–7.
64. Visser N, Gast ST, Bauer NJ, Nuijts RM. Cataract surgery with toric intraocular lens implantation in keratoconus: a case report. *Cornea.* 2011;30(6):720–3.
65. Jaimes M, Xacur-García F, Alvarez-Melloni D, Graue-Hernández EO, Ramirez-Luquín T, Navas A. Refractive lens exchange with toric intraocular lenses in keratoconus. *J Refract Surg.* 2011;27(9):658–64.
66. Nanavaty MA, Lake DB, Daya SM. Outcomes of pseudophakic toric intraocular lens implantation in keratoconic eyes with cataract. *J Refract Surg.* 2012;28(12):884–9.
67. Alió JL, Peña-García P, Abdulla Guliyeva F, Soria FA, Zein G, Abu-Mustafa SK. MICS with toric intraocular lenses in keratoconus: outcomes and predictability analysis of postoperative refraction. *Br J Ophthalmol.* 2014;98(3):365–70.

68. Kamiya K, Shimizu K, Miyake T. Changes in astigmatism and corneal higher-order aberrations after phacoemulsification with toric intraocular lens implantation for mild keratoconus with cataract. *Jpn J Ophthalmol*. 2016;60(4):302–8.
69. Visser N, Nuijts RM, de Vries NE, Bauer NJ. Visual outcomes and patient satisfaction after cataract surgery with toric multifocal intraocular lens implantation. *J Cataract Refract Surg*. 2011;37(11):2034–42.
70. Kretz FT, Breyer D, Klabe K, Hagen P, Kaymak H, Koss MJ, Gerl M, Mueller M, Gerl RH, Auffarth GU. Clinical outcomes after implantation of a trifocal toric intraocular lens. *J Refract Surg*. 2015;31(8):504–10.
71. Montano M, López-Dorantes KP, Ramirez-Miranda A, Graue-Hernández EO, Navas A. Multifocal toric intraocular lens implantation for forme fruste and stable keratoconus. *J Refract Surg*. 2014;30(4):282–5.
72. Hashemi H, Yekta A, Khabazkhoob M. Effect of keratoconus grades on repeatability of keratometry readings: comparison of 5 devices. *J Cataract Refract Surg*. 2015;41(5):1065–72.
73. Yağcı R, Kulak AE, Güler E, Tenlik A, Güragaç FB, Hepşen IF. Comparison of anterior segment measurements with a dual Scheimpflug Placido corneal topographer and a new partial coherence interferometer in keratoconic eyes. *Cornea*. 2015;34(9):1012–8.