How to Regularize Corneal Shape Before Cataract Surgery

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Received: September 28, 2020; Published: November 27, 2020

Abstract

Phototherapeutic keratectomy (PTK) is a surgical technique that aims to remove corneal irregularities using the excimer laser. Specifically, the sequential customized therapeutic keratectomy (SCTK) allows the execution of a personalized ablative treatment that allows to correct high order aberrations (HOAs). A core concept of SCTK procedure is the greater impact of corneal regularity over corneal transparency on vision quality. SCTK prior to IOL implantation cataract surgery, in aberrated corneas, has the potential to dramatically change the final result in terms of visual quality, biometry accuracy and patient satisfaction. The main objective of SCTK before cataract surgery with IOL implantation is therefore to eliminate, or in any case reduce, HOAs, without worrying about the refractive defect that may remain. The residual ametropia can be corrected with cataract surgery, thus the SCTK result can be achieved with minimal ablation depths, preserving as much tissue as possible, enabling even treatment in previously treated and thin corneas. The priority is to improve cornea regularity in order to optimize both, IOL selection and final quality vision of the patient. In this article we describe the benefits deriving from performing SCTK before cataract surgery from the surgeon and the patients’ point of view.

Keywords: High Order Aberration (HOA); Cataract Surgery; Phototherapeutic Keratectomy (PTK); Sequential Customized Therapeutic Keratectomy (SCTK)

Introduction

Phototherapeutic keratectomy (PTK) is a surgical technique that aims to remove corneal irregularities using the excimer laser. Recently, the introduction of customized refractive treatments has awakened new enthusiasm for PTK on the international scene. Specifically, the sequential customized therapeutic keratectomy (SCTK) allows the execution of a personalized ablative treatment that allows to correct high order aberrations (HOAs) using aberrometric data acquired step-by-step, during the course of the treatment itself, in order to improve the final outcome. One of the many emerging roles of SCTK is to achieve the best visual acuity in eyes with corneal irregularities that require cataract surgery. In these cases, in fact, SCTK can be performed before phacoemulsification with intraocular lens (IOL) implantation with the sole purpose of optimizing the shape and regularity of the cornea, reducing HOAs and guaranteeing the best visual result even in extreme cases, such as decentralized refractive treatments, ulcers, or trauma [1]. Moreover, the optimization of corneal shape and surface regularity results in an improved IOL calculation, due to more affordable preoperative biometric analysis.

The main advantage of this technique lies in the fact that, in patients who will undergo cataract surgery, customized ablation does not have the limit of having to treat the patient’s hyperopia or myopia, but only to regularize the corneal surface giving it a prolate shape. Furthermore, without this limit, the result can be achieved with minimal ablation depths and thus preserving as much tissue as possible. Afterwards, the spherical defects can be corrected with the implantation of the IOL during cataract surgery.

The main objective of SCTK is therefore to eliminate, or in any case reduce, HOAs, without worrying about the refractive defect that may remain. The priority is to improve the quality of the patient’s vision, not to eliminate the residual ametropia which can be corrected with cataract surgery. On the contrary, performing cataract surgery before a possible SCTK would make the treatment unsatisfactory as it would be limited by the need to take into account hyperopia or myopia which would require major tissue ablations.

In recent years, it has become increasingly common to have cataract surgery in patients who have previously undergone corneal surgery, such as excimer laser or radial keratotomies or patients with corneal surface abnormalities, due to leukomas or dystrophies. These categories of patients can greatly benefit from performing a SCTK before cataract surgery as aberrated corneas can often cause errors, even important ones, in calculating the IOL to be implanted. Furthermore, even with a correct biometric calculation, the visual quality would remain poor due to the aberrations and corneal irregularities.

The optical aberrations

The aberrations of an optical system are deviations from a perfect mathematical model for which the rays coming from infinity do not focus on a single point. In the human eye, they can determine an important limitation of vision. The introduction of new technologies, which make it possible to quantify the quality and quantity of optical aberrations of an eye, have opened up new possibilities for the study of visual quality. Optical aberrations are divided into LOAs and HOAs. Low-order aberrations include regular astigmatism, positive defocus (myopia) and negative defocus (hyperopia) and although these defects have an important impact on vision, they can be corrected with spherical or toric lenses. Otherwise, HOAs, often not considered or underestimated by ophthalmologists, cause a sharp decrease in visual acuity but cannot be corrected with any type of lens. The aberrations located near the center of the Zernike pyramid, in particular spherical aberration, coma and secondary astigmatism, are the most relevant from the point of view of visual quality. HOAs are divided into even order, such as spherical aberration and secondary astigmatism, and odd order, such as coma and trefoil. The even order determine a reduction in contrast sensitivity; the odd order a reduction in visual resolution. Visual quality is necessarily dependent on both good resolution and good contrast. Specifically, contrast sensitivity is defined as the ability to discriminate differences in luminance between neighboring areas and, although not tested during a routine eye examination, it is a key feature for good visual quality.

Eliminating HOAs is essential to obtain a good visual result, but currently there are no IOLs capable of partially or totally correcting these defects. Consequently, IOL implantation in an eye with corneal HOAs will certainly result in poor post-operative visual quality and frustration not only for the patient, but also for the ophthalmologist. In fact, this kind of occurrence usually leads the patient to the wrong conviction that the suboptimal post-operative visual acuity is due to mistakes in the surgical performance, consequently undermining the doctor-patient relationship. For this reason, it is always recommended to perform an aberrometry in the preoperative phase of cataract surgery, which would allow to select the most suitable patients and who would benefit most from a pre-cataract SCTK.

Theoretical rational of performing SCTK before cataract surgery

The aim of performing SCTK before cataract surgery is to regularize the corneal surface: this allows us to eliminate the HOAs that determine a high impact on contrast sensibility and visual acuity of the patient [2].
In fact, a core concept of SCTK procedure is the greater impact of corneal regularity over corneal transparency on vision quality [3].

The concept can be exemplified by an everyday life instance: a window glass is a transparent media and the rain drops on its surface are transparent as well; nevertheless, a window glass covered in rain drops doesn’t allow us to see through it and this is due to the irregularity of the refractive surface as a whole. Unlike, a pair of sunglasses permits a good vision quality despite being not perfectly transparent thanks to the regularity of the lenses. A clinical scenario in which this concept is evident is punctate keratopathy: patients affected by this condition usually present with both a subjective and objective drop in visual acuity that is not accompanied by significant corneal opacities. The explanation of this phenomenon is that punctate keratopathy causes defects and alterations in corneal epithelium layer that affect largely the corneal surface regularity.

By contrast, LOAs and corneal opacities should not be the main target of the treatment.

In fact, not only LOAs can be optimally corrected with cataract surgery but this brings also another big advantage, that is the sparing of a great amount of corneal tissue that would have been sacrificed in the correction of defocus and astigmatism [4]. By consequence, elevated residual spherical and astigmatic defects must be expected at the end of the SCTK procedure compared to the preoperative condition. This residual refractive error will then be corrected by the appropriate IOL calculation and implant in the context of phacoemulsification for cataract removal. The correction of a residual refractive error after cataract surgery, by contrast, requires an IOL-exchange or an Add-on IOL procedure. The timing of SCTK is therefore very important: it is essential that the procedure is performed before cataract surgery [5].

**Cases**

**Case 1: SCTK pre-cataract surgery in decentrated myopic PRK with residual HOA defects: an example of the results that can be achieved postponing LOAs correction**

In 1998 a 68-year-old female patient had undergone PRK in order to correct a 6-diopter myopia in her left eye (LE). Unfortunately, high HOAs have resideded after the treatment due to an incorrect centration of the laser ablation. In 2019 the patient was referred to our Eye Clinic because of impaired vision in both eyes. In her LE a dense cataract was observed and corrected distance visual acuity (CDVA) was 0.1 with -1.25 sph -1.25 cyl/145°. In order to ensure the best visual results for the patient, a SCTK before cataract extraction was proposed. The SCTK aimed to achieve a more regular corneal pattern in order to decrease the HOAs and calculate the biometry more accurately (Figure 1A and 1B). In detail, the treatment did not target emmetropic and the spherical defect was not taken into account. In this case, a higher myopia was intentionally induced on the patient, whose post-SCTK CDVA was 0.5 with - 6.25 sph - 0.75 cyl/155°. Therefore, the SCTK has allowed a regularization of the surface while saving tissue in an already thin cornea (Figure 1C). Finally, a more precise calculation of the K values to insert in the biometric formula was achieved. The IOL implant allowed the complete correction of the myopic defect induced by the SCTK and the final CDVA of the patient’s LE was 1.0 with - 0.25 sph - 1 cyl/140°.

The sparing of corneal tissue is of utmost importance in the case of post-refractive patients or previous corneal ulcerations. In these cases, the residual corneal thickness must be optimized in order to avoid the development of corneal ectasia [6].
Furthermore, it is essential to eliminate HOAs that couldn’t be corrected by cataract surgery alone. In this perspective, it should be reminded that SCTK is in the first place a therapeutic treatment, so great attention should be addressed to the preservation of biomechanical stability of the cornea [7].

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Case 2: SCTK pre-cataract surgery in patient with previous myopic PRK and corneal haze. Elevated spherical defect residuated after the treatment, then corrected with cataract surgery, in order to spare tissue in a previously treated cornea

This is the case of a 66-year-old male patient who underwent PRK in 1992 for correction of myopia equal to 4 diopters in the right eye. HOAs derived from the decentered treatment caused the patient a poor perceived visual quality and a suboptimal final visual acuity (0.5 with -7.50 sph - 1.25 cyl/100°). Moreover, the cornea of the treated eye was affected by a persistent annular corneal haze. Following treatment with SCTK and mitomycin C, the patient was brought to a vision of 0.7 with correction equal to -16 sph - 2 cyl/80°. Finally, he was subjected to phacoemulsification with IOL implantation, reaching a visual acuity of 1.0 with a correction equal to -0.25 sph - 0.75 cyl/85°. We can see how sacrificing the correction of the defocus error allowed a better correction of the coma and spherical aberrations and also led us to the loss of only 27 microns in corneal thickness in the thinnest point, which was 486 microns in thickness before the treatment. The spherical error was eventually corrected by means of the implant of the appropriately calculated IOL during cataract surgery. The pre and post SCTK pachymetric and tangential topographic maps and the variation of the aberrometric wave frame after treatment are illustrated in figure 2A-2C.

Another aspect to take into account is the influence of HOAs on the IOL calculation. In fact, every biometric formula requires the exact evaluation of the mean dioptric power of the steepest and the flattest meridian (K1 and K2) in order to predict the correct power of the IOL that should be implanted. The weight of these parameters on the calculation is even higher compared to the weight of the axial length. By consequence, if they are incorrectly acquired, as in the case of corneas affected by HOAs, it will reflect into a residual refractive error of the patient after cataract surgery. The regularization of the corneal surface after SCTK treatment would therefore have a positive effect on the accuracy of preoperative measurements of corneal power, providing the surgeon with a higher confidence on the IOL to be implanted.
**Figure 2A:** From left to right, the tangential map before SCTK, the tangential map after the treatment and the differential map between the two are shown.

**Figure 2B:** From left to right, the pachymetric map before SCTK, the pachymetric map after the treatment and the differential map between the two are shown.

**Figure 2C:** Aberrometric wavefront pre (left figure, Rms = 1.99µm) and post (right figure, Rms = 0.34 µm) SCTK.
Case 3: SCTK pre-cataract surgery in a patient with pterygium: a therapeutic success in a highly irregular cornea

A good example of the abovementioned degree of priority during the treatment can be detected in the case of a 68-year-old male patient, subjected to surgical removal of pterygium in the left eye and subsequent removal of 3 relapses, that arrived at our center showing a CDVA 0.3 (+7.75 sph -5 cyl/10°) in the left eye, caused by an extreme irregularity of the corneal surface accompanied by a central corneal leukoma as a result of previous surgery. The patient underwent a first treatment with avastin intralesional injection. He was subsequently subjected to treatment with SCTK and mitomycin C for adjuvant purposes, which led the patient to a vision of 0.8 (+ 4.50 sph - 0.75 cyl/180°). Subsequently, phacoemulsification with IOL implantation was performed, an operation that has led the patient to date to a natural visual acuity of 1.0. It is interesting to note that during the course of the treatment, regularization of the corneal surface was maintained as the main objective and the elimination of corneal astigmatism was maintained as a second priority. The spherical defect was instead overlooked, as its resolution was demanded to cataract surgery, allowing a considerable saving of tissue and a better result in terms of canceling the remaining optical aberrations. Lastly, IOL calculation was made much more accurate by the prior elimination of HOAs. This demonstrates how this scale of priorities is the optimal strategy in a long term perspective: not only it takes into account the eye of the patient as a whole but it also implies the concept to not settle for a suboptimal result. The variations in keratoscopy and in the tangential topographic map of the left eye following the various phases of the therapeutic process are represented respectively in figure 3A and 3B.

Figure 3A: The first image on the left shows the keratoscopy prior to avastin injection (visual acuity = 0.3). The central image shows the keratoscopy following avastin injection. Finally, the last image is the keratoscopy following SCTK treatment (visual acuity = 0.8).

Figure 3B: From left to right, the tangential topographic maps relating respectively to the cornea prior to avastin injection (visual acuity of 0.3 with 7.75 sph -5 cyl/10°), following avastin injection and after SCTK treatment (visual acuity of 0.8 with +4.50 sph -0.75 cyl/180°). The reduction of the differential curvature and the regularization of the corneal surface during the treatment are clear.

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Indications

Pathological conditions

- Superficial stromal dystrophies and degenerations.
- Recurrent erosions.
- Traumatic, surgical or post-infective leukoma.
- Corneal neovascularization.

Post refractive surgery

- PRK (postoperative corneal irregularities or opacities; small optic zones; decentered ablations).
- LASIK (decentered treatments; postoperative corneal irregularities or opacities; small optic zones; interface opacities).

Case 4: Pre-cataract SCTK surgery in a patient with previous radial keratotomy and huge corneal aberrations

A 47-year-old male patient, who underwent radial keratotomy in 1996 (8 radial cuts and preoperative refraction - 5.00 sph). The CDVA before the SCTK surgery was 0.3 (+ 2.50 sph - 5.00 cyl/15°), the patient showed on the tangential map (Figure 4A) a very narrow optical zone, with a very high curvature gradient, passing from 31 D to 50 D in 1 mm. This patient therefore presented an important positive spherical aberration, with a significant reduction in contrast sensitivity, already in photopic conditions, due to the narrow optical zone. In addition, it had an area of hyper curvature in the lower part of the optical zone, with a less specular curved area in the upper part of the optical zone: this generated a high-order optical aberration corresponding to coma, which significantly affected visual acuity.

Two months after the SCTK treatment (Figure 4B) the patient showed physiological optic zone, regularized surface and restored curvature gradient. CDVA was 0.9 (- 2.00 sph - 0.50 cyl/20°).

9 months after SCTK surgery (Figure 4C), the surface has reached a higher level of regularization, thanks to epithelium compensation: CDVA stabilized at 1.0 (- 2.00 sph - 0.50 cyl/10°). The patient would now be in the future a good candidate for IOL implantation.

Case 5: Pre-cataract SCTK in a patient with previous flap overgrowth in LASIK

Another case we report is a 58-year-old man who underwent LASIK in 2000 to correct a myopia of 14 diopters. The patient who came to our attention in 2017 presented a CDVA of 0.3 (- 0.50 sph - 0.50 cyl/20°). The OCT of the anterior segment and the pre-operative topographic maps are shown in figure 5A.

He underwent SCTK in 2017, after which he presented a CDVA of 0.4 (- 7.25 sph - 1 cyl/30°). The treatment achieved a regularization of the corneal surface as evidenced by OCT of the anterior segment and post-operative topographies maps as shown in figure 5B. Finally, cataract surgery was performed by implanting a + 13.5 Diopter lens with a CDVA of 1.0 with - 0.25 sph.

Figure 4: A. Preoperative tangential map. B. Tangential map two months after treatment. C. Tangential maps 9 months after treatment.

Figure 5A: Baseline images. At the top the OCT of the anterior segment is shown, from left to right the tangential map, the pachymetry and the epithelial map are shown. The tangential map shows a paracentral hyperprolature in outcomes of LASIK.
The final result is a patient who reported a spherical aberration improvement from 0.37 to 0.12 micron, a coma from 2.38 to 0.04 micron, a trefoil from 0.89 to 0.18 microns, and the remaining high order aberrations from 2.6 to 0.24 micron.

**Case 6: Pre- cataract SCTK in a patient with corneal irregularity following herpetic disciform keratitis**

We report a case of a 72 years old man with corneal irregularity following herpetic disciform keratitis in the right eye. The maps show a thinner inferotemporal area characterized by a low dioptric power and a steep surrounding area, therefore resulting in a significant coma...
The patient came with a CDVA of 0.4 (+ 2.25 sph, - 8 cyl/35°), with high spherical aberration, coma and others HOAs.

He underwent SCTK in 2020, the purpose of the treatment was to eliminate HOAs taking into account the thin area of the ulcer. The final result is a CDVA of 0.8 (- 6 cyl/20°) with a more regular surface and a reduction in HOAs. We highlight that in the thinnest point the

**Figure 6B:** From left to right: pachymetric map before treatment, during the sequences and at the end of the ablation.

**Figure 6C:** Intraoperative differential pachymetric map between Pre and Post SCTK shows a difference of only 41 microns in the thin area of the ulcer.

The intraoperative pachymetric difference between pre and post-SCTK was of only 41 microns, meaning that only the epithelium has been removed in this area and the result has been achieved by treating the surrounding area.

We therefore expect an improvement in the surface regularization with the re-epithelization. The patient is now eligible for a toric IOL implant to correct residual astigmatism with a complete resolution of the residual refractive defect.

**Discussion and Conclusion**

SCTK prior to IOL implantation cataract surgery has the potential to dramatically change the final result in terms of visual quality and patient satisfaction and should therefore become part of daily practice in suitable patients. In fact, the SCTK treatment aims to regularize the cornea and consequently achieve optimal visual quality, thanks to the reduction or elimination of obstacles such as diffuse fine irregularities and anomalies in the shape and profile of the cornea, or opacity of the optical surface area. The timing of SCTK is critical: laser ablation must be performed prior to cataract surgery with IOL implantation.

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The reason for the importance of this chronological sequence must be sought in the first place in the fact that this allows a drastic change in the patient’s perception of visual improvement after cataract surgery, thus leaving a feeling of complete resolution of the preoperative discomfort. In addition, regularizing the cornea allows the optimization of the instrumental effectiveness of IOL calculation. Furthermore, it allows the surgeon to even be able to propose the implantation of a multifocal lens in some selected patients, a choice otherwise not applicable in the case of the presence of HOAs, which could result in poor final visual quality.

Another important aspect to consider is the non-refractive nature of SCTK treatment if performed prior to cataract surgery with IOL implantation: since there is no need to achieve a spherical correction, ablation is limited to depth and volume and aimed at the sole purpose of regularizing the corneal surface. The reduced invasiveness of ablation also allows for stability of results over time. In consideration of the above, the same importance must be given to the personalization of the therapeutic options: a careful selection of patients eligible for this procedure and the possibility of performing a customized ablation are of crucial importance for the execution and optimization of this therapeutic approach.

In this perspective, we encourage and appreciate the participation of the eye community in the application of this procedure and we hope that this contribution will be useful in everyday clinical practice.

Bibliography

Volume 11 Issue 12 December 2020
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