RESEARCH ARTICLE

Effect of Circular Keratotomy on Progression of Keratoconus

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ABSTRACT

Purpose: Studies on keratoconus treatment with regard to the stage of the disease have not been published. We evaluated patient outcomes over a 5-year period after circular keratotomy (CKT) to treat stage I and II progressive keratoconus.

Setting: Clinic Krumeich, Bochum, Germany.

Design: Retrospective clinical study.

Materials and methods: We retrospectively evaluated the outcomes of 185 consecutive CKT procedures to treat early, progressing keratoconus. A 7-mm trephine incision, with a depth that was 90% of the thinnest pachymetry value but not less than 400 µm, was made with the guided trephine system concentric to the pupil and sutured with a double running anti-torque suture. Keratometry readings and astigmatism measurements at 1-year postsurgery were compared with values obtained at 3 and 5 years postsurgery. Preoperative values of best-corrected visual acuity with glasses were compared with values obtained at 3 and 5 years postsurgery. Statistical analyses for significance were performed.

Results: Keratometric readings revealed stability at 5 years postsurgery in 84.3% (n = 51) of those eyes for which all values at all time points were available. Likewise, astigmatism values revealed stability in 92.2% of eyes. Best-corrected visual acuity improved significantly from preoperative to 5 years in 73.68% (n = 38). Best-corrected visual acuity did not change in 18.42% (n = 36).

Conclusion: Circular keratotomy halted the progression of early-stage keratoconus for at least 5 years in 84.3% of the eyes studied. The stable keratometric results suggest that CKT treatment should be considered for patients diagnosed early in the progression of this disease.

Keywords: Circular keratotomy, Guided trephine system, Keratoconus treatment.

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INTRODUCTION

Currently, no treatment for keratoconus has been conclusively demonstrated to stop progression of the disease in its early stages. Little information exists to help corneal surgeons decide which initial treatment procedure to use for patients presenting with stage I or stage II keratoconus, nor can surgeons reliably evaluate the likelihood that an intervention will succeed clinically.

One treatment that has been investigated utilizes intrastromal ring segments to regularize the corneal contours and improve vision, and it has been reported to be effective in approximately 8% of early-stage keratoconus cases.[1] More recently, for Keratokonus with parenchymas thicker than 350 µm, the Cisis/MyoRing (DIOPTEX, Linz), a closed ring of 5 to 8 mm polymethyl methacrylate, is inserted in a pocket,[2] with no current basis for judgment due to very small groups and short follow-up.

The corneal surgery community enthusiastically reacted to reports of positive outcomes after corneal collagen cross-linking (CXL) via ultraviolet-A (UV-A) irradiation plus riboflavin.[3,4] The CXL was introduced in 2003 in Dresden, Germany, by Wollensak et al,[3] who developed a standard UV-A/riboflavin treatment protocol. Since then, several modifications have been suggested to optimize this primary schema.[4] Both intrastromal ring segments and CXL can postpone the need for subsequent invasive interventions, namely deep anterior lamellar keratoplasty (DALK) or penetrating keratoplasty.

In 2009, Krumeich and Kezirian[5] published a paper describing circular keratotomy (CKT), a corneal thickness-based partial trephination surgery, as a possible means of stopping keratoconus early in the course of the disease and for an extended period of time. Unlike radial keratotomy, CKT works by creating a rigid, circular scar with a minimum length of 400 µm, thereby strengthening the cornea. In that first study's case series (46 eyes from 36 patients), astigmatic changes stabilized within the 1st postoperative year in 19/28 (64%) eyes examined at 1 year and ≥2 years postoperatively. Furthermore, the astigmatism changed by ≤2.00 Dioptres (D) in 17 (94%) of these stabilized eyes between year 1 and the final examination.

The present study is an updated and expanded version of the 2009 report and utilizes a larger cohort, longer follow-up, and more extensive evaluations of visual acuity and astigmatism. In addition, the operative process was slightly modified.

MATERIALS AND METHODS

Study Design

The CKT procedures, follow-up exams, and the compilation of patient data for analysis were performed by one surgeon (JHK) at a single outpatient clinic in Bochum, Germany.

The study cohort consisted of consecutive surgeries over a 16-year period (1994–2010) and was initially thought to bridge progression phases in which CKT was performed to treat stage I or stage II keratoconus, according to the Krumeich clinical classification.[1] Stage I is characterized by eccentric steepening, induced myopia, and/or astigmatism of <5 D, a K-reading of ≤48 D, Vogt's lines or typical eccentric topography. In stage II, induced myopia and/or astigmatism ranges between 5 D and 8 D, the K-reading is ≤53.00 D, and pachymetry reveals a corneal thickness ≥400 µm. The stage of the disease is determined by the presence of any one of the characteristics.

All eyes included in the study were checked for progression by our own clinic, or they were sent by colleagues with the diagnosis of progressive keratoconus, or they had to have a change of glasses of more than 1 D within a year. When it became obvious that the procedure's effects were long-lasting, we decided to perform systematic evaluations 1, 3, and 5 years after the initial procedure. We considered a patient's disease to be progressive if there had been a shift in keratometric astigmatism >1.5 D or a loss of >1 line of Snellen visual acuity (best-corrected visual acuity, BCVA with glasses) within 1 year prior to surgery. Sex and age were not considered as inclusion criteria but were considered in the subsequent statistical analyses. The ophthalmological criteria for CKT were a minimum corneal thickness of 450 µm at the 7-mm site around the pupil and no previous corneal surgery or CXL.

Surgeries were performed using the guided trephine system (Polytech, Rossdorf, Germany), which has a CE Mark for partial or total corneal trephination. Each patient signed an informed consent form describing the procedure and the uncertainty of the procedure outcomes. The use of a CE-certified medical device (GTS) in line with its purpose was submitted to the Ethics Committee of the University of Muenster, which concluded that no further application for ethical approval was necessary.

Corneal analyses included manifest refraction, optical power mapping, corneal curvature, and topography with a scanning-slit topographer (Orbscan, Bausch & Lomb, Rochester, NY, USA), endothelial cell counting via specular microscopy (SP-1000, TOPCON, Willich, Germany), manual keratometry (Bausch & Lomb, Rochester, NY, USA), and automated keratometry (KM-500 NIDEK, Aichi, Japan). The same instruments were used for each follow-up assessment.

Surgical Procedure

In 157 patients (85%), the anesthesia was peribulbar; the remaining patients preferred general anesthesia.

The mid-pupillary projection was marked with gentian violet, and 8 circular bar lines were applied with a radial keratotomy marker. The guided trephine system was zeroed on a drum made by a dish covered with a flexible plastic sheath. The obturator – a glass body consisting of a dome-shaped surface inside the trephine – was chosen based on the keratometric measurements obtained for each patient's eye. The lower end of the obturator was chosen to match the mean radius of the patient's cornea. The irregularly astigmatic corneal surface was thereby averaged during the cut to simulate the postoperative situation.

Using this setup, the cut was applied in 4 × 100-µm intervals. The depth of the cut was verified with a tire profile-like device. If the exact intended depth was not obtained, the cut was completed via reapplication of the guided trephine system.

Treated corneas were sutured using a double-running anti-torque suture. Each suture had 8 bites crossing each other, forming neutralizing vectors from the corneal periphery to the center and vice versa (Fig. 1).

Clinical Outcomes

To determine if the progression of keratoconus would be halted by the treatment described above, we evaluated the stability of K-readings.

We noted during the evaluation that not one but three criteria were influenced by the procedure used to assess postoperative corneal stability, which were keratometry, astigmatism, and BCVA. Because we could not foresee
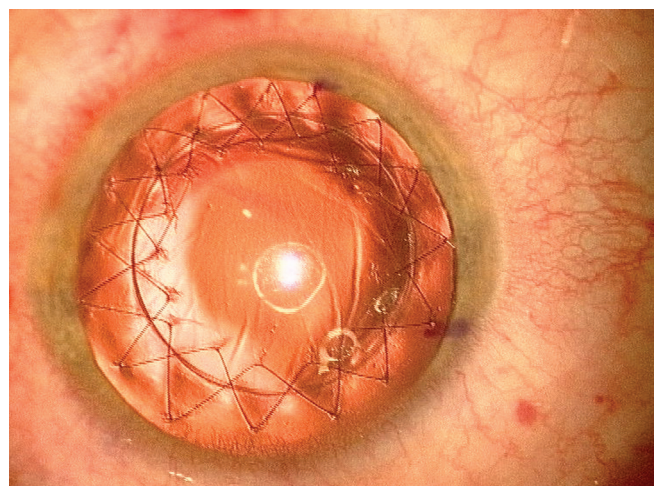

Fig. 1: Double-running anti-torque suture

that changes would occur to astigmatism and BCVA, we did not record all measurements at all time points to begin with. Only 51 eyes of the above group had all data at all time points, so these were the eyes that were analyzed statistically. For keratometry and astigmatism, we used the 1-year values as the baseline because the creation of the scar must have been effectuated before comparisons could be made. For BCVA, the preoperative value was used as baseline because it gave the clearest picture of the postoperative results obtained by the procedure.

Progression was defined for each metric as follows:
- Keratometry – Steepening of >1.5 D in the mean K-readings.
- Astigmatism – A change in the eye's astigmatism of >1.5 D in all consecutive follow-up visits.
- BCVA with glasses – A BCVA change of >1 Snellen line, better or worse, compared with the preoperative value.

Additionally, the treated eyes were assessed for evidence of acute corneal steepening after the sutures were removed. Immediately after removal, the radii of curvature were measured using the Orbscan imaging system and were remeasured 1 day later to determine if steepening had occurred. Because no changes in corneal radii were observed on corneas beyond 4 months postoperatively, sutures that became loose were removed at 4 to 6 months after surgery, whereas the standard was to leave them in for 12 months.

Statistical Analysis

Data were compiled by nonparticipating employees. Statistical analyses were performed using Microsoft Excel 14.0 for Mac (Microsoft, Redmond, Washington, USA) with a Statplus Mac version 5.8.3.8 plug-in (AnalystSoft, Walnut, CA, USA) and an Xlstat 2012 plug-in (Addinsoft, New York, NY, USA).

In the first step, all data were evaluated with regard to their distributions using the Kolmogorov–Smirnov test. Because the data were not normally distributed, nonparametric testing was performed. Pairwise comparison of metric data was performed using the Wilcoxon signed rank test, and nonmetric data were tested using the chi-square test. A p-value < 0.05 was considered significant.

Although other indicators were tracked in this study, we focused solely on the behaviors of the following two indicators for evidence of statistically significant progression of keratoconus in the treated eyes: (1) keratometric changes of >1.5 D and (2) changes in astigmatism of >1.5 D.

RESULTS

Patient Characteristics

In total, records from 185 eyes were examined for this study. As explained above, only the eyes with complete data at all

time points for keratometry (n=51), astigmatism (n=51), and BCVA (n=38) were analyzed and considered outcomes of this study. A parallel evaluation of those eyes that did not have all time point measurements was conducted to determine if the larger number of operated eyes would yield similar results. In the larger branch of this study, we have results of keratometry readings and astigmatism measurements at 3 years (n=114) as well as at 5 years postsurgery (n=67). The BCVA measurements are at 1 year (n=138), 3 years (n=79), and 5 years postsurgery (n=46).

Statistical Outcomes

Keratometry Main Group

Keratometry measurements exhibited stability at 3 and 5 years after CKT in 90.2 and 84.3% of eyes (n=51). The differences in keratometric values obtained at various time points are presented in Graph 1. The mean K-value at the 3 and 5-year follow-up was 46.46 D (SD: 2.44; range: 51.10–50.88) and 46.64 D (SD: 2.52; range: 40.20–51.00) respectively. The change in mean K-value was 0.376 D (SD: 0.959; range: –1.440–3.050, p=0.843) and 0.554 D (SD: 1.321; range: –3.450–3.770, p=0.661) respectively.

Keratometry Comparison Group

Keratometry measurements exhibited stability at 3 and 5 years after CKT in 88.6% (n=114) and 82.09% of eyes (n=67) respectively. The mean K-value was 46.40 D (SD: 2.37; range: 41.1–51.15) and 46.36 D (SD: 2.72; range: 40.00–51.00) at 3 and 5 years respectively. The mean change in K-value was 0.77 D (SD: 0.82; range: 0.00–4.15) and 0.58 D (SD: 1.45; range: –3.45–4.50) respectively.

Astigmatism Main Group

Astigmatism measurements exhibited stability at 3 and 5 years after CKT in 92.2 and 92.2% of the eyes (n=51).
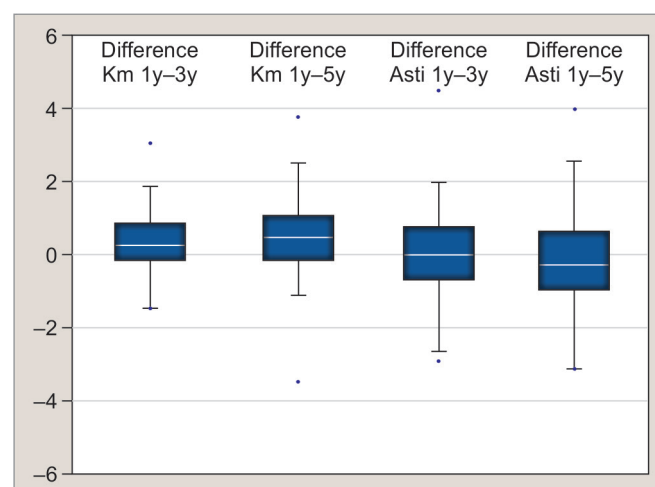
Graph 1: Differences in mean K-reading and astigmatism between time points, in Diopters

The differences in astigmatism values obtained at various time points are presented in Graph 1. Mean astigmatism at the 3- and the 5-year follow-up was 2.94 D (SD: 1.69; range: 0.45–6.75) and 2.69 D (SD: 1.76; range: 0.00–8.05) respectively. The astigmatism change was 0.008 D (SD: 1.363; range: –2.90–4.50, p = 0.998) and –0.248 D (SD: 1.458; range: –3.09–4.00, p = 0.877) respectively.

Astigmatism Comparison Group

Astigmatism measurements exhibited stability at 3 and 5 years after CKT in 88.6% (n = 114) and 85.71% of eyes (n = 67) respectively. Mean astigmatism at the 3- and 5-year follow-up was 3.05 D (SD: 1.69; range: 0.00–6.75) and 2.80 D (SD: 1.66; range: 0.00–8.90) respectively. The mean astigmatism change was 1.02 D (SD: 0.89; range: 0.00–4.50) and –0.02 D (SD: 1.66; range: –4.00–4.00) respectively.

Best-corrected Visual Acuity with Glasses Main Group

After surgery BCVA improved at 1, 3, and 5 years in 63.16% (p = 0.0004), 68.42% (p = 0.00001), and 73.68% of eyes (p = 0.00002) (n = 38) respectively, and did not change in 21.05, 23.68, and 18.42%. The distribution of BCVA changes at 5 years after surgery is presented in Graph 2. Specifically, the mean BCVA at 1, 3, and 5 years follow-up was 0.72 (SD: 0.19; range: 0.15–1.00), 0.78 (SD: 0.21; range: 0.15–1.20), and 0.77 (SD: 0.19; range: 0.25–1.00) respectively. The mean BCVA change was 0.14 (SD: 0.22; range: –0.30–0.80), 0.20 (SD: 0.24; range: –0.30–0.80), and 0.19 (SD: 0.23; range: –0.30–0.80) respectively.

Best-corrected Visual Acuity with Glasses Comparison Group

The BCVA improved in 65.94% (n = 138), 75.95% (n = 79), and 71.74% of eyes (n = 46) and did not change in 21.41, 17.72, and 17.39% of eyes respectively, meaning that after the initial change from preoperative to 1 year, there was hardly any change. The mean BCVA values at 1-, 3- and 5-year follow-up were 0.74 (SD: 0.18; range: 0.15–1.00), 0.76 (SD: 0.20; range: 0.15–1.20), and 0.73 (SD: 0.21; range: 0.25–1.00) respectively. The mean BCVA change at 1, 3, and 5 years after surgery was 0.15 (SD: 0.20; range: –0.30–0.80), 0.19 (SD: 0.22; range: –0.30–0.80), and 0.16 (SD: 0.23; range: –0.30–0.80) respectively.

Other Factors of Progression

In addition, we looked for factors that may increase the risk of progression for certain types of patients in the cohort. None of these factors were determined to be statistically significant using regression modeling (multiple linear regression as well as partial least squares regression). The factors investigated were patient age (p = 0.273), preoperative keratometry readings (p = 0.742), and sex (p = 0.234).

Clinical Outcomes

Patients reported little postoperative discomfort, although they did experience foreign-body sensation for approximately 3 days and increased blurriness for 1 to 4 weeks. Each patient abstained from work for 1 week or less.

Pull-through of double-running sutures was a problem in 19 (8%) of the eyes examined. If pull-through occurred within the first 3 months, traction sutures were applied (Fig. 2).

In 5 cases (3%), the sutures had to be replaced.

Orbscan graphs acquired immediately after CKT frequently exhibited a steepening from 0.5 D to slightly below 1 D. This effect may have been due to the circular sutures employed, but it had no apparent influence on the outcomes.
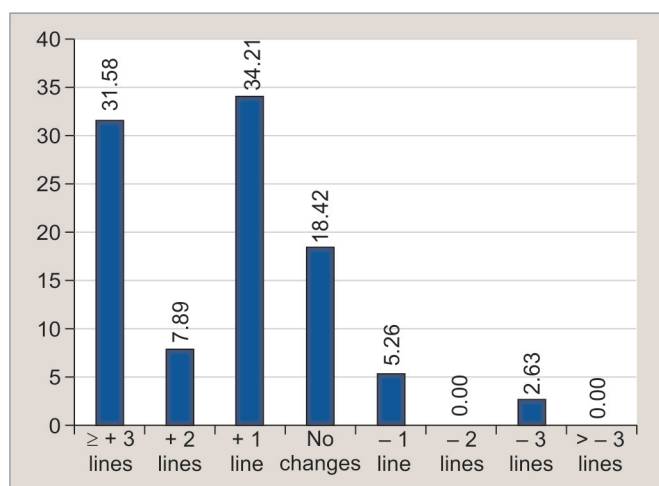
Graph 2: Distribution of gained and lost Snellen lines between preoperative and 5 years postoperative, in percentages
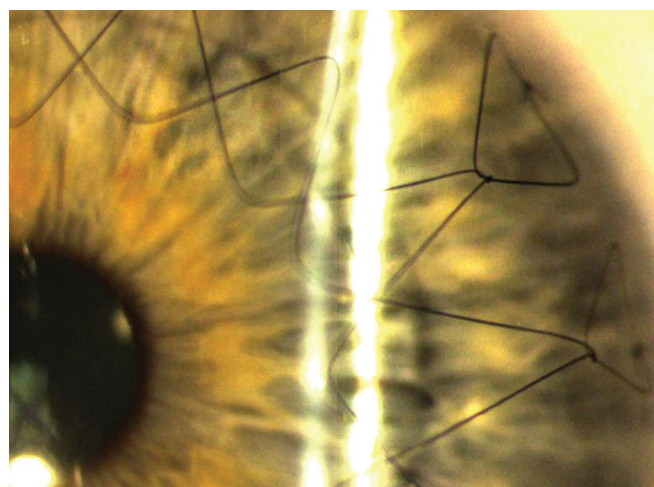

Fig. 2: New traction sutures to maintain tension on the double-running sutures

To achieve a stable keratometric result, a minimum of 3 months' adaptation to the sutures was required. Typically, the sutures were left in for 1 year, with a minimum of 4 to 6 months, then removed only when they became loose.

Complications

No serious sight-threatening complications were observed. There were no infections. The major postoperative problem was pull-through of the double-running sutures, which necessitated the placement of traction sutures or, if the eye was >3 months postoperative, removal of the double-running sutures.

In some cases, corneal tissues were so soft that, over time, the suture reversal points moved from near the limbus toward the center by 1 to 1.5 mm. Rinsing the suture channels with vancomycin and applying traction sutures (Fig. 2) enabled the double-running sutures to remain in place for the first 3 to 4 months. In 5 cases (3%) in which sutures had to be completely exchanged, we used suture material from a different manufacturer to exclude the possibility that the pull-through complications had been facilitated by an allergic reaction. It appeared that the goal of creating a firm scar in the cornea was not jeopardized in the eyes that had suture problems. These eyes' keratometric values were comparable with those obtained for corneas that uneventfully healed after CKT.

DISCUSSION

In an evidence-based ophthalmic practice, new treatments are accepted based on the demonstration of their proven effectiveness in large, prospective, randomized, and controlled clinical trials. Such studies are lacking with respect to keratoconus. The relative effectiveness of any single keratoconus treatment has not been demonstrated conclusively in larger groups or for longer times, nor is there documented evidence to help ophthalmic physicians tailor treatments to specific stages of the disease. Consequently, decisions related to keratoconus treatment are made empirically, often based on small studies designed to test varying techniques.

Our retrospective case series demonstrated that CKT can be an effective surgical treatment for patients experiencing stage I and II keratoconus. We observed stable, lasting clinical improvements for all of the criteria that define progression: K-value, astigmatism, and BCVA. Statistical analyses determined that all measures improved significantly after the operation.

One characteristic feature of the present study is the difference between the number of eyes for which we had all time point measurements (51) and the larger group of 114 eyes that we had to take out of the statistical evaluation because they lacked some of the time point measurements.

The parallel evaluation of these two groups showed that there was only a small difference in their K-readings (84.3% *vs* 82.09%) and BCVA improvement (73.68% *vs* 75.95%). Other measures – contact lenses, intrastromal ring segments – have not proven to halt keratoconus.

Regarding the newly developed Cisis/MyoRing, it is apparently used in all stages of the cone. There are reports only of very small groups (5–12 eyes) and no follow-ups longer than 1 year are available,[6] which therefore does not allow us to compare outcomes.

Regarding CXL with UV-A and riboflavin, O'Brart et al[7] and Nicula et al[8] reported long-term stability for the entire cohort, which was not differentiated by disease stage. There is no study on how CXL should be applied in relation to the stage of the disease. It is noteworthy that patients experiencing all four disease stages are currently being treated with CXL, despite the fact that there is no consensus regarding the methodology. Some surgeons bathe the entire cornea in riboflavin, whereas others instill the riboflavin into pockets or channels. Some surgeons scrape away the epithelium completely, whereas others do so partially or not at all. The riboflavin concentrations used vary from 0.025 to 0.1%.[4]

Uncorrected visual acuity (UCVA) and BCVA obtained after CXL range from worsening to no improvement to substantial improvement. Also, CXL has been associated with precancerous tissue changes. In 2014, Krumeich et al[9] reported the case of a keratoconus (stage II) patient who underwent CXL and, 2 years later, underwent a lamellar keratoplasty procedure, DALK. At the border between the transplant and recipient tissue, this patient developed conjunctival intraepithelial neoplasia.

In summary, our retrospective analysis demonstrated that CKT halted keratometric progression of early-stage keratoconus for at least 5 years in 84.3% of the eyes studied. The stable keratometry measurements of these eyes were supported by the stable or improved values of BCVA in 92.01% over the 5-year postoperative period, suggesting that surgical treatment with CKT should be considered for patients exhibiting stage I or stage II keratoconus.

What was known:
- Keratoconus, when diagnosed, generally progresses to the final stages with contact lenses until a corneal transplantation is unavoidable.
- The only current treatment is CXL, the results of which do not allow us to predict outcomes and stability according to the stage of the disease.

What this paper adds:
- Keratoconus stage I and II can be treated according to the stage of the disease.
- The generation of a circular scar around the optical axis preserves the patient's own cornea, with no need for a transplant.

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