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Setting: Institut für Refraktive und Ophtho-Chirurgie (IROC), Zurich, Switzerland.

Methods: In a prospective study, 117 eyes of 99 patients with verified progressive keratectasia were enrolled and received standard CXL. Preoperatively, 6 months and 12 months after CXL among others best spectacle-corrected visual acuity (BSCVA), slit lamp inspection, applanation tonometry, and Scheimpflug imaging (Pentacam) were used to follow the postoperative development. Statistical analysis included ANOVA and U-tests to detect risk-factors for complications.

Results: Approximately 90% completed the 12 month follow-up. The complication rate (percentage of eyes losing 2 or more Snellen lines) was 2.9% with a 95%-confidence interval of 0.6% to 8.5%. The failure rate of CXL (percentage of eyes with continued progression) was in this study 7.6%. As significant risk factors for complications the parameters "age>35 years" and "preoperative

BSCVA>20/25" were identified, preoperative high Kmax-reading was the only significant risk factor for failure. In 7.6% of the eyes sterile infiltrates and in 2.8% central stromal scars were found.

Conclusions: Changing the inclusion parameters may significantly reduce complications and failures of CXL: preoperative Kmax-readings of less than 58D may reduce the failure rate of CXL to less than 3% and restriction of the age of the patient to less than 35 years may reduce the complication rate to 1%.

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5 **Complications after corneal cross-linking (CXL)**  
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10 running head: CXL-complications  
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33 Dr. Mrochen has financial interest in the device UV-X used in this study  
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## Abstract

**Purpose:** To enumerate the complication rate of corneal cross-linking (CXL) for primary keratectasia and to find recommendations to avoid complications.

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**Conclusions:** Changing the inclusion parameters may significantly reduce complications and failures of CXL: preoperative  $K_{\max}$ -readings of less than 58D may reduce the failure rate of CXL to less than 3% and restriction of the age of the patient to less than 35 years may reduce the complication rate to 1%.

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2 Synopsis

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4 Corneal crosslinking for primary keratectasia has a low complication rate (1%) and few  
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7 failures (3%) if adequate inclusion criteria are respected  
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2 More than ten years ago, corneal cross-linking (CXL) by means of riboflavin and  
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4 ultraviolet light was proposed as a therapeutic approach to improve the biomechanical and  
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6 biochemical properties of the cornea<sup>1,2</sup>. The first reports on clinical experience with this  
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8 treatment for corneal melting appeared in 2000<sup>3</sup>. In 2003, a halt in progression of  
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10 keratectasia after CXL was shown in eyes with documented progression prior to the  
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12 treatment<sup>4</sup>. The authors reported a decrease in maximal K-reading along with an  
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14 improvement in visual acuity during the first postoperative years. This finding was  
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16 confirmed in 2006 by Caporossi et al.<sup>5</sup> in a 3 month follow-up after CXL and in 2008 by  
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18 Wittig et al.<sup>6</sup> and Koller et al.<sup>7</sup> in controlled prospective studies with a completed 1 year-  
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20 follow up. Other applications of CXL include iatrogenic keratectasia after LASIK<sup>8,9</sup> and  
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22 infectious keratitis<sup>10</sup>.  
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31 All these studies documented an excellent efficacy of CXL to stop progression of  
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33 keratectasia but suffered from small study group sizes which did not allow estimations  
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35 neither of complication nor of failure rates. Also, a list of indications and contraindications  
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37 is still missing.  
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43 In this prospective study, in a large group of eyes with primary keratectasia the  
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45 complications and failures of CXL during the first postoperative year were studied.  
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## Patients and Methods

### 1. Study group and protocol

One hundred and seventeen eyes of 99 patients with progressive keratectasia were enrolled in this study. Progression of the keratectasia was verified by repeated Scheimpflug images (Pentacam 70700, Oculus, Wetzlar, Germany) over at least 6 months and progression was accepted if the increase in maximal K-reading exceeded 1 diopter which equals 3 standard deviations<sup>7</sup>. Second eyes were treated not earlier than 6 months after the first one. Only eyes with mild to moderate keratoconus (maximal K-reading < 65 D, minimal corneal thickness > 400  $\mu\text{m}$ ) were included. Because of the broad overlap of the diagnoses pellucid marginal degeneration and keratoconus we did not distinguish between these two clinical subentities. Eyes with preoperative corneal opacities were not accepted because Scheimpflug photography may give false results. Additional exclusion criteria were: ocular pathology other than keratectasia, in detail cornea guttata or other endothelial irregularities, history of recurrent erosions, age under 18 years, actual or intended pregnancy, non-availability for follow-up examinations during 1 year, and connective tissue diseases. The study protocol was approved by the Ethikkommittee des Kantons Zürich.

The patients were examined preoperatively, early postoperatively (1 to 3 days until epithelial healing), at 1 month, 6 months, and 12 months after CXL. At every follow-up, except the early postoperative, a standard examination was performed consisting of autorefractometry and autokeratometry (Humphrey Model 599, Zeiss, Jena, Germany), corneal topography (Keratograph C, Oculus, Wetzlar, Germany), Scheimpflug imaging (Pentacam 70700), manifest refraction using the fogging technique, unaided and best

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2 spectacle-corrected visual acuity (BSCVA), applanation tonometry, and slit lamp  
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4 inspection of the anterior and posterior segments of the eyes. The haze in the anterior  
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6 stroma was graded in analogy to the scale used after PRK<sup>11</sup> although the corneal opacity  
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8 after CXL is not located strictly subepithelial but extends into deep stroma. At the 1 month  
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10 follow-up examination the depth of the demarcation line was estimated at the slitlamp as  
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12 percentage of central corneal thickness<sup>12</sup>.  $K_{\max}$ -readings were obtained as the average of  
13  
14 three Pentacam-measurements. The threshold of significant difference regarding  $K_{\max}$ -  
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16 readings of the Pentacam was 1 diopter (equals 3 standard deviations of the  
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18 reproducibility)<sup>7</sup>. For the calculation of means and comparisons visual acuities were  
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20 transferred to the logmar-scale.  
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29 The complication rate was defined as the percentage of eyes suffering from a loss in  
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31 BSCVA of 2 Snellen lines and more at the 12 months follow-up compared to preoperative  
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33 BSCVA. The failure rate of CXL was defined as the percentage of eyes experiencing an  
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35 increase in  $K_{\max}$  of more than 1 diopter compared to preoperative.  
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41 Patients using rigid contact lenses were asked not to use their lenses for at least 3 weeks  
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43 before the preoperative examination and one month after treatment. The lenses had to be  
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45 removed at least 3 weeks before each follow-up examination.  
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## 53 2. Treatment

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55 Topical anaesthesia of the cornea was obtained using oxybuprocaine and tetracaine  
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57 alternating every 3 minutes for 15 minutes. After insertion of a lid speculum, a corneal  
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2 abrasion with a diameter of 9mm was performed followed by the instillation of 0.1%  
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4 riboflavin drops every 3 minutes for 30 minutes. The riboflavin drops were prepared  
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6 immediately before the treatment mixing 0.5% aqueous riboflavin solution (Streuli&Co,  
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8 Uznach, Switzerland) with 20% dextrane T-500 solution (Roth, Karlsruhe, Germany).  
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10 Thereafter, central corneal pachymetry using ultrasound was performed. In cases with a  
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12 central thickness (without epithelium) of less than 400  $\mu\text{m}$  additional 0.1% riboflavin drops  
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14 without dextrane (hypoosmotic drops) were applied until the thickness exceeded 400  $\mu\text{m}$ .  
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16 The eyes were then inspected at the slit lamp to ensure that the riboflavin has arrived in the  
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18 aqueous (blue light). After this, the eye was irradiated for 30 minutes with UVA with an  
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20 irradiance of 3  $\text{mW}/\text{cm}^2$  (UV-X, Peschkemed Meditrade, Huenenberg, Switzerland).  
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22 During irradiation, the cornea was moistened every 3 minutes with 0.1% riboflavin drops  
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24 and oxybuprocaine drops at the patient's discretion. At the end of the procedure antibiotic  
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26 ointment (ofloxacin 0.3%) was applied and the eye was patched. The patient was asked to  
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28 use the antibiotic ointment five times a day for three days. After epithelial healing the  
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30 patients used topical fluorometholone twice a day for one week. In cases with sterile  
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32 infiltrates during the early postoperative phase dexamethasone drops were prescribed 5  
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34 times a day for a week taper during the following 2 weeks.  
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### 46 3. Statistical evaluation

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48 Variables were described using the mean, standard deviation and the 95% confidence  
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50 interval (CI). A one-factor ANOVA was performed including the variables age, preop  
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52  $K_{\text{max}}$ , change in  $K_{\text{max}}$  between preop and 12 months postop (delta  $K_{\text{max}}$ ), preop BSCVA,  
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54 and change in BSCVA between preop and 12 months postop (lines lost) followed by  
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56 multiple comparisons using the Scheffe-test. The same variable at different times during  
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2 the follow-up was compared using the Wilcoxon-test. Comparison of a variable in two  
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4 different groups (for example: preopBSCVA in the total group and in the failure group)  
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7 was performed using the U-test (Mann-Whitney). The odds-ratio of a risk factor and its  
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9 confidence interval was calculated by means the standard algorithm for a 2x2-table. All  
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11 calculations were performed with WinSTAT<sup>®</sup> for Excel (R. Finch Software, 2002).  
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14 Statistical significance was accepted if  $p < 0.05$ .  
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## Results

The demographic data demonstrate a strong skew towards male patients (62.2%) and left eyes (58.1%). Of the 117 eyes enrolled in the study 105 eyes completed the 1 year-follow up yielding a drop out-rate of 10.3%.

Epithelial healing was completed within  $3.25 \pm 1.4$  days (range 1 to 8 days, CI: 2 to 6 days). At the 1 month-examination, the anterior stromal haze was graded  $0.78 \pm 0.42$  (range 0 to 2) decreasing to  $0.18 \pm 0.28$  at 6 months and  $0.06 \pm 0.18$  at 12 months. The demarcation line in the deeper stroma was visible at the 1 month-examination in 84% of the eyes at a depth of  $62 \pm 17\%$  of central corneal thickness (range 25 to 100%, CI: 32 to 93%). Preoperative corneal thickness over the pupil center as determined by means of Scheimpflug imaging was  $483 \pm 36 \mu\text{m}$  (CI:  $424\mu\text{m}$  to  $540\mu\text{m}$ ). No statistical significant difference was found when comparing applanation tonometry preoperative and 1 year after CXL.

The one-factor ANOVA revealed a high statistical significance regarding interaction of the variables age, preop  $K_{\text{max}}$ , delta  $K_{\text{max}}$ , preop BSCVA, and lines lost. The “post hoc” multiple comparisons are summarized in Table 1 demonstrating the influence of the variables preop  $K_{\text{max}}$  and age on all the other parameters.

Comparing BSCVA at 1 year after CXL with preoperative yielded a loss of 2 Snellen-lines and more in 3 out of 105 eyes, equivalent to a complication rate of 2.9% with a 95%-confidence interval of 0.6% to 8.5%. When comparing this complication subgroup with the

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2 total group, at a first glance, age, preoperative BSCVA, and preoperative curvature  $K_{max}$   
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4 may be predictive parameters. However, the two groups are statistically different only  
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6 regarding age (37.7 vs. 29.2 years,  $p=0.029$ ) and preoperative BSCVA (0.98 vs. 0.53,  
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8  $p=0.012$ ). An age of more than 35 years and a preoperative BSCVA of better than 20/25  
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10 were clearly identified as risk factors (age: odds ratio 13.14, CI 1.3 to 132.7; BSCVA: odds  
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12 ratio 18.18, CI: 1.78 to 185.8). Introducing an age limit of 35 years as inclusion criterion  
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14 would reduce the complication rate in this study group to 1.04% (CI: 0.03% to 5.4%).  
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17 Unfortunately we could not find any morphological or optical reason for the visual loss.  
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24 Regarding efficacy 8 out of 105 eyes (7.6%, CI: 3.3 to 14.7%) showed an increase of 1D  
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26 and more during the first postoperative year (Table 2) and must, therefore, be considered as  
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28 failures of CXL. When comparing the failure-subgroup with the total group there are  
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30 obvious differences regarding gender (female 62.5% vs. 38.8%,  $p=0.048$ ), preop BSCVA  
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32 (0.39 vs. 0.55,  $p=0.16$ ) and preop  $K_{max}$  (61.3D vs. 55.0D,  $p=0.04$ ) but only the preoperative  
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34 curvature  $K_{max}$  and gender may be considered statistically significant parameters. The odds  
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36 ratio of the risk factor  $K_{max}>58$  is 5.32 with a CI ranging from 1.19 to 23.79 that one of  
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38 gender female is 3.11 with a CI ranging from 0.7 to 13.7. Changing the inclusion  
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40 parameter limit for  $K_{max}$  from  $<65D$  to  $K_{max}<58D$  would have reduced the failure rate in  
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42 this study group from 7.6% (CI: 3.3 to 14.7%) to 2.8% (CI: 0.6 to 8.5%).  
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51 Sterile infiltrates occurred in 7.6% of the cases and a stromal scar developed in 3 corneas  
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53 (2.9%). None of these complications resulted in a significant loss in BSCVA and in all 3  
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55 cases with stromal scars (Fig 1) the unaided visual acuity increased drastically. The scars  
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57 faded within the first postoperative year substantially and the corresponding flattening in  
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2 topography reduced (Fig.2). None of the numerical parameters of this study were identified  
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4 as predicting factors for these complications. Other complications with the need for  
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6 medical or surgical interventions did not occur in this series.  
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11 Such a complicated case after CXL was, however, referred to our clinic and shall be  
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13 presented here to demonstrate the vulnerability of the early postoperative cornea. The 21  
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15 year-old man received CXL in his right cornea because of progressive keratoconus. At day  
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17 3 after CXL a large oval infiltrate was observed paracentral inferiorly. Despite maximal  
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19 topical antibiotic and antimycotic treatment at post-op day 5 satellite infiltrates and a large  
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21 erosion had developed. Microbiotic cultures and a corneal biopsy were taken and the  
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23 patient was referred to our clinic (Fig. 3). We performed another CXL the same day (0.2%  
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25 riboflavin, 50 min irradiation with 7mW/cm<sup>2</sup>) and the inflammation reduced gradually  
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27 within the following 2 weeks. The epithelium was fluorescein-negative at day 10 after  
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29 secondary CXL. Two weeks later BSCVA had increased to 0.3 (from light perception).  
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## Discussion

Since the introduction of CXL in 1996<sup>1-3</sup> several clinical studies have been presented in the literature demonstrating an excellent efficacy of CXL<sup>3-5</sup> to stop progression in keratectasia, however, the study groups were too small to allow conclusions about the real efficacy and the safety of the procedure. Singular cases with complications after CXL appearing in the literature<sup>13-15</sup> are important but do not allow an estimation of the complication rate. In refractive surgery, a complication is defined by a loss in BSCVA of 2 Snellen-lines and more<sup>16</sup> at an appropriate time after surgery (6 months or 1 year). Also, a refractive surgical procedure is considered safe if this complication rate is less than 5%<sup>17</sup>. In this study we found a complication rate of 2.9% flawed with a relatively high confidence interval of 0.6 to 8.5% because of the small group size (n = 105). Refractive surgery is dealing with elective surgery and a high safety standard is, therefore, mandatory and appropriate. In contrast, corneal cross-linking is currently the only option to halt or even reverse progression in keratectasia and should not be considered elective any more.

Risk factors for a visual loss after CXL seem to be (1) age over 35 years and (2) a BSCVA of 20/25 and better. Fortunately these parameters do not characterize the typical patient needing CXL because the majority of the candidates for CXL currently is in the 3<sup>rd</sup> decade of life and is motivated to receive this treatment due to substantial visual losses. From a strategic point of view one may speculate that the earlier the CXL is performed the better for the patient because the primary target of CXL is to stop progression. BSCVA > 20/25 as a risk factor contradicts this strategy because at this early stage BSCVA is usually still good and, therefore, the patient is going the risk to lose visual acuity. In contrast, the other

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2 risk factor, age > 35 years, does not represent such a strategic obstacle because patients in  
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4 this age know about their disease since many years and, in the future, may have had CXL  
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6 much earlier. Establishing an upper age limit of 35 years would reduce the complication  
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8 rate in this study to 1.04% (CI: 0.03% to 5.4%) a number that characterizes an  
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10 extraordinarily safe procedure (for comparison: adverse reactions during general anesthesia  
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12 in children occur in 3%<sup>18</sup>).  
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19 Failures are not considered complications but may have impact on the complication rate.

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21 The only risk factor for a failure detected in this study was a  $K_{max}$ -reading of more than 58  
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23 diopters and, indeed, limiting the preoperative  $K_{max}$ -readings to 58 D and less would have  
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25 reduced the failure rate to 2.8%. Such a limitation would have had no influence on the  
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27 complication rate in this study. This failure rate of 2.8% is significantly higher than failure  
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29 rates of CXL reported in the literature ranging from 0%<sup>4,5</sup> to 1%<sup>19</sup>.  
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36 There was a discussion whether haze is a normal finding after CXL and whether this haze  
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38 may have impact on vision<sup>15</sup>. Yes, haze is normal after CXL and it gradually fades during  
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40 the first postoperative year from grade 0.78 to 0.06. The haze seen after CXL differs from  
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42 the haze seen after PRK in the stromal depth: whereas the haze after PRK occurs strictly  
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44 subepithelial, the haze after CXL extends into the anterior stroma approximately 60% deep  
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46 which is on average equal to an absolute depth of 300 $\mu$ m. The nature of this haze is  
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48 unclear but we associated it with the depth of cross-linking and the loss of keratocytes<sup>12,14</sup>.  
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53 The evaluation of the depth of sufficient CXL might become important regarding a  
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55 potential surface ablation to regularize the irregular astigmatism<sup>20</sup>. More investigations  
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57 including confocal microscopy are necessary to elucidate this complex.  
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4 We have not seen severe complications in this study group, however, during the last year a  
5 number of serious complications have been reported at conventions. In corneal infections  
6 after CXL, like in the case presented here, the contact with the infectious agent most likely  
7 happened after the operation during the early-postoperative phase because during CXL not  
8 only the keratocytes are damaged but also bacteria and fungus, an effect that is used with  
9 the application of CXL for infectious keratitis<sup>21</sup>. The healing of the epithelium took in this  
10 study group up to 8 days and may take even longer in some cases, for example in patients  
11 with atopic disease, and during this phase the cornea has to be considered vulnerable  
12 regarding infections and melting. In order to shorten this time interval, besides bandage  
13 lenses also the use of amnion may be indicated. One of the complications had also  
14 beneficial aspects: the central stromal scars resulted in a significant flattening of the cornea  
15 and increase in unaided VA. During the follow-up the initially strong flattening effect  
16 underwent a regression paralleled by fading of the scar (Fig. 2).  
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39 In summary, CXL appears to be a safe treatment with a complication rate of approximately  
40 1% if inclusion parameters are respected such as age of the patient < 35 and BSCVA  
41 <20/25. Also it seems to be an effective procedure as long as corneas with a maximal K-  
42 reading < 58D are treated. More studies will be necessary to find rare complications and to  
43 establish a list of indications regarding age, diagnosis (PMD vs. KC) and stage of the  
44 keratectasia.  
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2 Ultraviolet A/riboflavin corneal cross-linking for infectious keratitis associated with  
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4 corneal melts  
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7 Cornea 2008;27:590-4  
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7 Figure 1

8 Stromal scar 2months after CXL. The scar extends approximately the anterior 50% of  
9 stromal depth and is paralleled by a significant flattening of the cornea.  
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14 Figure 2

15 Regression of the flattening effect during 12 months after CXL.  
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20 Figure 3

21 Cornea 7 days after CXL and postoperative infection. The satellite foci appeared at post-  
22 op. day 4 and are most probably do to a fungal infection.  
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Table 1: ANOVA post hoc multiple comparisons (Scheffe,  $p < 0.05$ )

	BSCVA	BSCVA lost	$\Delta K_{\max}$	age	preop $K_{\max}$
BSCVA	-				
BSCVA lost	no	-			
$\Delta K_{\max}$	no	no	-		
age	yes	yes	yes	-	
preop $K_{\max}$	yes	yes	yes	yes	-

Table 2: Progression vs. regression within 1 year after CXL

progression ( $\Delta K_{\max} < -1D$ )	unchanged ( $-1D \leq \Delta K_{\max} \leq +1D$ )	regression ( $K_{\max} > +1D$ )
8 (7.6%)	58 (55.2%)	39 (37.1%)

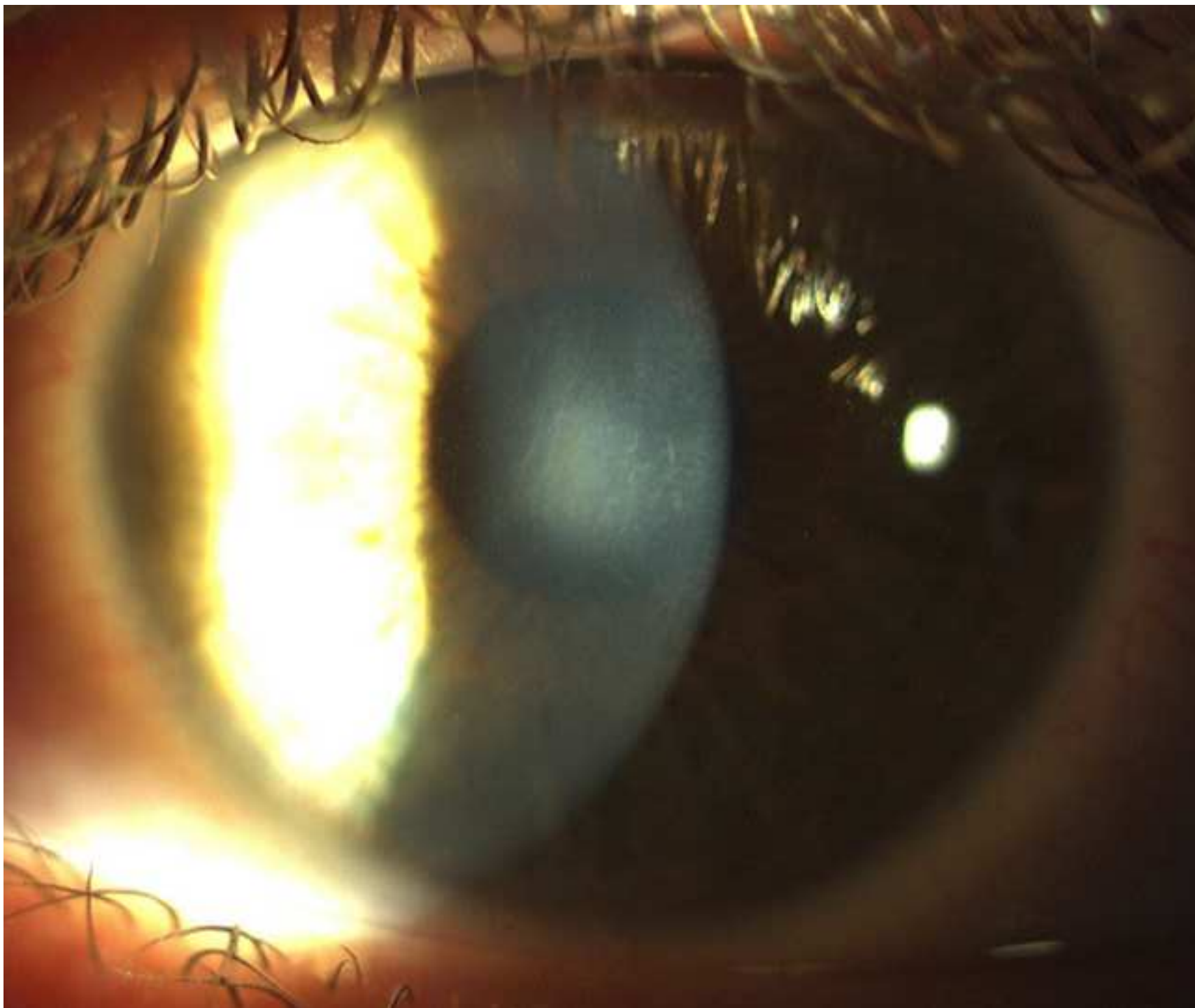
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## Synopsis

Corneal crosslinking for primary keratectasia has a low complication rate (1%) and few failures (3%) if adequate inclusion criteria are respected.

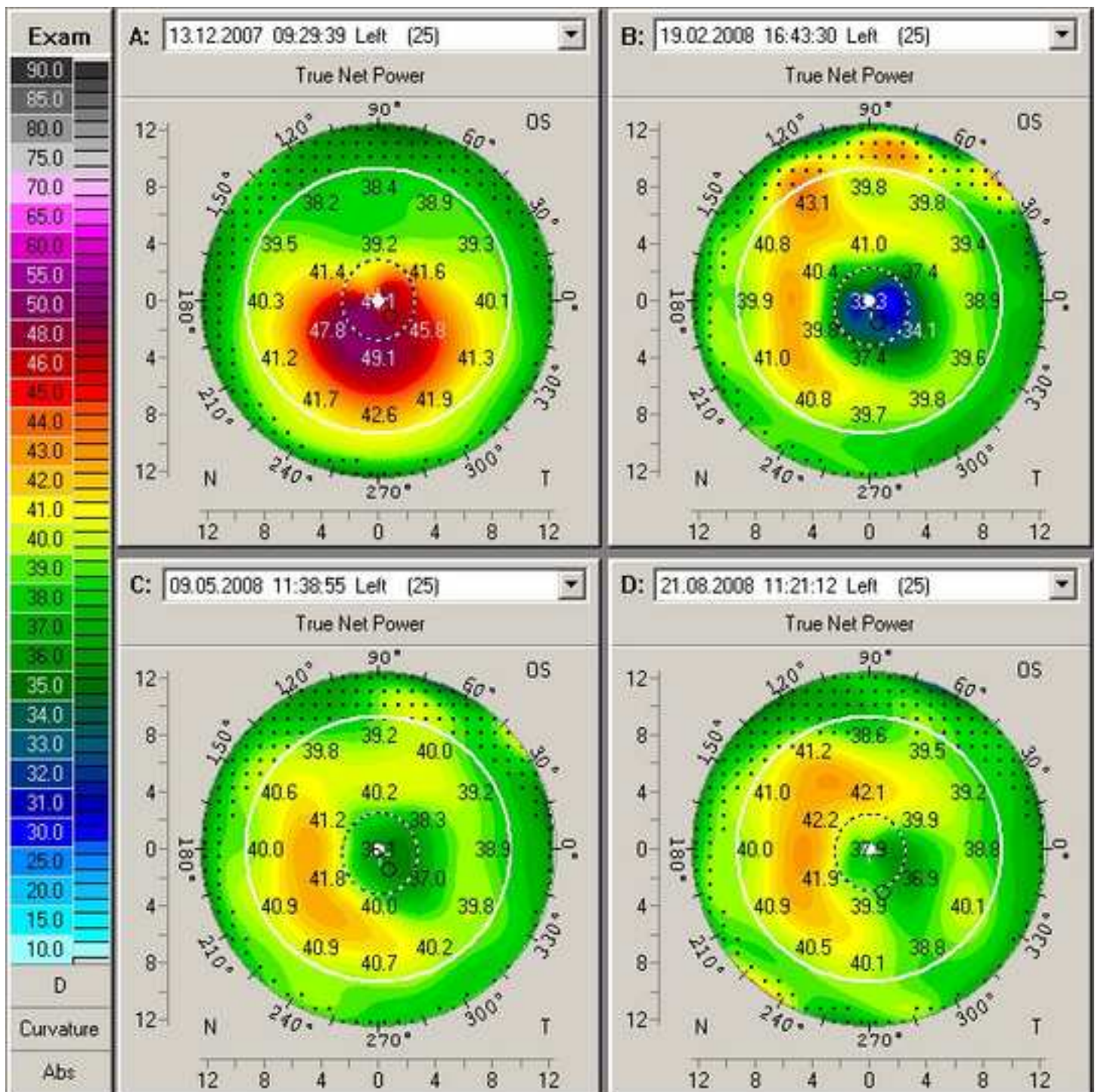
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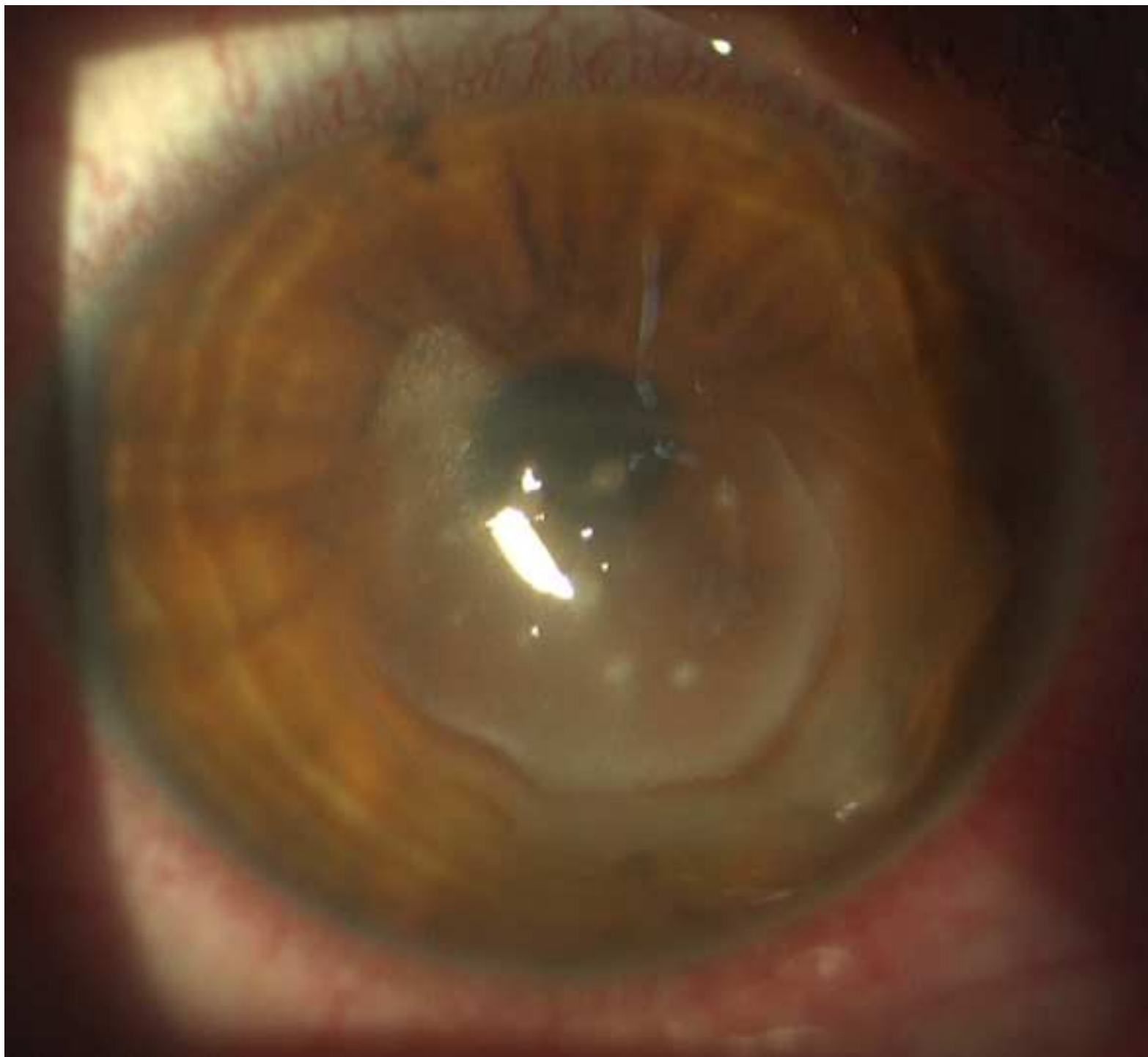


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age	yes	yes	yes	-	
preop $K_{\max}$	yes	yes	yes	yes	-

Table 2: Progression vs. regression within 1 year after CXL

progression ( $\Delta K_{\max} < -1D$ )	unchanged ( $-1D \leq \Delta K_{\max} \leq +1D$ )	regression ( $K_{\max} > +1D$ )
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