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Original research

OPD scan III accuracy: Topographic and aberrometric indices after accelerated corneal cross-linking

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Abstract

Purpose: To determine topographic and aberrometric changes after accelerated cross-linking (ACXL; 18 mW/cm^2 for 5 min) as measured with OPD Scan III (Nidek Inc., Tokyo, Japan) and their repeatability in patients with mild and moderate keratoconus (KCN).
Methods: In this prospective study, 25 eyes with mild KCN [Ksteep = 47.24 ± 3.11 diopter (D)] and 20 moderate cases (Ksteep = 52.86 ± 4.39 D) were examined under mesopic conditions (20 lux) twice, 30−45 min apart, at baseline and 6 and 12 months afterwards. Extracted indices were Ksteep, Kflat, ocular and corneal irregularity, ocular and corneal total higher order aberrations (HOAs), coma, trefoil, and spherical aberration (SA). Repeatability index (RI) and intraclass correlation coefficients (ICCs) were determined.
Results: In mild cases, Ksteep and corneal irregularity had lower RI, but Kflat and ocular irregularity had higher RI (all $P > 0.050$) at 1 year. The RI for ocular total HOAs, coma, and SA decreased and showed no significant change for trefoil (all $P > 0.050$). Moderate cases showed non-significant increases in RI for Ksteep, Kflat, ocular and corneal irregularity (all $P > 0.050$), and all aberrometry indices, and significant increases in RI for ocular coma ($P = 0.046$) and corneal trefoil ($P = 0.037$). At 1 year, ICC was >0.75 for all indices except ocular and corneal trefoil (ICC = 0.613 and 0.390) in moderate cases.
Conclusions: At one year after ACXL, OPD Scan III showed acceptable repeatability in mild cases. In moderate cases, topographic indices had acceptable repeatability but poorer compared to the mild group. Overall, ocular HOAs showed better repeatability than corneal ones. These changes should be considered in the interpretation of measurements.
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Keywords: Repeatability; OPD Scan III; Accelerated cross-linking; Mesopic condition; Repeatability index

Introduction

Corneal parameters have a pivotal role in the diagnosis, monitoring, and post-treatment follow-ups of keratoconus (KCN). KCN is defined with changes in keratometry, corneal thickness, and irregularity indices,[1] and the response to treatment is determined based on changes in the very same indices. One of the treatment options to stop disease progression is corneal cross-linking (CXL) using standard[2,3] and accelerated protocols.[4,5] The long-term efficacy of standard methods has been illustrated,[2,3] but there is concern about long-term results with accelerated protocols despite acceptable mid-term outcomes.[5] The effectiveness of CXL in halting disease progression is assessed with indices such as the thickness, keratometry, biomechanics, and shape of the cornea.

Any device capable of assessing all corneal functions with a single measurement can provide a time and cost-effective approach to evaluate the effectiveness of treatment. OPD

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Scan III (Nidek, Tokyo, Japan) is a multifunctional device that measures the shape and curvature of the cornea and wavefront aberrations. Since the goal is to monitor changes after the treatment, it is necessary to determine OPD Scan III measurement accuracy. A previous study has reported the repeatability of its measurements in patients with emmetropia, ametropia, and KCN.[6] The study indicated acceptable repeatability in cases of mild and moderate KCN; therefore, in this study, we examined the repeatability of OPD Scan III up to one year after accelerated cross-linking (ACXL; 18 mW/cm^2 for 5 min) in patients with mild and moderate KCN under mesopic conditions (20 lux). This information will help understand whether treatment-related changes in the cornea can influence device repeatability and measurement accuracy. Results can provide a guide in clinical decision making in subtle and mild cases in terms of treatment efficacy.

Methods

This prospective study was conducted in 2013 with the approval of the Ethics Committee of Tehran University of Medical Sciences. Patients with confirmed diagnosis of progressive KCN [at least one diopter (D) increase in maximum keratometry (Kmax), manifest cylinder, or manifest refraction spherical equivalent in the last 12 months] were referred from the keratoconus clinic for testing and signed informed consents to participate. Inclusion criteria included diagnosis of progressive KCN, age between 15 and 35 years, Ksteep < 55.0 D, and minimal corneal thickness (MCT) of at least 400 μm. Patients had no ocular surgery before enrollment or during the study. We selected patients with grade I–III KCN [mild (I, I–II) and moderate (II, III)] based on the index reported by Pentacam (Oculus Optikgerate GmbH, Germany), index of surface variance ($30 \leq ISV \leq 90$), and keratoconus index ($1.07 \leq KI \leq 1.25$).[7] Twenty-five eyes (25 patients) were allocated to the mild group and 20 eyes (20 patients) to the moderate group. Mean Ksteep measured in the 3 mm central cornea by Pentacam was 47.24 ± 3.11 D in the mild group and 52.86 ± 4.39 D in the moderate group ($P = 0.002$).

Surgical technique

The surgical method has been described before elsewhere.[8] In brief, after administering local anesthesia and removing the epithelium of the central 9 mm of the cornea, the lid speculum was removed to instill 0.1% riboflavin in 20% dextran (Streulipharmeceuticals, Uznach, Switzerland) onto the cornea at a rate of one drop every 3 min for 30 min. Then irradiation was done using the CCL 365 (PESCHKE Meditrade GmbH, Waldshut-Tiengen, Germany) at 18 mW/cm^2. At the conclusion, the corneal surface was rinsed, a soft bandage contact lens (Night & Day, Ciba Vision, Duluth, US) was placed, and a drop of levaquin eye drop was instilled. After the procedure, patients were prescribed levaquin eye drop four times daily, betamethasone 0.1%, and preservative free artificial tears as needed. Also, daily follow-up exams were performed until re-epithelialization was observed, and at this time, the contact lens was removed, levaquin was discontinued, and betamethasone, 4 times daily, was continued for another week.

Measurement protocol

All examinations were performed between 9 and 12 a.m. Imaging was done using OPD Scan III (Nidek Inc., Tokyo, Japan) in a dark room. OPD Scan III is a multifunctional device which projects Placido ring images onto the cornea for topographic measurements. The reflected image is captured with a camera, and image analysis is done to determine the shape of the cornea. The device is also capable of wavefront aberration analysis using Zernike polynomials.

To adjust the lighting conditions, daylight was blocked from the test room and room illuminance was measured with a light meter (Sekonic L-308DC, Japan). Patients remained in the room with 20 lux illumination for 10–15 min before the test to adjust to lighting conditions. Then they were seated at the device, and imaging was done after aligning the device and asking the patient to blink a few times. Patients remained in the test room after the first acquisition, and the second imaging was done after 30–45 min. The device was realigned after each acquisition. Imaging was repeated for cases with incomplete maps or blinking. These examinations were repeated at 6 and 12 months after ACXL (18 mW/cm^2 for 5 min).

Indices extracted from OPD Scan III included topographic variables such as Ksteep, Kflat, and ocular and corneal irregularity, as well as aberrometric indices such as ocular and corneal total higher order aberrations (HOAs), coma, trefoil, and spherical aberration (SA).

Statistical analysis

All analyses were based on mesopic pupil data. Only cases that had completed both the 6 and 12 month follow-ups were included in the analysis. Since corneal indices change between 6 and 12 months after CXL, the intraclass correlation coefficient (ICC) and repeatability index (RI) between the two measurements conducted 30–45 min apart at each follow-up was calculated to determine measurement repeatability in each of the mild and moderate groups. To calculate RI, the standard deviation of within subjects (Sw) was multiplied by 2.77.[9] RI is an index of test-retest variability which can only be used for indices measured in the same measurement unit; lower values are indicative of better repeatability. In other words, it represents the value under which the difference between any two repeat measurements on the same patient acquired under identical conditions should fall with 95% probability.

Results

Twenty-three of the 25 eyes in the mild group and 18 of the 20 eyes in the moderate group completed their 6 and 12-month follow-up exams. Mean age of the participants was 23.5 ± 3.9 years, and 60.0% were male. Mean MCT in the mild and moderate groups was 485.5 ± 28.2 μm and 447.9 ± 27.8 μm ($P = 0.002$), respectively.

In the mild group, The ICC was higher than 0.75 for all indices except baseline ocular SA (ICC = 0.671). Based on the ICC values presented in Tables 1 and 2, the procedure had no significant effect on the repeatability of topographic indices or ocular aberrations. Its effect on SA was a positive one, and it increased from 0.671 to 0.996. As for corneal aberrations, the outcome was slightly reduced repeatability with ICC changing from 0.829 to 0.896 at one year.

Ksteep and corneal irregularity had non-significantly lower RI, but Kflat and ocular irregularity had non-significantly higher RI (all $P > 0.050$) at 1 year. The RI for ocular total HOAs, coma, and SA decreased and showed no significant change for trefoil (all $P > 0.050$).

In the moderate group, the ICC was higher than 0.75 for all topographic indices, but among aberrometric indices, the ICC was less than 0.75 for ocular coma (ICC = 0.324) and ocular SA (ICC = 0.668) at 6 months and for ocular trefoil (ICC = 0.613) and corneal trefoil (ICC = 0.390) at 12 months after the procedure. As presented in Tables 1 and 3, treatment had no significant effect on topographic indices. In this group, the repeatability of total ocular HOAs was reduced mainly owing to the decrease in the ICC for trefoil. The influence on the repeatability of corneal HOAs was mild except for SA for which the ICC improved from 0.928 to 0.948.

The RI for Ksteep, Kflat, ocular irregularity, and corneal irregularity showed a non-significant increase (all $P > 0.050$). The RI for aberrometry indices was also increased insignificantly with the exception of a significant increase in the RI for ocular coma ($P = 0.046$) and corneal trefoil ($P = 0.037$).

Discussion

KCN results in irregular astigmatism, corneal steepening, and increased HOAs.[10,11] CXL can reduce aberrations by decreasing Ksteep and corneal irregularity.[12] However, studies examining HOAs in low light conditions at 1 year after CXL reported no significant change in HOAs and the halted progression of KCN.[8] The variance of measurements with imaging devices is an important point in the study of changes. Although there is a considerable number of studies on the repeatability of topographic and aberrometric indices measured with Placido-based devices in normal subjects,[13–17] they are quite limited in patients with KCN,[14,18,19] and to the best of our knowledge, no study has been done after CXL. Also, most of these studies have focused on Orbscan or EyeSys.

Hashemi et al[18] demonstrated reduced repeatability of keratometry readings with Orbscan Placido disk at higher degrees of KCN, and they reported that the RI for Ksteep was 0.84 in cases with mild KCN and 1.22 in cases with a Ksteep > 55.0 D. In our study, these numbers were 0.4 and 1.04, respectively. One reason for the inter-study difference is the difference between the two devices (Orbscan vs. OPD Scan

Table 1
Repeatability of topographic indices measured with the OPD scan III in cases of mild and moderate keratoconus after accelerated cross-linking (ACXL).

		Pre op				After 6 M				After 12 M			
		Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI
Mild	Ksteep	47.3 ± 2.9	47.4 ± 3.1	0.976	0.62	47.7 ± 3.6	47.8 ± 3.5	0.997	0.49	47.3 ± 3.5	47.4 ± 3.4	0.996	0.40
	Kflat	44.2 ± 1.9	44.0 ± 1.8	0.987	0.33	44.2 ± 2.1	44.2 ± 2.1	0.998	0.27	44.0 ± 2.1	44.1 ± 2.0	0.983	0.50
	Ocular irregularity	1.8 ± 1.3	1.6 ± 1.3	0.995	0.36	1.9 ± 1.3	1.9 ± 1.3	0.992	0.34	2.0 ± 1.4	1.9 ± 1.3	0.991	0.41
	Corneal irregularity	2.9 ± 2.9	3.0 ± 3.0	0.918	1.28	3.2 ± 2.6	3.1 ± 2.1	0.916	1.56	3.5 ± 2.6	3.0 ± 2.5	0.907	1.23
Moderate	Ksteep	52.4 ± 4.5	52.4 ± 4.6	0.999	0.39	52.4 ± 5.2	52.6 ± 5.2	0.998	0.81	52.2 ± 4.9	52.2 ± 5.0	0.994	1.19
	Kflat	46.8 ± 4.2	46.7 ± 4.2	0.999	0.38	46.8 ± 4.7	46.9 ± 4.7	1.000	0.36	46.2 ± 3.8	46.0 ± 4.0	0.996	0.75
	Ocular irregularity	3.3 ± 1.3	3.5 ± 1.3	0.981	0.59	3.7 ± 1.5	3.4 ± 1.4	0.863	1.24	3.0 ± 1.6	3.1 ± 1.4	0.980	0.81
	Corneal irregularity	5.9 ± 2.8	5.7 ± 1.9	0.934	1.18	6.5 ± 3.1	5.4 ± 1.7	0.916	2.78	4.9 ± 2.4	5.4 ± 2.7	0.982	1.58

Pre op: Preoperative; ICC: Intraclass correlation coefficient; RI: Repeatability index; Ksteep: Maximum keratometry in 8.00 mm; Kflat: Minimum keratometry in 8.00 mm.
Ocular and corneal irregularity was extracted from mesopic pupil condition.

Table 2
Repeatability of aberrations with the OPD Scan III after accelerated cross-linking (ACXL) in cases of mild keratoconus.

		Pre op				After 6 M				After 12 M			
		Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI
Ocular	Total HOA	1.6 ± 0.9	1.4 ± 0.8	0.988	0.37	1.7 ± 0.9	1.6 ± 0.9	0.986	0.33	1.7 ± 0.8	1.7 ± 0.8	0.982	0.32
	Coma	0.9 ± 0.6	0.8 ± 0.5	0.986	0.23	1.0 ± 0.6	1.0 ± 0.6	0.976	0.23	1.0 ± 0.6	1.0 ± 0.6	0.992	0.19
	Trefoil	1.0 ± 0.7	0.9 ± 0.7	0.971	0.35	0.9 ± 0.6	0.9 ± 0.7	0.973	0.32	0.9 ± 0.6	0.9 ± 0.6	0.959	0.35
	SA	0.4 ± 0.4	0.3 ± 0.3	0.671	0.13	0.5 ± 0.4	0.5 ± 0.4	0.992	0.11	0.5 ± 0.5	0.5 ± 0.5	0.996	0.08
Corneal	Total HOA	2.4 ± 1.5	2.6 ± 2.5	0.879	0.96	2.7 ± 1.4	2.7 ± 1.8	0.912	1.10	3.0 ± 2.0	2.5 ± 1.3	0.776	1.17
	Coma	1.8 ± 1.2	1.7 ± 1.1	0.988	0.35	2.0 ± 1.1	2.2 ± 1.5	0.944	0.64	2.3 ± 1.4	1.9 ± 1.1	0.852	0.70
	Trefoil	0.9 ± 0.7	1.2 ± 1.8	0.765	0.66	0.9 ± 0.6	0.9 ± 0.6	0.802	0.59	1.1 ± 0.9	0.8 ± 0.5	0.664	0.69
	SA	0.5 ± 0.5	0.6 ± 1.0	0.829	0.44	0.7 ± 0.7	0.7 ± 0.8	0.951	0.39	0.8 ± 0.9	0.6 ± 0.8	0.896	0.48

Pre op: Preoperative; HOA: Higher order aberration; SA: Spherical aberrations; ICC: Intraclass correlation coefficients; RI: Repeatability index.

Table 3
Repeatability of aberrations with the OPD Scan III after accelerated cross-linking (ACXL) in moderate keratoconus.

		Pre op				After 6 M				After 12 M			
		Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI	Take 1	Take 2	ICC	RI
Ocular	Total HOA	3.6 ± 1.4	3.6 ± 1.4	0.988	0.47	3.6 ± 1.5	3.5 ± 1.4	0.983	0.62	3.3 ± 1.7	4.4 ± 3.7	0.604	2.71
	Coma	2.5 ± 1.1	2.5 ± 1.1	0.993	0.30	3.1 ± 2.6	2.4 ± 1.0	0.324	0.74	2.3 ± 1.3	2.4 ± 1.0	0.956	0.74
	Trefoil	1.8 ± 1.0	1.7 ± 1.2	0.969	0.58	1.8 ± 1.1	1.7 ± 1.3	0.951	0.81	1.8 ± 1.2	2.6 ± 2.8	0.613	1.86
	SA	1.1 ± 1.0	1.2 ± 1.0	0.984	0.28	1.4 ± 1.7	1.0 ± 0.9	0.668	1.10	0.7 ± 0.5	0.9 ± 0.6	0.884	0.65
Corneal	Total HOA	6.1 ± 3.0	5.7 ± 2.0	0.943	1.20	6.3 ± 3.0	5.6 ± 1.8	0.902	2.21	6.9 ± 6.1	5.6 ± 2.4	0.505	1.37
	Coma	4.7 ± 2.3	4.5 ± 1.6	0.958	0.83	5.0 ± 2.3	4.4 ± 1.3	0.878	2.10	5.1 ± 3.5	5.6 ± 1.9	0.734	1.12
	Trefoil	1.5 ± 1.0	1.5 ± 1.2	0.984	0.31	2.0 ± 1.6	1.6 ± 1.1	0.897	1.19	2.6 ± 2.9	1.9 ± 1.8	0.390	0.70
	SA	2.4 ± 2.0	2.1 ± 1.9	0.928	0.92	2.1 ± 1.7	1.9 ± 1.8	0.968	0.81	2.1 ± 2.5	1.5 ± 1.2	0.948	0.60

Pre op: Preoperative; HOA: Higher order aberration; SA: Spherical aberrations; ICC: Intraclass correlation coefficients; RI: Repeatability index.

III). Although both devices are Placid-based, certain differences may exist between these devices; just as keratometry measurements with EyeSys have shown better repeatability than Orbscan.[20,21] Larger analyzed areas improve repeatability.[22] OPD Scan III measures 8 mm keratometry with 33 mires while the mentioned study used Orbscan measurements in the 3 mm with 6 mires. Thus, the difference between the two studies can be attributed to differences in analyzed areas.

In terms of the repeatability of aberrations with Placido disk devices, Wang et al[23] reported that total HOAs, coma, and SA in normal subjects had an RI of 0.24, 0.16, and 0.05, and an ICC of 0.858, 0.897, and 0.981, respectively. For the same indices, the group with mild KCN in our study demonstrated RI of 0.32, 0.19, and 0.08, and ICC of 0.982, 0.992, and 0.996, respectively, at one year after CXL. But in the moderate group, the indices were 2.71, 0.74, 0.65, and 0.604, 0.959, and 0.884 respectively. It seems that the repeatability of aberrometry in our sample was close to normal subjects, but in cases with moderate KCN, results were significantly different from normal cases. The improved IR and ICC in mild cases in the present study compared to moderate cases could be due to better CXL efficacy in this group.

According to our findings, part of the changes observed in the follow-up of KCN patients after CXL is due to differences in measurement repeatability and should not be attributed to the impact of the CXL procedure. For instance, device repeatability can be responsible for up to 0.5 D change in Ksteep after CXL in patients with mild KCN and 1.0 D change in moderate KCN. Also, increased corneal aberrations after the procedure can be partly due to reduced repeatability in treated cases. Given the reduced repeatability of the device measurements, data concerning corneal aberrations should be interpreted with caution in these cases, and observed increases in different parameters should not be automatically attributed to treatment failure or disease progression. Another point is that in both mild and moderate groups, ocular aberrations were mostly trefoil and coma, and corneal aberrations were mostly of the coma type. The same was observed at 1 year after CXL.

In conclusion, at 1 year after ACXL, changes in topographic and aberrometric measurement repeatability with OPD Scan III are acceptable in mild cases of the disease. In cases with moderate KCN, the repeatability of topographic indices is acceptable at one year after ACXL, but weaker compared to mild cases. The repeatability was acceptable for coma and ocular SA, but corneal indices, with the exception of SA, had weaker repeatability compared to mild cases, and differences in repeatability should be considered in the interpretation of results after CXL. Overall, ocular HOAs showed better repeatability compared to corneal ones. There seems to be a compensatory mechanism in the eye to correct cornea aberrations and improve total aberrations of the eye.

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