ORIGINAL ARTICLE

Corneal ECC Biomechanics Parameters after Different Laser Vision Correction Procedures

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Abstract

Aim: Evaluation of the changes in deformation amplitude (DA) ratio, integrated radius (IR), stress–strain index (SSI), and stiffness parameter at first applanation (SP-A1) obtained by the corneal visualization Scheimpflug technology (Corvis ST) and this is before and after different laser vision correction (LVC) procedures.

Methods: An interventional study that is prospective, randomized, and comparative. Individuals having a maximum astigmatism of −3.00 D and a maximum [(mean refractive spherical equivalent (MRSE)] of −7.00 D. Using the Corvis ST, measurements were made of the DA ratio, IR, SSI, and SPA1 prior to and following three distinct LVC procedures: Photorefractive keratectomy (PRK; group I), laser assisted *in situ* keratomileusis (LASIK; group II), and Femto-LASIK (Femto-laser assisted *in situ* keratomileusis; group III).

Results: Comparison between pre- and posttreatment showed significant increase in the DA ratio and IR with no significant change in SSI in group I. While in group II and III showed significant increase in DA ratio, IR and significant decrease in SSI. The SP-A1 change was significantly decreased in all three groups.

Conclusion: The response of the corneal biomechanical to the three surgical procedures varied differently and the significant change was in the IR and SP-A1, where the SSI and DA ratio was nonsignificant. The results of LASIK and PRK showed the highest and lowest reductions in total corneal stiffness, respectively, while Femto-LASIK stayed in between.

Keywords: Accelerated, Acute hydrops, Allergic conjunctivitis.

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Introduction

Corneal functions are mainly affected by its biomechanical properties, especially the elastic component which is responsible for the globe integrity and refraction stability.

Biomechanical instability in subclinical keratoconus is thought to be the initiating cause in ectasia triggered by different refractive surgeries.[1,2]

In 2005, Luce[3] introduced the ocular response analyzer (ORA) which was used widely for biomechanical assessment *in vivo*.[4–6]

Recently, the properties of the corneal biomechanics are assessed *in vivo* using the corneal visualization Scheimpflug technology (Corvis ST) as a clinical tool for evaluation. It uses ultrahigh speed Scheimpflug camera to provide much more information than ORA.[7]

To analyze corneal biomechanics, this device records the deformation parameters and shows corneal deformation in real time.[8]

In our recent study, corneal biomechanical properties comparison was done to normal patients before performing different laser vision correction (LVC) and then after the following three procedures; Laser assisted *in situ* keratomileusis (LASIK), photorefractive keratectomy (PRK) and Femto-laser assisted *in situ* keratomileusis (Femto-LASIK).

Measurements were obtained using the Corvis ST included; the deformation amplitude (DA) ratio, IR, stress–strain index (SSI), and stiffness parameter at first applanation (SP-A1), then we can estimate the change of these parameters in the cornea before and after different LVC procedures.

The DA ratio calculation is based on the ratio between the vertical displacement of the DA at the corneal apex and 2-mm nasal and temporal to it, while the central radius of curvature during the concave phase of the deformation is calculated. The IR is the area under the inverse radius vs time curve, after calculating the inverse radius (1/*R*).[9]

The elastic intrinsic properties of the cornea are described using Stress-strain curves. Shifting the curves to the left means a stiffer cornea while shifting to the right means a softer one, the location of the curve is described by the SSI.[10]

Stiffness parameter at the first applanation the consequent pressure of the first applanation calculated as the adjusted pressure of the cornea at first applanation minus biomechanical corrected intraocular pressure (IOP) and then divided by the deflection amplitude.[11]

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Patients and Methods

Study Design

An interventional study that is prospective, randomized, and comparative that was carried on 66 eyes at the interval between March 2020 and January 2022 in Dar El Oyoun Hospitals, Cairo, Egypt and Research Institute of Ophthalmology Giza, Giza, Egypt. During study, adherence was to the Helsinki declaration rules for research and approved by the Cairo University Ethical Committee in January 2020 with a unique identifier (UID) of 12-2020.

Inclusion Criteria

Patients must be older than 18 years and have normal corneal tomography, topography, and biomechanical characteristics, as well as established preoperative stable refraction for at least a year.

Patients' refraction of maximum mean refractive spherical equivalent (MRSE) of −7.00 D and with maximum astigmatism of 3.00 D.

A postoperative residual stromal bed of at least 350 µm and a planned postoperative flat *K*-value of at least 38 D are required. Planned percentage tissue altered (PTA) not more than of 35%.

Exclusion Criteria

Preoperative patients' corrected distance visual acuity (CDVA) of worse than 20/30, individuals who have experienced corneal dystrophies, herpes simplex infections, or previous ocular surgeries. Patients with glaucoma and other ocular disorders, such as uveal or retinal diseases, were not included in the study.

Patients with systemic diseases includes uncontrolled DM and autoimmune diseases were also excluded.

Methodology

Preoperative Assessment

All study patients were subjected to the following prior to the surgery:

- History taking with special emphasis on age and history of previous surgery. Informed consent and ethical approval were obtained for all patients.
- Anterior segment was examined using slit lamp biomicroscopy, intraocular pressure measurement and then dilated fundus examination was done.
- Measurement of best corrected visual acuity (CDVA) and patient's refraction.
- Patients' corneal indices will be studied as follows:

Images were captured before and after 3 months in different LVC procedures including Femto-LASIK, LASIK, and PRK with Pentacam and Corvis ST to detect the following parameters:

- Deformation amplitude ratio.
- Integrated radius.
- Stress–strain index.
- Stiffness parameter at first applanation.

Surgical Technique

- Group I (22 eyes) underwent PRK.
- Group II (22 eyes) underwent LASIK using a Moria M2 mechanical microkeratome.
- Group III (22 eyes) underwent Femto-LASIK using Alcon Wavelight FS200 laser with flap diameter of 8.7 mm, 110-µm thickness, and 115° of inverted side cut angle.

The surgery was done after application of topical anesthesia bilaterally using three drops of topical anesthetic (benoxinate hydrochloride 0.4%) 2–3 minutes prior surgery.

Group I (PRK group) had their epithelium removed manually using Hockey Epithelium Removal Knife; in group II (microkeratome LASIK group), Moria M2 (Moria, Antony, France) microkeratome with single-use 90-µm calibrated head was used to create the flaps and in group III (FemtoLASIK group) used the refractive platform Alcon Wavelight FS-200 femtosecond to create their flaps. The EX500 excimer laser is applied to perform corneal ablation in all patients, Contact Lens was placed only to patients of group I.

Postoperative Care

For 2 weeks, all patients had a topical steroid while antibiotic applied only for 5 days. A minimum of 4 weeks, hyaluronic acid lubricating drops were administered.

Pentacam and Corvis ST examination were done for every patient 3 months postoperatively together with the UCVA and CDVA.

Statistical Analysis

Version 23 of the Statistical Package for Social Science (SPSS; IBM) was used to collect, edit, and review the data. The ranges, standard deviations (SDs), and mean of the quantitative data were displayed. Qualitative variables were displayed as percentages and numbers.

One-way analysis of variance (ANOVA) test is applied in comparison between more than two groups with parametric distribution and quantitative data.

Paired *t*-test is applied in comparison between two paired group using parametric distribution and quantitative data.

A margin of error of 5% was acceptable, and a confidence interval of 95% was established. As a result, the following *p*-value was regarded as significant:

- $p > 0.05$: Nonsignificant (NS).
- $p < 0.05$: Significant.
- $p < 0.01$: Highly significant (HS).

Results

Demographically, the studied patients showed 33 patients with total 66 eyes with a mean age of 29.12 ± 7.13 (range: 18–40 years). The percentage of women was 72.7% (24 patients) and percentage of men 27.3% (9 patients) (Table 1).

Our main outcome was to quantify how many multiples of the SD each parameter has changed from measurement A (preoperative) to B (postoperative) and whether this change is indicating a stiffening, a softening or no significant change.

This outcome could be carried out through the following factors:

Table 1: Demographic data of the studied patients

	N = 33
Age	
Mean ± SD	29.12 ± 7.13
Range	18–45
Sex	
Female	24 (72.7%)
Male	9 (27.3%)

Table 2: Pre- and posttreatment in the group I comparison

PRK group	*Pretreatment*	*Posttreatment*	*Difference*	*Test value*	*p-value*	*Significance*
DA						
Mean ± SD	4.60 ± 0.32	5.32 ± 0.68	0.72 ± 0.49	−6.840	0.000	HS
Range	4.1–5.2	3.2–6.2				
IR						
Mean ± SD	8.35 ± 0.61	9.73 ± 0.97	1.38 ± 0.59	−11.034	0.000	HS
Range	7–9.2	7.8–11.1				
SSI						
Mean ± SD	1.02 ± 0.11	0.96 ± 0.17	−0.06 ± 0.14	2.026	0.056	NS
Range	0.8–1.2	0.8–1.3				
SP-A1						
Mean ± SD	95.8 ± 13.2	78.0 ± 17.5	17.8 ± 10.1	8.284	0.001	HS
Range	74–125	47–106				

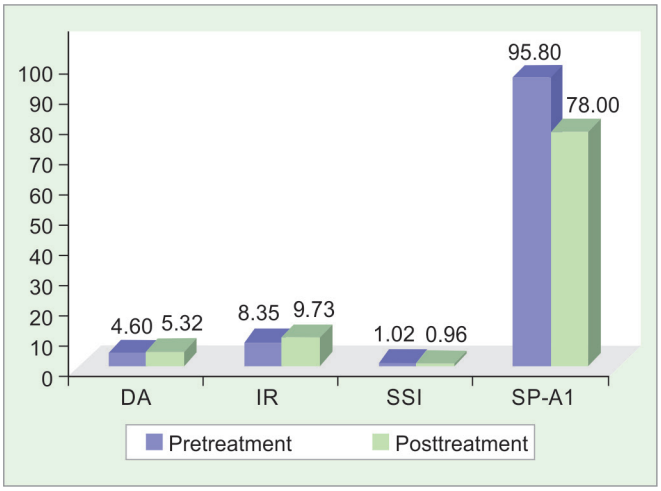

Fig. 1: The DA, IR, SSI, and SP-A1 levels pre- and posttreatment in group I

- Comparing the pre- and post-LVC variations in the DA ratio, IR, SSI, and SP-A1.
- Comparison between delta changes in the three different LVC procedures regarding the same previous indices.

Group I of patients was scanned with Corvis ST before and after PRK and comparison between pre- and posttreatment showed significant increase regarding the DA ratio and IR indicating softer corneas after PRK while no significant change in SSI (Table 2 and Fig. 1).

The SP-A1 showed statistically significant decrease indicating postoperative softer cornea.

Group II of patients was scanned with Corvis ST before and after LASIK and comparison between pre- and posttreatment showed significant increase regarding the DA ratio, IR as well as significant decrease in SSI and SP-A1 indicating softer corneas after LASIK (Table 3 and Fig. 2).

Group III of patients was scanned with Corvis ST before and after Femto-LASIK and comparison between pre- and posttreatment showed significant increase regarding the DA ratio, IR while there was significant decrease in the SSI and SP-A1 indicating softer corneas after Femto-LASIK (Table 4 and Fig. 3).

Comparison between delta changes pre- and posttreatment in the three different LVC procedures regarding the same previous indices (Table 5), the results showed the following:

- Nonsignificant changes in the DA ratio.
- Significant changes regarding the IR.
- Nonsignificant changes in the SSI.
- Nonsignificant changes in the SP-A1.

Discussion

The treatment of keratoconus and refractive surgery screening is highly dependable on the early detection of corneal ectasia. Measuring the corneal mechanical stability, which is believed to be the initiating step of progression has been of great challenge using the conventional instruments. Optical coherence tomography and videokeratography either topography or tomography analysis are more concerned with shape alteration as thinning and curvature steepening rather than mechanical stability.[12,13]

Therefore, it is of great importance now to develop devices that allow early detection of any corneal biomechanical changes before even changes occur in the shape whether topography or tomography or even when they are still normal.

In our study we evaluated four important biomechanical indices using Corvis ST including DA ratio, IR, SSI, and SPA1 before and after three different LVC procedures which are PRK, LASIK, and Femto-LASIK.

In our study the results varied pre- and post-LVC according to each group where in group I patients who underwent PRK there was increase in the DA ratio and IR significantly with a nonsignificant decrease related to the SSI, while SP-A1 showed a significant decrease.

Group II who underwent LASIK and group III who underwent Femto-LASIK showed almost same results regarding an increase in the DA ratio and IR with a decrease in the SSI and SPA1 significantly with more change in LASIK than Femto-LASIK regarding the previous parameters.

Comparing the three groups together showed the least changes were in the PRK followed by the Femto-LASIK and then LASIK indicating the smallest reduction of corneal stiffness for the three LVC procedures, respectively.

Table 3: Pre- and posttreatment in group II comparison

LASIK group	*Pretreatment*	*Posttreatment*	*Difference*	*Test value*	*p- value*	*Significance*
DA						
Mean ± SD	4.27 ± 0.38	5.15 ± 0.50	0.87 ± 0.44	−9.329	0.000	HS
Range	3.4–4.8	4.4–6.6				
IR						
Mean ± SD	7.23 ± 1.04	9.68 ± 0.74	2.45 ± 0.88	−13.070	0.000	HS
Range	5.2–9	8.7–11.3				
SSI						
Mean ± SD	1.09 ± 0.20	0.98 ± 0.16	−0.11 ± 0.16	3.138	0.005	HS
Range	0.7–1.4	0.7–1.2				
SP A1						
Mean ± SD	108.1 ± 14.6	91.1 ± 14.5	17.0 ± 11.1	7.220	0.001	HS
Range	79–132	60–112				

$p > 0.05$: NS; $p < 0.05$: Significant; $p < 0.01$: HS; Paired *t*-test

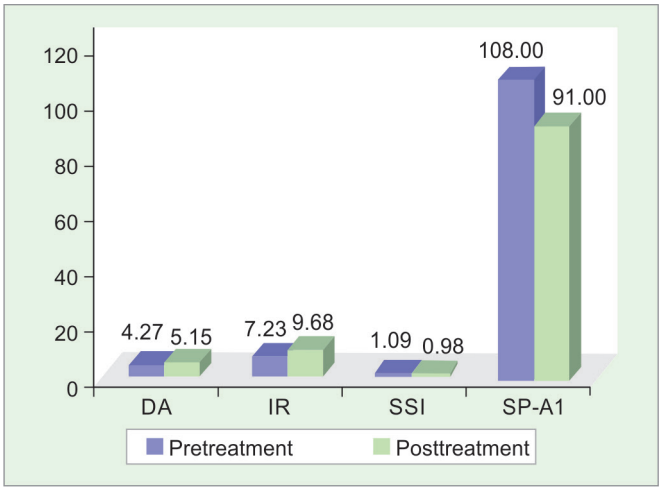

Fig. 2: The DA, IR, SSI, and SP-A1 levels pre- and posttreatment in group II

Table 4: Pre- and posttreatment in the group III comparison

Femto-LASIK group	*Pretreatment*	*Posttreatment*	*Difference*	*Test value*	*p-value*	*Significance*
DA						
Mean ± SD	4.43 ± 0.23	5.39 ± 0.43	0.95 ± 0.46	−9.787	0.000	HS
Range	3.90–4.8	4.50–6.1				
IR						
Mean ± SD	7.91 ± 0.60	9.81 ± 0.94	1.90 ± 1.03	−8.613	0.000	HS
Range	6.40–9	8.50–12.2				
SSI						
Mean ± SD	1.00 ± 0.15	0.87 ± 0.11	−0.12 ± 0.13	4.405	0.000	HS
Range	0.7–1.3	0.7–1.1				
SP-A1						
Mean ± SD	99.5 ± 10.5	81.6 ± 13.0	17.9 ± 10.6	7.933	0.001	HS
Range	85–127	54–103				

$p > 0.05$: NS; $p < 0.05$: Significant; $p < 0.01$: HS; Paired *t*-test

Xin et al.[14] evaluated the biomechanical responses *in vivo* including the DA ratio, DA ratio at 2 mm from the apex (DA ratio 2 mm), inverse IR and SP-A1 detected by the Corvis, before and after three main LVC surgeries which were transepithelial

photorefractive keratectomy (tPRK), Femto-SMILE and Femto-LASIK. The study included 227 patients all had one of the three surgeries mentioned above. The range of myopia and astigmatism for the patients was from −1.00 to −9.75 D (mean −4.82 ± 1.57 D) and from 0 to −3.00 D (mean −0.76 ± 0.59 D), respectively. The patients were divided into 74 underwent tPRK, 81 underwent femtosecond-assisted laser in situ keratomileusis (FS-LASIK), and 72 went for SMILE. Results concluded a significant increase in IR and DA ratio and a significant decrease in the postoperative SP-A1, collectively indicating reduction in the overall corneal stiffness. At 1 month, the SP-A1 decreased in all groups compared with the prior to surgery stage (all $p < 0.01$), and that indicated overall reduction in corneal stiffness. Post 6 months comparison was done and showed the change in SP-A1 was lowest in tPRK (−27.40 ± 16.91 mm Hg/mm), lower in SMILE (−32.40 ± 10.42 mm Hg/mm, nonsignificant when compared with tPRK, $p = 0.090$), and highest in FS-LASIK (−34.15 ± 13.17 mm Hg/mm, significant when compared with tPRK, $p = 0.008$).

In all groups, another evidence of a general decrease in stiffness was observed in the increased in DA at post 1 month significantly in comparison to the presurgery stage in all groups ($p > 0.05$), This increase in DA ratio continued to rise in all postoperative follow-ups at 1 month till 6 months.

Comparison between the three groups showed decreased stiffness which was highest in the Femto-LASIK, then the small-incision lenticule extraction (SMILE) and then the smallest decrease was in the tPRK group.

The previous study is much similar to our results, except that one of the groups underwent SMILE instead of LASIK.

Lee et al.[15] evaluated various dynamic corneal responses in their study together with the biomechanical corrected intraocular pressure (bIOP) before and after tPRK and Femto-LASIK using Corvis device for screening. The study concluded 129 patients, 65 had tPRK and 64 had Femto-LASIK whose mean age was 28.1 ± 5.4 years (range: 20–41 years). In transepithelial PRK group, women were 72.3% and the Femto-LASIK group the women percentage was 56.3% ($p = 0.057$). Preoperative characteristics including age, ablation depth, optical zone, spherical equivalent, sphere, cylinder, and CCT, between the two groups showed no significant statistical differences.

Between both surgeries there was no significant differences when compared the corrected IOP, however after surgery, the SP-A1 and Ambrosio rational thickness (ARTh) decreased, and the IR and DA ratio increased. Comparison between surgeries also showed that the changes in corneal stiffness were smaller in the tPRK than the Femto-LASIK ($p < 0.001$). Taking into consideration the change in corneal thickness and error of refraction as a covariate and by using covariance analysis, the changes in integrated inverse radius and DA ratio 2.0 mm were less in tPRK than Femto-LASIK ($p < 0.001$).

These results also were conclusive with ours; however, they had the bIOP and other covariants were taken into consideration during their study.

Cao et al.[16] studied the effect of cutting in the femtosecond laser on corneal biomechanics following SMILE or Femto-LASIK. The study was a prospective, nonrandomized study. It concluded 80 patients including 80 eyes and they were treated either with SMILE (40 eyes) or FS-LASIK (40 eyes). They used the Corvis to detect the CCT, IR, highest concavity (HC) radius, DA ratio 2 and 1 mm and bIOP at 1-day preoperatively, and then directly after the creation of flap or lenticule, during subsequent excimer laser ablation or

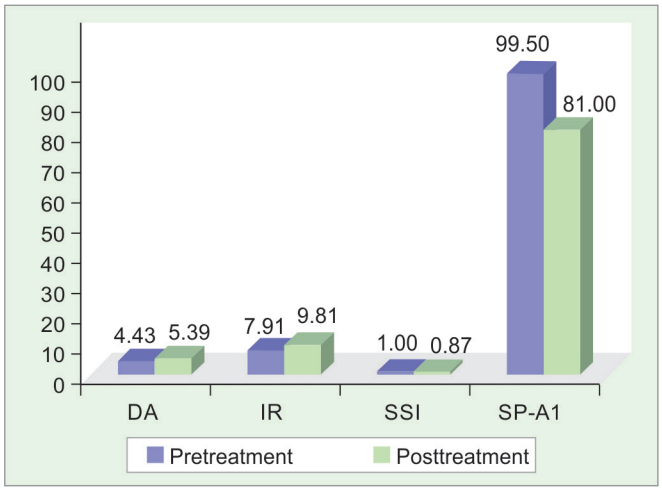

Fig. 3: The DA, IR, SSI, and SP-A1 levels pre- and posttreatment in group III

Table 5: Comparison between the three studied groups regarding rate of change (pretreatment – posttreatment) of DA, IR, SSI, and SP-A1

	PRK group	*Femto group*	*LASIK group*			
Rate of change	*N = 22*	*N = 22*	*N = 22*	*Test value*	*p- value*	*Significance*
DA						
Mean ± SD	0.72 ± 0.49	0.95 ± 0.46	0.87 ± 0.44	1.476	0.236	NS
Range	−1–1.4	−0.1–1.8	−0.3–1.9			
IR						
Mean ± SD	1.38 ± 0.59	1.90 ± 1.03	2.45 ± 0.88	8.686	0.000	HS
Range	−0.3–2.3	−0.1–4.5	0.4–4.2			
SSI						
Mean ± SD	−0.06 ± 0.14	−0.12 ± 0.13	−0.11 ± 0.16	1.188	0.312	NS
Range	−0.3–0.2	−0.4–0.1	−0.4–0.2			
SP-A1						
Mean ± SD	17.8 ± 10.1	17.9 ± 10.6	17.0 ± 11.1	0.042	0.959	NS
Range	3.0–33.0	0.0–34.0	1.0–40.0			

$p > 0.05$: NS; $p < 0.05$: Significant; $p < 0.01$: HS; One-way ANOVA test

lenticule extraction, and then postoperative follow-up at 1 week, followed by 1 month and then at 3 months. After operation, the two groups showed no significant differences in any parameters ($p > 0.05$), however the laser cutting of the Femtosecond during lenticule cut has a more effect on the biomechanics of the cornea than flap creation.

To focus on the indices related to our study, their results showed FS-LASIK had increased post-operative values of those two parameters DA ratio and IR, indicating more stiffness reduction, however the differences were not significant between it and SMILE.

Reinstein et al.,[17] Wang et al.,[18] and Lee et al.[15] observed in their studies that high myopia affects the changes in the biomechanics induced by surgery larger than in low and moderate myopia groups and this was expected due to more tissue removal. This was confirmed by the changes in the postoperative values of the SP-A1, IR, and DA obtained after all procedures. This observation was also noted in our study during data collection however it was not in our scope for statistical analysis.

Conclusion

Corneal biomechanical response varied after PRK, mechanical LASIK, and Femto-LASIK. The results of LASIK and PRK showed the greatest and lowest reductions in total corneal stiffness, respectively, while Femto-LASIK stayed in between.

Limitations

- The statistical power may be decreased due to the study's limited patient number.
- Short period of follow up postsurgery.
- Other covariant as optical zone, ablation depth, IOP, and CCT.

Recommendations for Further Research

- Increase the sample size.
- Longer term period for follow up of the patients up to years than months.
- Studying other biomechanical indices with previously mentioned other covariant.
- Including more LVC procedures especially lenticular extraction techniques.

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